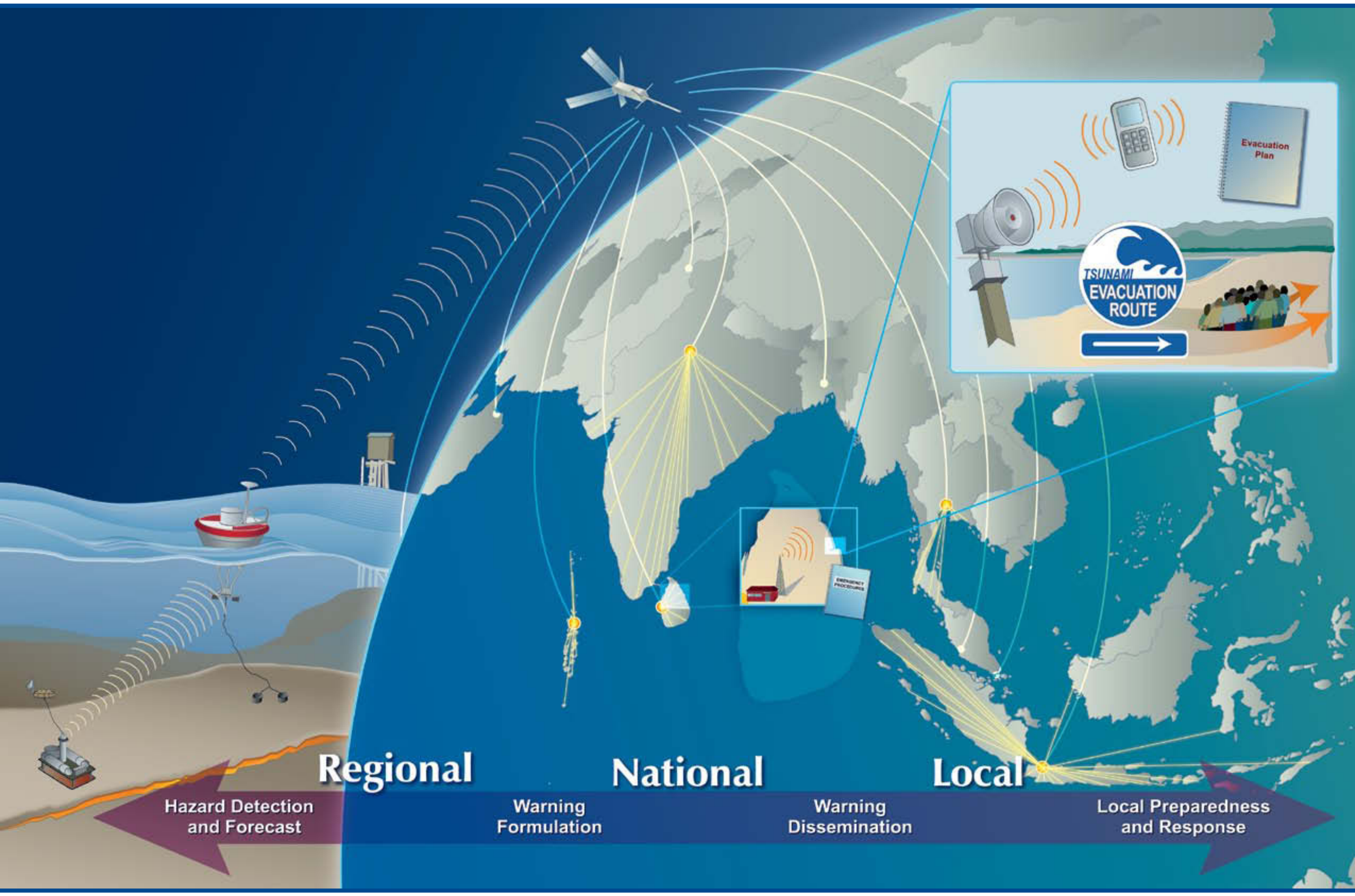
TSUNAMI WARNING CENTER REFERENCE GUIDE



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U.S. Contribution to the Indian Ocean Tsunami Warning System

TSUNAMI WARNING CENTER REFERENCE GUIDE

U.S. Indian Ocean Tsunami Warning System Program

2007

Printed in Bangkok, Thailand

Citation:

U.S. Indian Ocean Tsunami Warning System Program (US IOTWS). 2007. Tsunami Warning Center Reference Guide supported by the United States Agency for International Development and partners, Bangkok, Thailand. 311 p.

This publication is made possible through support provided by the United States Agency for International Development (USAID) under the terms and conditions of a Participating Agency Program Agreement with the National Oceanic and Atmospheric Administration (NOAA).

The U.S. Indian Ocean Tsunami Warning System (US IOTWS) Program is part of the international effort to develop tsunami warning system capabilities in the Indian Ocean following the December 2004 tsunami disaster. The U.S. program adopted an "end-to-end" approach—addressing regional, national, and local aspects of a truly functional warning system—along with multiple other hazards that threaten communities in the region. In partnership with the international community, national governments, and other partners, the U.S. program offers technology transfer, training, and information resources to strengthen the tsunami warning and preparedness capabilities of national and local stakeholders in the region.

U.S. IOTWS Document No. 26-IOTWS-07

ISBN 978-0-9742991-3-6

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OCTOBER 2007

This publication was produced for review by the United States Agency for International Development. It was prepared by the US Indian Ocean Tsunami Warning System Program.

Acknowledgements

This guide was prepared as a collaborative effort between members of the US IOTWS Program and staff of the National Oceanic and Atmospheric Administration (NOAA). Principle authors were Christopher Hill, NOAA NWS Office of International Activities and Andre LeDuc and Krista Mitchell, University of Oregon.

Technical input and review was invaluable to the development of the guide. These reviews were conducted by Edward H. Young, Jr., NOAA National Weather Service (NWS) Pacific Region Deputy Director; Curt Barrett and Jennifer Lewis, NOAA NWS Office of International Activities; Dr. Paul Whitmore, Director WC/ATWC and staff; Dr. Charles McCreery, Director PTWC and staff; Dr. Laura Kong, Director International Tsunami Information Center; Dr. Eddie Bernard, Director NOAA Pacific Marine Environmental Laboratory; David McKinnie, NOAA PMEL; Dr. Geoff Crane, Bureau of Meteorology of Australia, and Dr. Stan Goosby, Pacific Disaster Center, Kihei, Maui, Dr. Pariatmono, Indonesia Ministry of Research and Technology and Dr. Sunarjo, Indonesia Meteorological and Geophysical Agency (BMG); S.H.M.Bapon Fakhruddin, Asian Disaster Preparedness Center; Deanne Shulman, USDA/Forest Service; Ranjith George, NOAA contractor, International Tsunami Notification Coordinator; Chris Maier, NOAA. Technical editing was conducted by Dr. Kitty Courtney, editorial review by Kerry Brodersen, and graphics and layout by Regina Scheibner and Krista Carlson, all of Tetra Tech Inc. under NOAA Contract No. WC133F04CQ003.

Many agencies and organizations that have contributed to the development of this Guide. In particular, we would like to acknowledge the following:

- Intergovernmental Oceanographic Commission (IOC), Intergovernmental Coordination Group (ICG)/IOTWS (Indian Ocean Tsunami Warning and Mitigation System) member countries, the Secretariat and participants in the Working Group 5 (Interoperability Among Centres)
- SOPAC (The Pacific Islands Applied Geoscience Commission)
- Secretariat for the Pacific Regional Environment Programme (SPREP)
- World Meteorological Organization, Region V (South-west Pacific) Subregional Office, Apia, Samoa

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Forward

Reflecting on the devastation wrought by the Indian Ocean tsunami of December 2004 underscores the importance of a robust tsunami warning system that can effectively save lives should such a seismic chain of events repeat itself.

To counter the threat of tsunamis to the United States, the National Oceanic and Atmospheric Administration (NOAA) has developed the many components of an end-to-end warning system including Deep-ocean Assessment of Reporting Tsunami buoy technology, numerical tsunami propagation models, establishing tsunami warning centers, and development of the TsunamiReady program to prepare coastal communities for tsunamis. NOAA has shared technical leadership, technology and capacity-building on aspects such as these as part of the U.S. Government's response to the Indian Ocean region after the 2004 tsunami.

In establishing an operational warning system for one of nature's most intense and severe threats to coastal populations, NOAA developed a Concept of Operations (CONOPS) that defined the human, scientific, and technological resources required to provide critical warning to communities at risk. This document represents the knowledge accumulated by NOAA in accomplishing an operational warning program for the United States–it represents our "best practices."

We hope this document, the *Tsunami Warning Center Reference Guide*, will assist the United Nations Education, Science and Cultural Organization's Intergovernmental Oceanographic Commission in its effort to encourage countries to establish tsunami warning systems. The CONOPS within should help the countries surrounding the Indian Ocean establish warning programs for national centers as well as regional watch providers. In addition, this document could serve as a catalyst toward developing a multi-hazard CONOPS.

Many countries recognize that an integrated end-to-end multi-hazard warning capability is essential to reduce vulnerability and risk to future disasters such as the 2004 tsunami. We hope this CONOPS contributes to the critical efforts underway in the Indian Ocean region and the efforts in development elsewhere around the globe. In keeping with the Tsunami Warning and Education Act, NOAA pledges continued support to the international community.

Conrad Lautenbacher

Conrad C. Lautenbacher, Jr.
Vice Admiral U.S. Navy (Ret.)
Under Secretary of Commerce for Oceans and Atmosphere and
NOAA Administrator

Chapter 1

Introduction to the Tsunami Warning Center Reference Guide

In the aftermath of the Great Sumatra Earthquake and Indian Ocean Tsunami of December 26, 2004, countries of the Indian Ocean basin formed an Intergovernmental Coordination Group (ICG) for the development of an Indian Ocean Tsunami Warning System (IOTWS). An effective end-to-end tsunami early warning system could have saved thousands of lives that were lost in the devastating tsunami. The ICG/IOTWS was formed under the auspices of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Intergovernmental Oceanographic Commission (IOC). Subsequently, ICGs have also been established in the Caribbean, Atlantic, and Mediterranean basins to guide the development of tsunami warning centers in those areas. A tsunami warning system can only be successful if it spans the continuum of activities associated with an "end-to-end" approach. An end-to-end tsunami warning system begins with the rapid detection of a tsunami wave and ends with a well prepared community that is capable of responding appropriately to a warning (Figure 1-1).

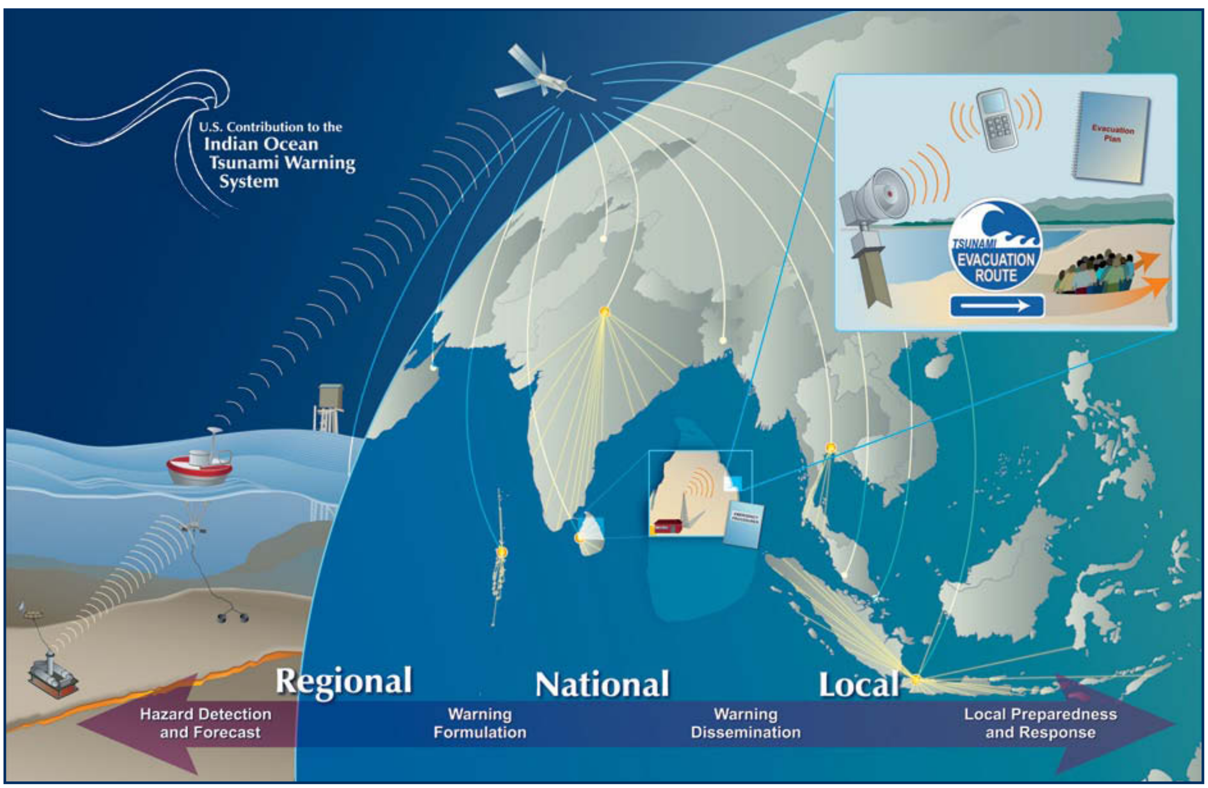


Figure 1-1. Overview of an End-to-End Tsunami Warning System

The operation of a tsunami warning center is a vital part of an end-to-end tsunami warning system. A tsunami warning center is not only involved in acquiring and processing data for detecting a tsunami, but also in formulating and disseminating tsunami warnings and connecting with communities at risk to ensure that they understand the warning and have the capacity to respond. Tsunami warning centers must develop partnerships with international organizations; national, subnational, and local agencies; community leaders and organizations; businesses; and local citizens to ensure warnings are received and understood by local communities.

Under a U.S. IOTWS Program supported by the United States Agency for International Development (USAID), the National Oceanic and Administration (NOAA) is contributing to this international effort to develop an end-to-end tsunami warning system through the transfer of appropriate technologies and operational procedures from its nearly 40-year involvement and leadership in the ICG for the Pacific Tsunami Warning and Mitigation System. This Tsunami Warning Center Reference Guide is one of NOAA's contributions to the development of an effective end-to-end tsunami warning system for the Indian Ocean.

Purpose of the Guide

The purpose of this Guide is to serve as a reference for countries that are establishing new or maintaining and enhancing existing tsunami warning centers as part of an overall end-to-end tsunami warning system. This document describes a concept of operations for a National Tsunami Warning Center (NTWC) or Regional Tsunami Watch Provider (RTWP) and also provides outreach and education resources for these centers. Additionally the Guide is designed to assist individuals, organizations, and governmental entities who operate or interact with a tsunami warning system. Some of the groups and individuals who will find the information contained in this document useful include, but are by no means limited to:

- International policy makers
- National government policy decision makers
- Government agency planners
- National and local government preparedness officials
- Disaster responders, including nongovernmental organizations (NGO)
- Television, radio, and newspaper reporters and editors
- Tsunami warning center staff members

This Guide describes the key operational components of a tsunami warning center and the relationship of each component within an end-to-end tsunami warning system. The document incorporates lessons learned from the two NOAA operational tsunami warning centers: the West Coast/Alaska Tsunami Warning Center (WC/ATWC) in Palmer, Alaska, and the Pacific Tsunami Warning Center (PTWC), based in Hawaii.

PTWC works closely with other regional and national centers, including those operated by France, Russia, and Japan, and NOAA's WC/ATWC. As a result, the Guide is a concept of operations (CONOPS) based on guidance established by the IOC.

This document is not an operations manual and does not provide step-by-step instructions for establishing a tsunami warning system. Furthermore, this Guide does not set forth warning system operational procedures and shift duties, sometimes referred to as Standard Operating Procedures (SOP). SOPs are unique to each tsunami warning center and are coordinated through the IOC for that respective basin ICG.

The Guide documents and communicates overall quantitative and qualitative aspects of a tsunami warning system, with a specific focus on NTWCs. The concept of operations for an RTWP is very similar to that of a national center, but the RTWP CONOPS must satisfy a broader multilateral legal framework and requires more extensive international cooperative agreements.

Organization of the Guide

This Guide is organized into chapters that provide an overview of the operational and organizational requirements of a tsunami warning center, followed by one chapter for each of the seven key operational components (Figure 1-2). Each chapter begins with a general overview of the component and its role in an end-to-end tsunami warning system. Sections within each chapter describe subcomponents essential for the operation of a tsunami warning center. Throughout the document, critical information and examples are highlighted in tip boxes.

Tip

Given the complexity of the information presented and the diversity of the audience, this Guide is designed to help the reader move smoothly through the text by providing visual clues wherever possible. These include figures and tables, summaries of key points, tip boxes, and examples or case studies.

Chapter 1 - Introduction

Chapter 1 is this introduction, which provides a description of the purpose and intended use of the Guide as well as some of its limitations. This chapter has introduced the meaning of an end-to-end tsunami warning system and the vital role of a tsunami warning center within that system.

Chapter 2 - Overview of the Operational and Organizational Requirements of a Tsunami Warning Center

Chapter 2 provides an overview of the key operational and organizational requirements of a tsunami warning center as they currently exist at the two NOAA tsunami warning centers and at the Japan Meteorological Agency (JMA). The operational requirements of a tsunami warning center are presented as a "systems description" in the context of a people-centered multi-hazard early warning system. The organizational requirements of a tsunami warning center include staffing,

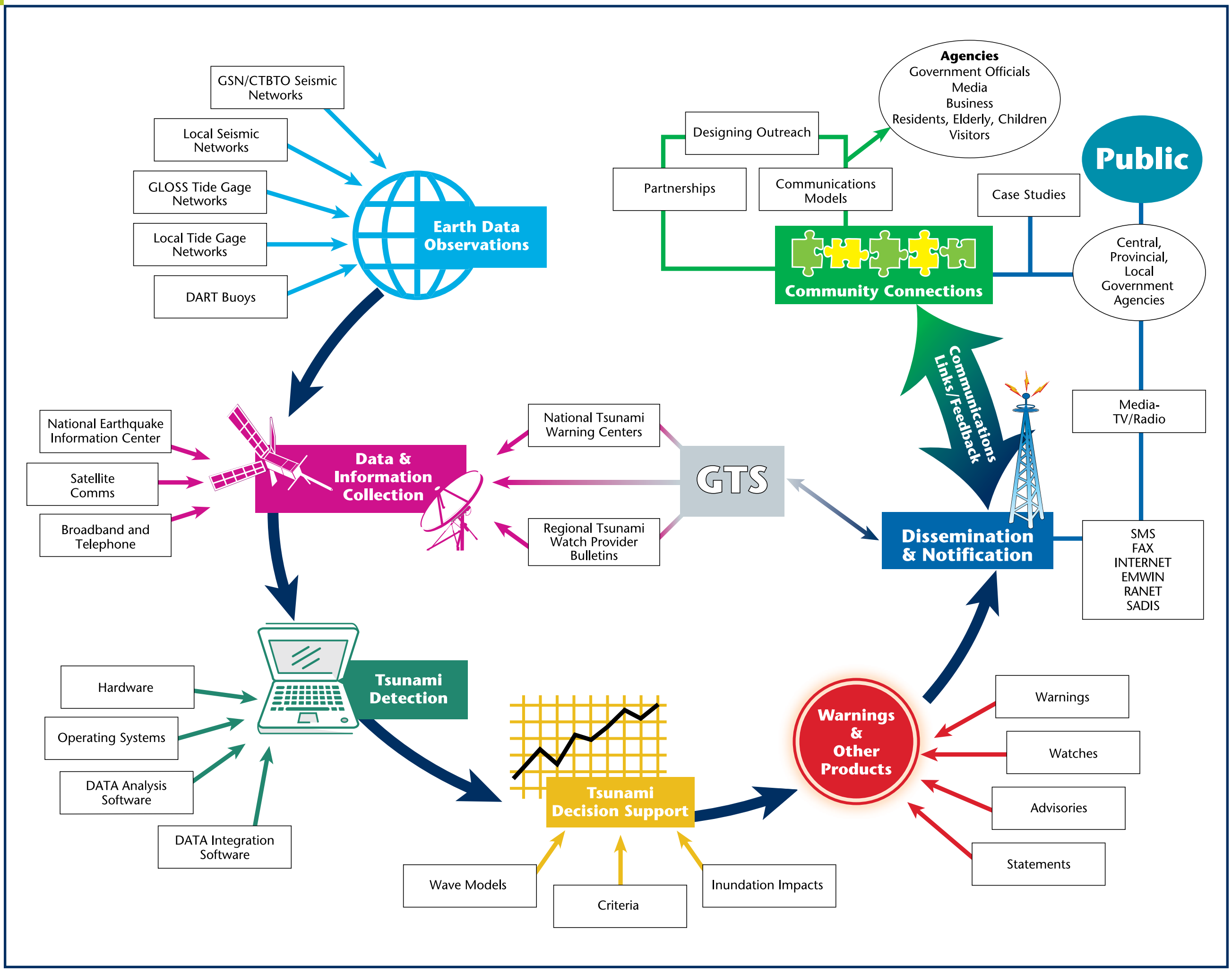


Figure 1-2. Key Operational Components of a Tsunami Warning Center

documentation, and interoperability requirements and performance measures. The chapter provides an overview of the various links in the end-to-end chain. These include data collection and monitoring, decision making and warning issuance, and working with partners to get warnings "all the way to the beach." The chapter is a blueprint for the operation of a tsunami warning center and its contribution within a successful end-to-end tsunami warning system.

Chapters 3 to 9 - Descriptions of Each Operational Component

Chapters 3 through 9 present more detailed information on the key operational aspects and components of the various systems including data, equipment, products, telecommunications, outreach strategies and tools that comprise a full, people-centered tsunami warning system. The information in these chapters is derived from various sources, including PTWC, WC/ATWC, JMA, UNESCO, World Meteorological Organization (WMO), U.S. Geological Survey, University of Hawaii, University of Washington, and Harvard University, just to name a few.

Appendices

The appendices consist of such resources as a list of acronyms (Appendix A), glossary of terms (Appendix B), position descriptions for tsunami warning center staff positions (Appendix C), a list of working documents a center should develop and maintain (Appendix D), and lists of references and additional resources for each chapter (Appendix E).

Chapter 2

Overview of a Tsunami Warning Center's Operational and Organizational Requirements

A *tsunami* is a **series** of ***ocean*** surface waves generated by a submarine earthquake, submarine volcanic eruption, landslide, or meteor impact. Offshore earthquakes are by far the most common cause of tsunamis. Currently there is no global tsunami early warning system, although an ocean-wide system has been operational in the Pacific basin under the auspices of the Intergovernmental Oceanographic Commission (IOC) of United Nations Educational, Scientific, and Cultural Organization (UNESCO) for more than 40 years.

Within the IOC's Intergovernmental Coordination Group (ICG) framework, there are two types of operations centers. A National Tsunami Warning Center (NTWC) operates within the legal framework of the country in which it resides and serves. It provides warnings, watches, and advisories to its citizenry and public and private agencies. A Regional Tsunami Watch Provider (RTWP), through international agreements (which include meeting IOC/ICG requirements), provides tsunami forecasts and other information to another or several other countries in a particular region or oceanic basin. An RTWP may also serve a dual role as the NTWC for the country in which it resides. For the purpose of this Guide, the term "tsunami warning center" will be used as a generic term for either an NTWC or RTWP, unless the requirements discussed are specific to either type of operations center.

The United Nations International Strategy for Disaster Reduction provides a framework for an effective tsunami early warning system that is people-center and integrates four interrelated elements: (1) knowledge of risks faced, (2) technical monitoring and warning service, (3) dissemination of meaningful warnings to those at risk, and (4) public awareness and preparedness to act. While tsunami warning centers are focused primarily on monitoring and warning, they play a vital role in providing technical input and developing community partnerships for the other elements of risk reduction that are essential for an effective tsunami early warning system.

The Pacific Tsunami Warning Center (PTWC), based in Ewa Beach, Hawaii, serves as the operational headquarters for the Pacific Tsunami Warning and Mitigation System (PTWS). PTWC works closely with other regional and national centers in monitoring seismological and sea level stations and instruments around the Pacific Ocean to evaluate potentially tsunamigenic earthquakes. The PTWS disseminates tsunami information and warning messages to over 100 locations across the Pacific. Regional tsunami warning centers operated by the United States, France, Russia, and Japan provide regional warnings to Alaska, the U.S. west coast, and Canada; French Polynesia; and

Tip

In recent years new shorthand terminology has been used to describe the entire process required to detect, warn, and elicit protection measures for a natural hazard. Increasingly this comprehensive process is referred to as "end to end," meaning from initial to final steps required for a successful system. The term "end to end" does not always translate accurately, and some cultures prefer to refer to the process as "beginning to end". In the case of a tsunami system this of course means from the beginning, i.e. earthquake detection, to the end, i.e. evacuation or cancellation of the warning.

the northwest Pacific, respectively. The tsunami warning system in the Pacific is one of the most successful international scientific programs with a direct humanitarian aim: to mitigate the effects of tsunamis to save lives and property.

The heart of a tsunami warning system is its operations center. The primary mission of a full-service NTWC or RTWP is to provide accurate and timely tsunami warnings and bulletins to coastal populations in its area of responsibility (AOR) 24 hours per day, 7 days per week. To accomplish this mission, a tsunami warning center detects and analyzes earthquakes throughout its adjacent ocean basin. Earthquakes that are above a previously established threshold activate the center's alarm system and initiate an earthquake and tsunami investigation that includes the following four basic steps:

- Locate and characterize the earthquake's source and its probability of creating a tsunami via the collection of data from seismic networks
- Review automated earthquake analysis, and if necessary, modify (by the duty scientist or watch stander) the automated results
- Obtain continuous sea level data from tide gage sites, and where available, data from Deep Ocean Assessment and Reporting of Tsunamis (DART™) buoys, to verify the existence of a tsunami and to calibrate models
- Prepare and disseminate information to appropriate emergency management officials and others

Initial tsunami warning bulletins are based solely on seismic data. Once an initial tsunami warning bulletin has been issued, the nearest tide gages and tsunami detectors are monitored to confirm the existence or nonexistence of a tsunami, and its degree of severity. Tsunami warning bulletin text includes warning/watch extent, earthquake parameters, evaluation, and the tsunami estimated time of arrival (ETA) for sites throughout the center's AOR. Bulletins should be updated every 30 minutes when possible to minimize rumors and confusion. However, routine updates should not delay the issuance of additional warnings.

As an integral part of the international community, an NTWC or RTWP should issue tsunami bulletins in collaboration with neighboring NTWCs (and RTWPs where appropriate) whenever time permits. The NTWC issues bulletins to state or province departments of emergency services, federal disaster preparedness agencies, and many other recipients in its AOR. Earthquakes large enough to be felt near the coast, but below the tsunami warning threshold size, should prompt informational messages to these same recipients to help prevent needless evacuations.

Tsunami history and pre-event modeling, along with observed tsunami amplitudes, are taken into account in determining the extent of danger to a center's AOR. The center may refrain from issuing a warning, or issue the warning for only selected areas, if tsunami history (and modeling, if available) indicates there is no danger or danger only to selected areas. Historical events have shown that tsunami damage is possible to a site if waves reach 50 centimeters (cm) or more in amplitude. Therefore, if a tsunami is expected to reach 50 cm or more, or if the tsunami potential cannot be accurately judged, warnings should be continued. Tsunamis cannot be predicted exactly, so the 50-cm cutoff is considered general guidance.

Operational Components of a Tsunami Warning Center

The key operational components of a tsunami warning center are to provide real-time monitoring, alert of seismic and tsunami activities, timely decision making, and dissemination of tsunami warnings, advisories and information (Figure 2-1). The chain

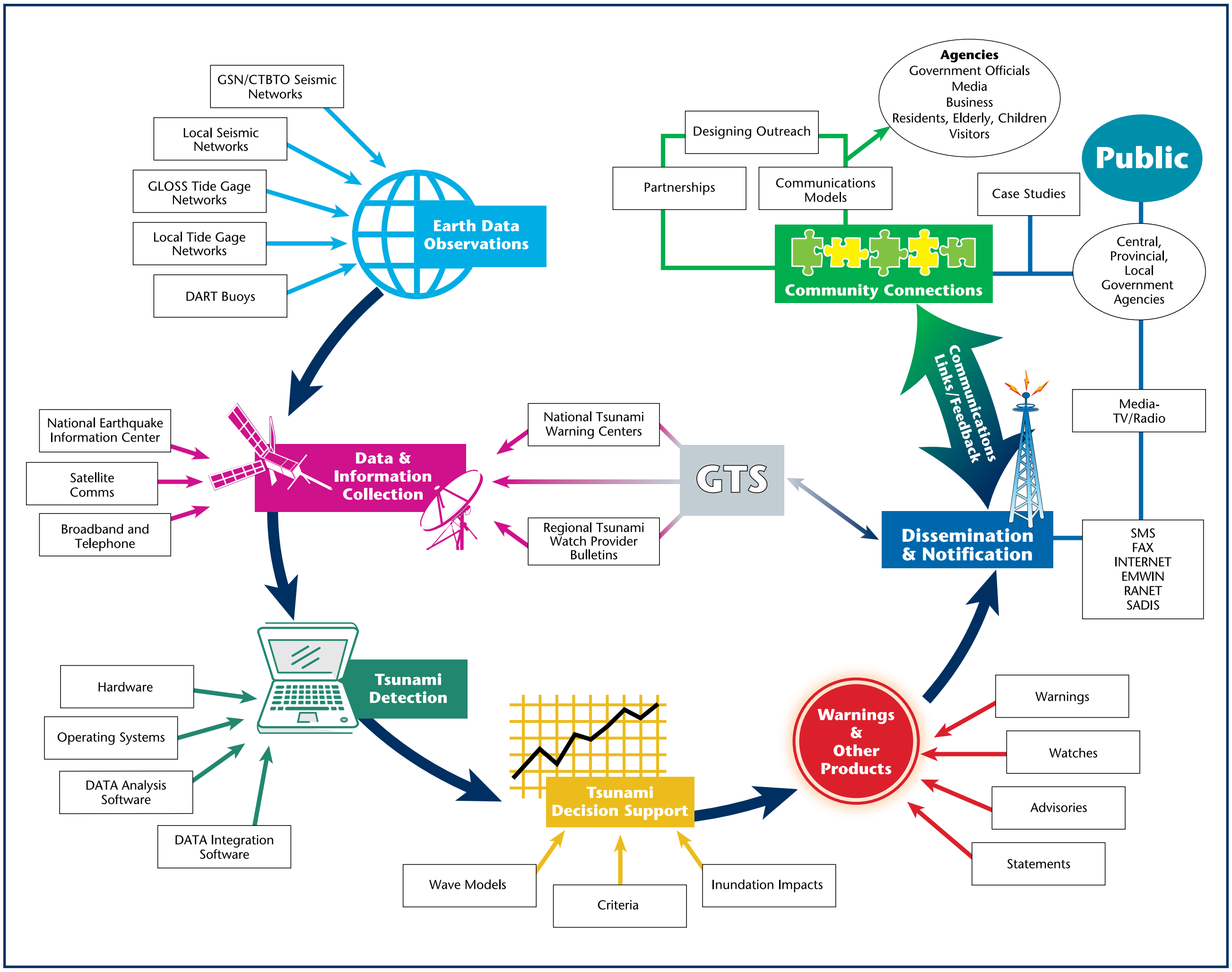


Figure 2-1. Key Components of a Tsunami Warning Center End-to-End Chain

begins with data collection and ends with saving lives. Each country decides how the information received from its RTWP, if it has one, will be utilized. In some cases the RTWP warning products by prior bilateral agreement, may go to an NTWC for direct in-country distribution. In these instances the receiving country is depending upon the RTWP for data monitoring and warnings. At the other extreme of the spectrum of service, RTWP products may be used simply as one of many inputs to a fully developed NTWC's decision process. In such cases the country is relying on its own NTWC for data collection and warning decisions, as well as notification and dissemination.

As can be seen in Figure 2-1, and discussed throughout this document, there are numerous technologies and human intervention points in the end-to-end system. These components are all linked through an overarching system that cascades from international to national to local levels. These components are summarized below and can be thought of as links in a chain, with each being crucial to the overall strength of the chain.

Earth Data Observations (Chapter 3)

Earth data observations are an essential component of the hazard detection and forecast capacity of a tsunami warning center. The rapid detection and characterization of tsunami-generating earthquakes provides the first indication of a potential tsunami in an end-to-end tsunami warning system. Initial seismic-based warnings based on data from networks of seismic gages are subsequently refined by the detection of tsunami-generated changes in sea level, measured by coastal tide gages and buoys.

Tip

Initial tsunami warnings are based on earthquake magnitude and location.

The refinement of initial seismic-based warnings with data on sea level changes can greatly increase the credibility of the warnings by decreasing false alarms. To make this refinement, the tsunami warning center must have a basic understanding of the mechanisms that cause changes in sea level, and how a tsunami wave registers on a tide gage. A tsunami warning center must utilize seismic and sea level data from international, and sometimes local, networks in order to detect earthquakes and the potential generation of a tsunami.

Data and Information Collection (Chapter 4)

The timely collection of data and information from locally maintained and international earth data observation networks is a crucial function of NTWCs and RTWPs. Several telecommunications connections are required to collect data and information needed to detect a tsunami. Some data, especially seismic and sea level data from international networks, are available in real time through the internet and satellite downlinks. Data from locally maintained networks often require alternate communications paths such as land lines, wireless telephone, or radio. Seismic and sea level data are of little value to the center if the data are not received in time to allow analysis. Thus, the second link in the chain, data communications (discussed in several sections of Chapter 4), is critical to the success of the end-to-end system. This requires the use of international communication methods like the World Meteorological Organization's (WMO) Global Telecommunications System (GTS), and also alternate ways of obtaining seismic, tide gage, and DART buoy data.

The center should also acquire, in the most effective and efficient way, real-time earthquake and tsunami information released by other tsunami warning centers and earthquake observatories, such as the U.S. Geological Survey (USGS) National Earthquake Information Center (NEIC), the PTWC, Japan Meteorological Agency, West Coast/Alaska Tsunami Warning Center (WC/ATWC), and RTWPs coordinated by the UNESCO IOC. Information should be acquired from other NTWCs through faxes, posted on Internet web sites, the GTS, and other alternate public and non-public information sources. In all cases, the communications programs must be continually maintained and upgraded by an Information Technology Officer (ITO) on, or available to, the center staff.

Tip

Communications are the lifeblood of a multi-hazard warning center. All aspects of operations, from collecting data to disseminating warnings to developing community connections all depend on effective communications.

Tsunami Detection Requirements (Chapter 5)

The next crucial link in the end-to-end chain, as discussed in depth in Chapter 5, is the forecast of whether a tsunami has or has not been generated from a seismic event, and the refinement of the forecast by sea level data. This requires incorporating seismic and sea level data from the communications channels into an integration and analysis subsystem that integrates all the necessary input information together, and analyzes this information as input to a decision making subsystem.

A decision making subsystem that is composed of useful aids to the operational watch stander is needed to assist making quick decisions on the issuance of seismic information bulletins and tsunami warning products. This may be an automated system or one that is an interactive man-machine mix. Tsunami forecast models, and the computer systems they run on, must be developed, adapted, and upgraded at the center by good computer programmers.

Tsunami Warning System Decision Support (Chapter 6)

Once the tsunami's existence and its amplitude have been forecasted there must be a system to assess the potential impact of the tsunami. As discussed in Chapter 6, this tsunami prediction subsystem should have an appropriate historical database, with possible inundation areas under different scenarios of tsunami occurrences. This subsystem should quickly generate the necessary forecasts to expedite the determination of the possible impact of a tsunami. This is necessary for the issuance of credible warnings that cover only areas actually affected, if possible, with few "false alarms" that lead to unnecessary and costly evacuations.

A large part of this decision support system includes local inundation maps for various tsunami amplitudes. These maps often are generated locally, and updated as new technologies (such as better inundation mapping or higher resolution topographic data) become available. Increasingly, it also entails running "what if" scenarios to produce probabilities of various degrees of impact from the seismic event.

Warnings and Other Products (Chapter 7)

Once the decision is made to issue a warning or other bulletin, the NTWC and RTWP products should not cause confusion. For this reason the products sent to constituents should adhere as closely as possible to international standards and formats. This includes standards for warnings, watches, advisories, and information statements. Lead times for each type of product should be established by centers in conjunction with the needs of their customers. Product examples are illustrated in Chapter 7. The basic definitions of these warning and other products are described below.

Tsunami Warning: A Tsunami Warning is issued by NTWCs when a potential tsunami with significant widespread inundation is **imminent or expected**. Warnings alert the public that widespread, dangerous coastal flooding accompanied by powerful currents is possible and may continue for several hours after arrival of the initial wave. Warnings also alert emergency management officials to take action for the entire tsunami hazard zone. Appropriate actions to be taken by local officials may include the evacuation of low-lying coastal areas, and the repositioning of ships to deep waters when there is time to do so safely. Warnings may be updated, adjusted geographically, downgraded, or canceled. To provide the earliest possible alert, initial warnings are normally based only on seismic information.

Tsunami Watch: A Tsunami Watch is issued by RTWPs and NTWCs to alert emergency management officials and the public of an event that **may later** impact the Watch area. The Watch may be upgraded to a Warning or Advisory (or canceled) based on updated information and analysis. Therefore, emergency management officials and the public should prepare to take action. Watches are normally issued based on seismic information without confirmation that a destructive tsunami is under way.

Tsunami Advisory: A Tsunami Advisory is issued by RTWPs and NTWCs for the threat of a potential tsunami that may produce strong currents or waves dangerous to those in or near the water. Coastal regions historically prone to damage due to strong currents induced by tsunamis are at the greatest risk. The threat may continue for several hours after the arrival of the initial wave, but significant widespread inundation is not expected for areas under an Advisory. Appropriate actions to be taken by local officials may include closing beaches, evacuating harbors and marinas, and the repositioning of ships to deep waters when there is time to do so safely. Advisories are normally updated to continue the Advisory, expand or contract affected areas, upgrade to a Warning, or cancel the Advisory.

Information Statement: An Information Statement is issued by centers to inform emergency management officials and the public that an earthquake has occurred. In most cases, Information Statements are issued to indicate there is no threat of a destructive tsunami affecting the issuing tsunami warning center's AOR and to prevent unnecessary evacuations, as the earthquake may have been felt in coastal areas. An Information Statement may, in appropriate situations, caution about the possibility of destructive local tsunamis. Information Statements may be reissued with additional information, though normally these messages are not updated. However, a Watch, Advisory, or Warning may be issued for the area, if necessary, after analysis and/or updated information becomes available.

Bulletin Content: Tsunami bulletins, i.e. warning, watch, advisory, or statement as appropriate, should be issued by the RTWP or NTWC, in general, when an earthquake with the magnitude 6.5 or greater occurs, or when a quake strong enough to cause concern among coastal residents occurs. IOC/ICG has agreed that warning, watch, advisory, and information products should contain:

- **Earthquake Information**
  - Origin time (UTC)
  - Coordinates (latitude and longitude) of the epicenter
  - Location (name of geographical area)
  - Magnitude (M)
  - Depth (only for an earthquake occurring at a depth of 100 km or more) below the ocean floor
- **Tsunami Information**
  - Evaluation of tsunamigenic potential based on the empirical relationship between M of earthquake and generation/nongeneration of tsunami in the NTWC's or RTWP's AOR basin(s).
  - Estimated tsunami travel times to reach the respective coasts in the NTWC's or RTWP's AOR (only for an earthquake of M greater than or equal to 7.0). This is best handled by specifying forecast points that are well known to emergency managers and the populace.

Dissemination and Notification (Chapter 8)

A comprehensive information dissemination program is critical to an effective end-to-end tsunami warning system. If the proper stakeholders are not identified, and if they do not receive crucial warnings, the end-to-end system will have failed to deliver the message to the last mile, to the beach. As discussed in detail in Chapter 8, bulletin recipients and communications methods should be identified and established well in advance of any events. The entire dissemination system should be tested on a routine basis. Dissemination processes should take advantage of all technologies available to the center and be automated as much as possible to

Tip

If the people in harm's way do not receive and properly respond to an accurate tsunami warning, then the system has failed.

decrease the time required to issue warnings and improve efficiency in providing warnings. Whenever possible, there should be redundant communications paths to ensure receipt of critical data and complete dissemination of important bulletins.

After the initial bulletin has been issued, the center must monitor recorded tsunami effects via coastal tide gages and DART detectors to confirm the existence or non-existence of a tsunami, and its degree of severity. In coordination with neighboring NTWCs and RTWPs, the center should issue a cancellation, extension, or final bulletin as appropriate.

Bulletin thresholds may vary somewhat due to local circumstances. However, a center should strive to adhere as closely as possible to the generally accepted values recommended by IOC/IOTWS – II (January 2006), and used by the current operational NTWCs and RTWPs.

In addition to international dissemination via GTS, and use of regional satellite based dissemination systems, such as the Emergency Managers Weather Information Network (EMWIN), Radio and Internet for the Communication of Hydro-Meteorological and Climate-Related Information (RANET), and *GEONETCast (a global network of satellite based data dissemination systems providing environmental data to a worldwide user community)*, some of the more local communications channels should be used for dissemination include:

- Dispatching short text messages via Short Message Service (SMS) to mobile phones.
- Sending electronic or telephonic faxes to relevant disaster management agencies.
- Transmitting relevant information to mass media and mass media broadcasting systems consisting of radio, television, and print media.
- Assisting emergency management officials in alerting the targeted public through public announcement systems using sirens, alarms, and all hazards alert broadcast systems.
- Alerting the public through conventional phones and SMS based text messages *using cell broadcast tower technology to reach all mobile phone users in an area at risk*.
- Automated updating of earthquake and tsunami web pages.

Successful end-to-end systems require cooperation at all levels, a commitment of all stakeholders to work together during a tsunami warning, and over the long term, a sustained effort of activity to keep awareness and preparedness at high levels. A mechanism to build organizational support and long-term commitment is through Tsunami Coordination Committees (TCC) that bring together stakeholders from warning centers, emergency management and first responders, tsunami scientists, other government agencies, nongovernmental organizations, and the private sector. The TCC's mission is to enable and advocate for policies, procedures, and programs that are needed to save lives and property from tsunamis. TCCs are discussed in Chapter 8, in the section on NTWC and RTWP community preparedness programs. Due to the infrequent nature of tsunamis, it is also strongly advised that a tsunami warning system be embedded in a multi-hazards framework to ensure sustainability.

An NTWC or RTWP might not be directly responsible for some of the links in the end-to-end chain. In many cases, other government agencies and private groups will be charged with taking tsunami warning center products and notifying the populace. These authorities must provide understandable safety messages to the public to ensure that persons at risk move to safe areas. Even when not directly charged with notification and action planning, the tsunami warning center can contribute to stronger links in the overall chain if the center understands and works with the other groups to ensure the warnings get all the way to the beach and proper actions are taken. A tsunami warning center will usually work with two distinct groups:

- **Partners** are generally other government and nongovernment groups that play some role in the detection, warning, and preparedness process. These will include:
  - Domestic and international data providers
  - Government and private entities (including the mass media) that serve as communications conduits for product dissemination
  - Government and private sector groups that train and educate other NTWC and RTWP partners and customers
  - Business and economic groups like coastal hotel operators
- **Customers** are those groups and individuals that rely on the NTWC or RTWP and its partners for timely and accurate tsunami watches and warnings, for protection of their lives and the opportunity to minimize the impact on their property. Customers include:
  - General public
  - Nongovernmental organizations (NGO) and other private sector groups that must respond to events
  - Government agencies that must respond to events

A center's outreach and education program must recognize these two distinct classes of constituents since each has unique requirements. The NTWC may even have to employ different techniques to identify and deal with the major groups that comprise each of these two categories. These constituents are also discussed in Chapter 8 in the section on NTWC and RTWP community preparedness programs.

Community Connections (Chapter 9)

The final link in the end-to-end chain is the action taken by those that will be affected by a tsunami warning. For local tsunamis that can come ashore in 10 minutes or less, alerts should reach the public within minutes to be effective. For distant tsunamis, which could take hours to reach shore, tsunami warning centers and national disaster management organizations have ample time to organize evacuations, so that no one should ever lose their life from a distant tsunami.

Local preparedness and commitment is the key for success, because ultimately, warning systems will be judged on their ability to reach people on the beaches and to lead them safely inland or to higher ground before the first tsunami waves hit.

Tip

A warning that fails to generate the proper response is not an effective warning—it is an exercise in futility.

The goal and focus of NTWC and RTWP outreach should be to educate the public and other partners about tsunami safety and preparedness and promote the center's tsunami warning program through public events, media workshops, and the public school system. During actual tsunami events, the tsunami warning center should have a designated public affairs officer to coordinate media response. During annual tsunami exercises, the public affairs officer is responsible for notifying the media. A center's public affairs officer should also provide media training and guidance to agency representatives, respond to media requests, organize news conferences, coordinate briefings and tours at the warning centers, develop informational materials, assist with briefings of government officials, and plan outreach activities. Chapter 9 will discuss public outreach and education extensively, with the hope that tsunami warning centers will be a strong partner and resource to other groups.

Organizational Capacity Requirements of a Tsunami Warning Center

A tsunami warning center's operations require constant attention and must be provided the resources needed to conduct 24/7 operations as well as maintain all the earth data gages, computers, computer programs, and communications needed to fulfill its mission. Both NTWCs and RTWPs should maintain up-to-date documentation including a concept of operations, standard operating procedures, and agreements with partners and customers. Finally, the goal for each RTWP should be to maintain or exceed the capability and interoperability requirements as defined by the IOC and the applicable ICG.

Staffing Requirements

In addition to staffing around-the-clock operational shifts, additional resources are needed for staff training and conducting or integrating research into center operations. This is the only way to ensure that a center keeps pace with advances in technology and science. To meet its full mission, an NTWC requires several critical positions to ensure that all necessary functions are accomplished. Experience at PTWC and WC/ATWC shows that an NTWC should have a staff of at least 17 people to be effective. That experience has also shown that the staffing structure depicted in Figure 2-2 is the minimum necessary to ensure an effective NTWC.

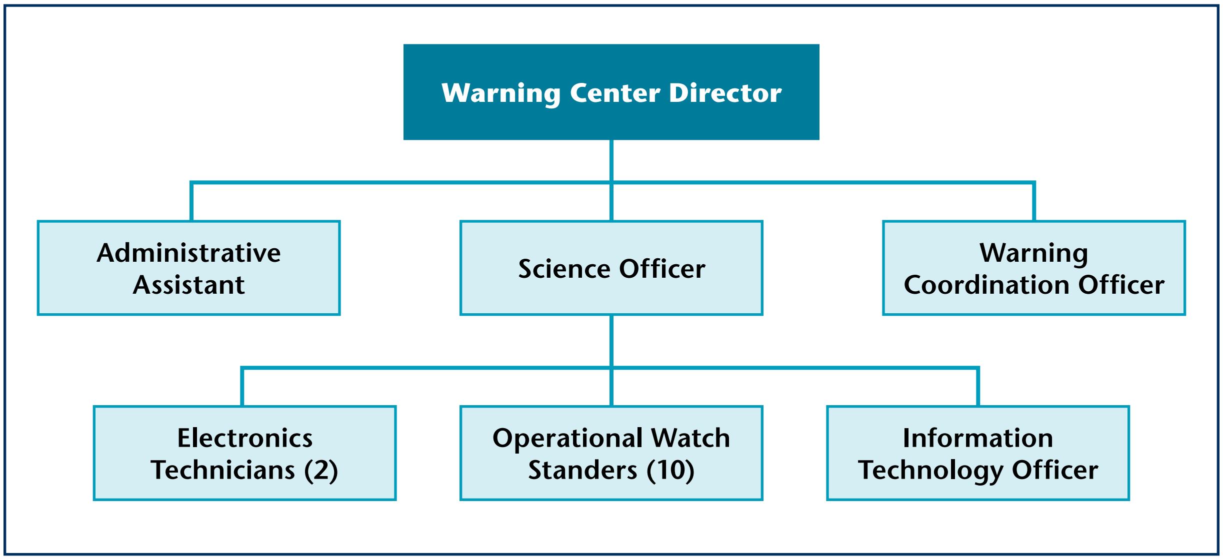


Figure 2-2. Organizational Chart for 24/7 NTWC

Description of each of the functions depicted in Figure 2-2 and the major duties and knowledge required for each position are detailed in Appendix C

Equipment and Maintenance Requirements

At a minimum, a tsunami warning center maintenance program consists of computer hardware and software maintenance. This includes local area network and communications hardware and software maintenance and upgrades. Technicians may also be called upon to maintain fiscal plant systems such as backup generators, telephone systems, etc., and install and maintain seismic and coastal tide gages at remote locations. The latter often requires expert knowledge in order to locate good observational sites.

The size of a maintenance program is heavily impacted by the number of earth data gages deployed and maintained by a center. Some centers may be able to function without the need to augment international seismic and coastal sea-level gage networks. Centers that have a local tsunami threat and must deploy their own gages will require additional electronics technicians, sufficient financial and travel resources, and adequate spare equipment to properly maintain the local equipment. For large centers that must maintain numerous pieces of equipment, it is recommended that a system be established to track routine and emergency maintenance so that staffing can be adjusted to meet workloads, and poorly performing equipment can be identified and replaced.

Communications Requirements

Communications hardware and software are crucial to the success of a tsunami warning center. This includes the communications systems for collecting earth data observations, and the often different systems for collaborating with other centers and disseminating critical warning messages to government agencies and the public. Once identified and integrated into center operations, these pathways must be continually tested to make sure they will be performing as needed during actual events. When tests indicate a failure, the problem should be resolved as quickly as possible as the next event can occur at any time.

Tip

Proper documentation, e.g. CONOPS, Operations Manual, User's Guide. etc., must be kept up-to-date to be useful and effective.

Documentation Requirements for Tsunami Warning Centers

To be effective, an NTWC or RTWP requires documentation that clearly states the center's mandate, authority, and relationship to other government agencies. Equally important are references that document the center's concept of operations, standard operating procedures, and agreements with partners and customers. In June 2007, the UNESCO IOC Tsunami Coordination Unit recommended that NTWCs and RTWPs include, at a minimum, the following documentation.

NTWC/RTWP Concept of Operations (CONOPS): This is a document that is global, basinwide, or countrywide in scope, depending upon the AOR of the center. It should be a high-level document for decision makers and describe the system and how it functions in general terms. It should identify who is involved and clearly define their roles and responsibilities. It should be maintained by the IOC or the applicable country.

Operations Manual: This document details how a particular NTWC or a Disaster Management Office's Emergency Operations Center (EOC) works to carry out its roles and responsibilities. The manual should be designed to be used by the duty people at that center. It should include information on emergency management plans and standard operating procedures (SOP), such as criteria for action, data streams, communications links, analysis software, messaging software, notification and dissemination methods, and general troubleshooting. It should be maintained by the NTWC or EOC as appropriate. SOPs can be defined as:

- A set of written instructions describing a routine, or repetitive activity conducted by an organization. The instructions are stakeholder agreed-upon steps that will be used in coordinating the Who, What, When, Where, and How aspects of the Tsunami Emergency Response Plan (TERP) described later in this chapter.
- A mechanism for operating effective and reliable warning systems and disaster management systems. The NTWC SOPs must be linked at all levels from international to national to local warning institutions, and must be simultaneously connected to the corresponding Disaster Management Office's SOPs, and vice versa.

SOPs should cover a number of CONOPS activities to enable an end-to-end response process. SOPs can range from data processing, analysis, and warning communication procedures to action checklists for conducting public coastal evacuations, coordinating stakeholder organizations, and establishing the roles and jurisdictions for government, nongovernment, and private-sector agencies.

SOPs also should facilitate good decision-making by describing in detail the actions taken by an agency to carry out its responsibilities, as defined in the system's CONOPS document. The existence and use of SOPs are especially essential for rapid, efficient tsunami response since tsunamis are rapid-onset disasters with little time to prepare. Because of this, all responses need to be preplanned, well practiced, and automatically enacted to minimize loss of life through quick public notification.

Examples of operations manuals for tsunami warning centers include: PTWC and WC/ATWC Operations Manual (2006), USGS NEIC Earthquake Response Plan (2006), and the Japan Meteorological Agency's Manual on Operations and Systems for Tsunami Warning Service (2007).

Examples of operations manuals for EOCs include: The Guide to the National Civil Defense Emergency Management Plan - New Zealand (2006), The British Columbia (Canada) Tsunami Warning and Alerting Plan (2001), California (USA) Local Planning Guidance on Tsunami Response (Second Edition, 2006), Wakayama Prefecture (Japan) Plan of Mobilization and Transmittal of Tsunami Forecast (2007), and Kushimoto City (Japan) Municipal Local Tsunami Response Procedures (2007).

Operations Troubleshooting Manual: This document should provide details on what actions to take when a system has failed. This can be computer hardware failure, communications link failure, a software problem, etc. It should be maintained by the NTWC or RTWP as appropriate. Examples these manuals include PTWC's Operations Troubleshooting Manuals and the USGS NEIC Earthquake Analysts Manual (Draft 2006)

Tsunami Warning System Users Guide: This guide should contain general information for customers on tsunamis and the tsunami threat, tsunami warning center procedures, and the criteria for action, along with sample messages. It should include a general description of that center's system: seismic data, sea level data, warning center message dissemination, public safety actions, and public responses, including evacuation. It should also include guidance on what the user or customer can expect from the tsunami warning center, including how to interpret messages for action, definitions of terms, and what to do when warnings are issued. For RTWPs, the document may be maintained by the IOC. For a national system, it should be maintained jointly by the NTWC and partners. The users guide can be divided into two parts, with each part published separately: a national guide and a supplemental local response users guide.

Examples of tsunami warning system users guides include: PTWS Users Guide (new edition in August 2007), current WC/ATWC Operations Plan (Users Guide), Users Guide for the IOTWS (February 2007).

NTWC/RTWP Stakeholder Contacts: This document generally comprises contacts responsible for overall tsunami mitigation, for tsunami warning operations, and for tsunami emergency response operations.

- For RTWPs, these are Tsunami Warning Focal Points for 24/7 action on tsunami emergencies, and national stakeholders or ICG Tsunami National Contacts responsible for tsunami mitigation. The document should be maintained by IOC for the global system; an efficient means will be by secure website that is password protected, or other easily accessed, secure method. At the international level, the stakeholder group is the ICG.
- For NTWCs, the document should be similar but involve emergency response as well. Documents should be maintained by the NTWC and EOC national, provincial, district, and/or local levels of government.

Tsunami Warning System Directives: This is a collection of official, authoritative documents covering national or local procedures and responsibilities. Descriptions are in more detail than CONOPS, but less detail than operations manuals. Directives describe the authority, coordination, roles, and responsibilities of services and organizations involved. They should be maintained by each country or local authority that carries out procedures. Examples of NOAA's NWS Tsunami Directives (2006) can be found at: **http://www.weather.gov/directives/010/010.htm** NDS 10-7 Tsunami Warning Services.

Tsunami Emergency Response Plans (TERP): NTWCs and their NDMO partners, must create and customize written Tsunami Emergency Response Plans (TERP) to meet their specific needs. The documents form the basis on which to conduct routine drills to ensure response procedures can be effectively enacted by a 24/7 duty staff. These can range from stakeholder familiarization workshops, agency and multiagency drills, tabletop scenario exercises, and functional communications tests, to full-scale response agency field deployment exercises, which may or may not include public evacuations. Documents and drills also ensure the consistency of actions as duty staff may turn over several times between actual tsunami events.

NTWC and DMO TERPs, and their accompanying SOPs and checklists, should also describe procedures, protocols, and expected actions for tsunami emergencies. For the NTWC, this may mean procedures followed when a tsunami alert is received from international RTWPs, or how an NTWC monitors earthquakes and evaluates their tsunamigenic potential. The goal of the NTWC is to then issue an urgent local, regional, and/or distant tsunami warning to its DMO and/or its citizens.

For the DMO, this means the immediate alerting of communities and households, and as required, the evacuation of people out of the predesignated tsunami evacuation zone. For a local tsunami warning and evacuation order, these decisions and actions may have to take place immediately, within minutes after an earthquake is felt.

Together, these are the *minimum* documentation requirements for establishing a fully functioning, efficient tsunami warning center.

Capability and Interoperability Requirements of an RTWP

The initial goal of the IOC is for RTWPs to be interoperable within each basin (Pacific Ocean, Indian Ocean, Caribbean, North Atlantic, and Mediterranean), with the end goal being a fully interoperable tsunami warning system for the globe. Recipient countries should make bilateral arrangements with as many individual RTWPs as they choose and their ICG permits.

Initially each of the four ICGs is defining RTWP minimum capability requirements, with the hope that these requirements will converge quickly to a set of requirements that has global consensus.

Based upon 40 years of PTWS experiences and the requirements defined by the IOTWS IOC/WG5 in August 2007, it is recommended that an RTWP have the capability to perform the following functions:

- Operate 24 hours per day, 7 days per week
- Have access to seismic and sea-level data in real time via more than one communications path
- Produce standardized seismic (location, magnitude, depth) parameters in a reasonable amount of time (as agreed upon in bilateral agreements with NTWCs served)
- Use the scale Mwp (moment magnitude from p waves) to allow intercomparison of earthquake magnitudes from other sources
- Maintain or have access to tsunami scenarios for their AOR
- Be able to determine which countries in their AOR might be affected, and the level of hazard, based on standardized or otherwise agreed upon thresholds (magnitude and amplitude), i.e., which countries are at risk and which are outside the risk zone
- Revise their predictions in light of additional seismic and sea level data
- Provide products in standardized format in accordance with global practices
- Transmit products on the GTS in a timely manner, and have one or more backup dissemination paths in place and tested
- Provide NTWCs with predicted tsunami arrival times, at a minimum.
- Arrange with another RTWP to provide backup service in the event of a major communications failure or other catastrophe at the RTWP
- Provide NTWCs access to all RTWP products

- Collaborate with other affected RTWPs and NTWCs before issuing products (as time permits).
- Coordinate cancellation messages with neighboring centers.

RTWP Performance Indicators

Each RTWP should work with the NTWCs that they have bilateral agreements with to quantify their performance indicators. Recommended performance indicators are provided in Table 2-1.

Table 2-1. Recommended Performance Indicators for Regional Tsunami Watch Providers

1. Elapsed time from earthquake to Watch issuance (The goal is to reduce elapsed time to less than 20 minutes.)
   a. Accuracy of earthquake parameters – location, depth, magnitude
2. Elapsed time from issuance to receipt at serviced NTWC
3. Percentage of served countries that receive timely Watch products
4. Elapsed time to tsunami detection
5. Elapsed time to tsunami evaluation
6. Accuracy of forecast
   a. Countries affected
   b. Hazard level from scenarios
7. Elapsed time to cancellation
8. Reliability of RTWP office (power, computers, communications, 24/7 operations)
9. Trained and competent staff
10. Regular exercising of the system

Chapter 3

Earth Data Observations

Earth data observations, in particular seismic and sea level data, are needed to detect the occurrence of a tsunami. This chapter describes the seismic and sea level data, the types of instruments used to collect these data, and the forces behind tsunami-generating earthquakes. Earth data observations are needed by National Tsunami Warning Centers (NTWC) and Regional Tsunami Watch Providers (RTWP) (Figure 3-1). In addition to local seismic and sea level data networks, these data are also available in real time for use by tsunami warning centers through international observation networks. This chapter should be read by those who need to understand the types of earth data that are necessary for a warning center to function and the importance of maintaining instruments to detect tsunamis.

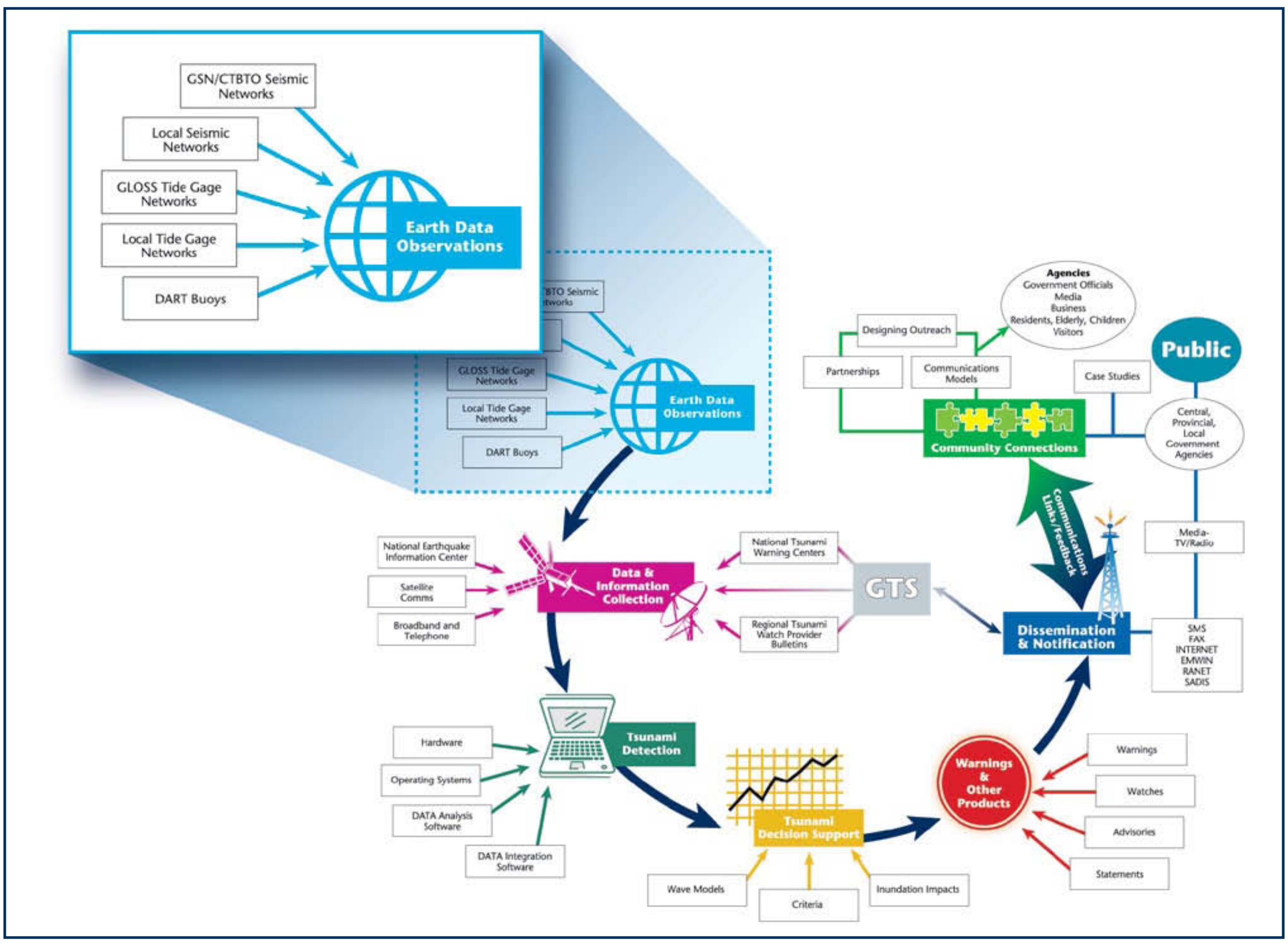


Figure 3-1. Components of a Tsunami Warning Center's Earth Data Observation Requirements

How Do Earth Data Observations Fit Into an End-to-End Tsunami Warning System?

Earth data observations are part of the hazard detection and forecast component of an end-to-end tsunami warning system. The rapid detection and characterization of tsunami-generating earthquakes provides the first indication of a potential tsunami in an end-to-end tsunami warning system. Initial seismic-based warnings based on data from networks of seismic gages are subsequently refined by the detection of tsunami-generated changes in sea level, measured by tide gages and buoys.

The refinement of initial seismic-based warnings with data on sea level changes can greatly increase the credibility of the warnings by decreasing false alarms. To make this refinement, tsunami warning centers must understand the mechanisms that cause changes in sea level, and how a tsunami wave registers on a tide gage. While critical, tide gages do have limitations due to local bathymetry and other factors. Deep ocean buoys, where available, usually provide a better assessment of the nature of a tsunami.

Critical seismic and sea level data must be received rapidly at tsunami warning centers to be of any use in the warning process. Thus, data collection communications systems are crucial to the success of the warning system.

What Is in This Chapter?

This chapter contains sections that discuss the following topics:

- **Seismic data requirements for tsunami detection:** This section highlights the importance of seismic data in the success of the end-to-end warning process.
- **Physical forces that generate tsunamis:** This section presents discussions on the types of faults and seismic waves, locating earthquake hypocenters, and the distinction between earthquake magnitude and earthquake intensity.
- **Instruments used to detect seismicity:** This section describes the various types of seismometers and their strengths and weaknesses in accurately measuring the intensity of strong, damaging, tsunamigenic earthquakes.
- **Seismic network and processing requirements:** This section discusses necessary seismic data network and processing equipment for a center to issue a tsunami warning within 5 minutes of the occurrence of a tsunamigenic earthquake.
- **Sea level data requirements for tsunami detection:** This section highlights the importance of sea level data in the success of the end-to-end warning process.
- **Causes of sea level variations and detection of the tsunami wave signal:** This section discusses the various physical forces that cause changes in sea level, and describes the characteristic signal of a tsunami in sea level gage recordings.

- **Using tide gages to measure changes in sea level:** This section surveys various types of tide gages, their strengths and weaknesses, and the importance of multiple-use gages in constructing a sustainable warning system.
- **Coastal tide gage network and processing requirements:** This section discusses tide gage data network and processing requirements for NTWCs and RTWPs.
- **Using tsunameter buoys to detect a tsunami wave signal:** This section provides an overview of the Deep Ocean Assessment and Reporting of Tsunamis (DART™) II system, including operating modes and real-time transmission of data.

What Are the Most Important Points to Remember about Earth Data Observation Requirements for NTWCs and RTWPS?

- Two types of data are critical to tsunami warning center operations.
  - **Seismic** data, received with minimum delay, are required to issue initial timely warnings.
  - **Sea level** data, again with little delay in receipt, are needed to adjust and cancel warnings, in form of observed values for real-time verification and as input to models, as an event unfolds. Sea level data come from tide gages and from DART buoys in the open ocean.
  - Run-up data can also be invaluable in assessing the local impact of a tsunami.
- International seismic gage networks and international sea level gage networks can be accessed by tsunami warning centers as a source of earth data observations.

Seismic Data Requirements for Tsunami Detection

A tsunami, in the ocean or other body of water, is a wave train generated by a vertical displacement of the water column. Earthquakes, landslides, volcanic eruptions, explosions, and even the impact of meteorites, can generate tsunamis. Tsunami waves can cause severe property damage and loss of life where they impact the coastline.

The vast majority of tsunamis are caused by subduction zone earthquakes at locations where tectonic plates converge on the sea floor. Knowing the type and the strength of an earthquake is critical in determining its potential for generating a tsunami. As a result, seismic data play a crucial role in the tsunami warning process. To produce accurate moment magnitudes, NTWCs and RTWPs require reliable, broad frequency, low noise, high dynamic range, digital seismic data in real time. Seismologists employ data from networks of seismometers to determine whether an earthquake is a strike slip, a normal slip, or a thrust (reverse) fault. While thrust faults cause the majority of tsunami events, tsunamis can be generated by strike slips or oblique slip faults. As a result, warnings should not be prevented or canceled based on that criterion alone.

Internationally coordinated networks like the Global Seismic Network (GSN) are sufficiently robust to support warnings for teleseismic events, i.e. earthquakes at distances greater than 1,000 km from the measurement site, provided they are properly telemetered, interrogated with sufficient frequency, and properly maintained. However, NTWCs may find that national or local networks are also required, especially if the center's area of responsibility (AOR) includes local tsunami sources. In this case, the NTWC will require a seismometer installation and maintenance program, and a communications program to obtain and process data in real time. If resources or other factors do not permit an NTWC to conduct equipment and communications programs, the center will work to obtain data from regional network operators.

Important Points to Remember about Seismic Data

- Most tsunamis are generated by subduction zone earthquakes at locations where tectonic plates converge on the sea floor.
- NTWCs and RTWPs require seismic data to rapidly detect potential tsunamigenic events and issue initial timely warnings.
- There are international seismic gage networks that warning centers can access, although in some instances, existing networks may not meet a center's requirements for rapid detection and warning of **local tsunami events**. In these cases, a center may need to establish and maintain gages that augment the available international networks.
- A center should have real-time access to multiple networks via multiple communications channels to ensure that all seismic events are captured in the event of a network or communications problem.
- Real-time data collection by robust and reliable communications channels is essential to the success of a tsunami warning program.

Physical Forces that Generate Tsunamis

A variety of physical forces may contribute to the generation of tsunamis. This section provides a detailed discussion of the following topics:

- Types of faults
- Plate tectonics
- Seismic waves

Types of Faults

The Normal Fault

The normal fault, despite its name, is ***not*** the most common of faults (Figure 3-2). What is normal about it is that its movement tends to follow the gravitational pull on the fault blocks involved (Figure 3-2). The fault plane on the normal fault is generally very steep. In a normal fault the two involved blocks are (by gravity) pulling away from one another, causing one of the fault blocks to slip upward and the other downward with respect to the fault plane (it is hard to determine whether both or just one block has moved.). The exposed upward block forms a cliff-like feature known as a fault scarp. A scarp may range from a few to hundreds of meters in height, and its length may exceed 300 kilometers.

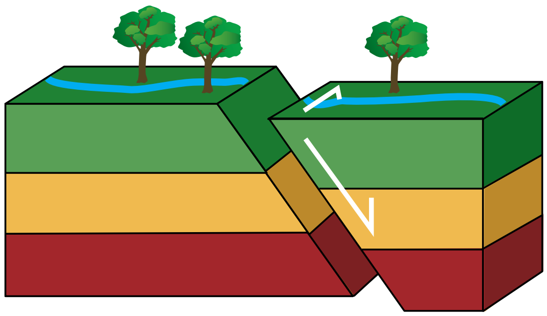


Figure 3-2. A Normal Slip Fault

The Reverse or Thrust Fault

The reverse fault is a normal fault except the general movement of the fault blocks is toward each other, not away from each other as in the normal fault (Figure 3-3). This forms an expression on the surface with material overlaying other material.

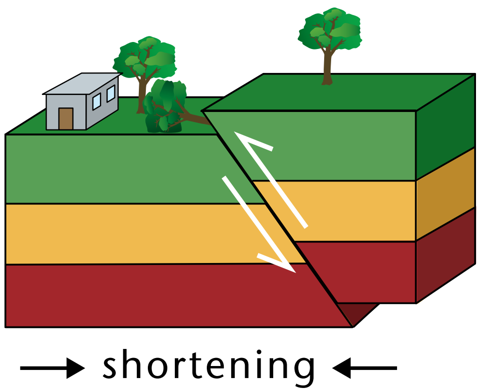


Figure 3-3. A Reverse or Thrust Fault

The Strike-Slip or Transcurrent Fault

Probably the best known and most studied fault is the strike-slip or transcurrent fault type, as exemplified by the San Andreas Fault in California (Figure 3-4). Movement on a strike-strip fault is generally horizontal (Figure 3-4). On the surface, scarps form as hills crossing this fault zone are torn apart by movement over time. Anything crossing this fault zone is either slowly torn apart, or offset.

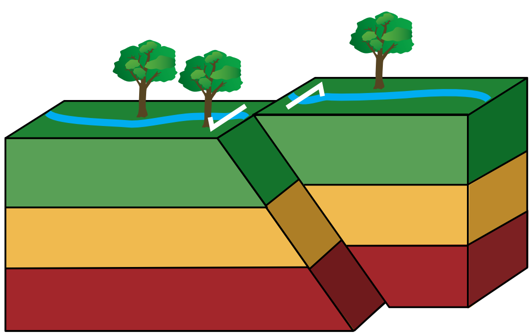


Figure 3-4. Strike-Slip or Transcurrent Fault

For a comprehensive discussion on fault plane solutions, with effective animations, see the web site: **http://www.learninggeoscience.net/free/00071/** authored by Arild Andresen of the University of Oslo, Norway.

Plate Tectonics

Figure 3-5 illustrates the main features of plate tectonics, which include:

- The Earth's surface is covered by a series of crustal plates (see Figure 3-5).
- The ocean floors are continually moving, spreading from the center, sinking at the edges, and being regenerated.
- Convection currents beneath the plates move the crustal plates in different directions.
- The source of heat driving the convection currents is radioactivity deep in the Earth.

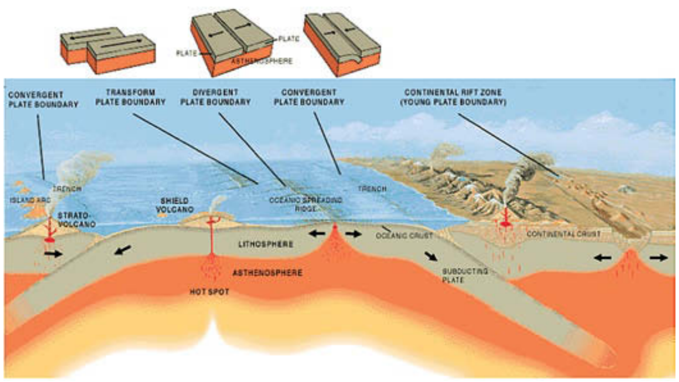


Figure 3-5. Cross Section of the Earth's Plate Tectonic Structure
(Source: U.S. Geological Survey (USGS) Map, "This Dynamic Planet")

Mid-Oceanic Ridges

The mid-oceanic ridges rise 3000 meters from the ocean floor and are more than 2000 kilometers wide, surpassing the Himalayas in size. These huge underwater mountain ranges have a deep trench that bisects the length of the ridges and in places is more than 2000 meters deep. Research into the heat flow from the ocean floor during the early 1960s revealed that the greatest heat flow was centered at the crests of these mid-oceanic ridges. Seismic studies show that the mid-oceanic ridges experience an elevated number of earthquakes. All these observations indicate intense geological activity at the mid-oceanic ridges.

Deep Sea Trenches

The deepest waters are found in oceanic trenches, which plunge as deep as 35,000 feet below the ocean surface. These trenches are usually long and narrow, and run parallel to and near the ocean margins. They are often associated with and parallel to large continental mountain ranges. There is also an observed parallel association of trenches and island arcs. Like the mid-oceanic ridges, the trenches are seismically active, but unlike the ridges they have low levels of heat flow.

Island Arcs

Chains of islands are found throughout the oceans and especially in the western Pacific margins; the Aleutians, Kuriles, Japan, Ryukus, Philippines, Marianas, Indonesia, Solomons, New Hebrides, and the Tongas, are some examples. These "Island arcs" are usually situated along deep sea trenches on the continental side of the trench, i.e., on the overriding plate subduction zone.

These observations, along with many other studies of our planet, support the theory that below the Earth's crust (i.e., the lithosphere: a solid array of plates, as depicted in Figure 3-6) lies a malleable layer of heated rock known as the asthenosphere, heated by radioactive decay of elements such as uranium, thorium, and potassium. Because the radioactive source of heat is deep within the mantle, the fluid asthenosphere circulates as convection currents underneath the solid lithosphere. This heated layer is the source of lava we see in volcanoes, the source of heat that drives hot springs and geysers, and the source of raw material which pushes up the mid-oceanic ridges and forms new ocean floor.

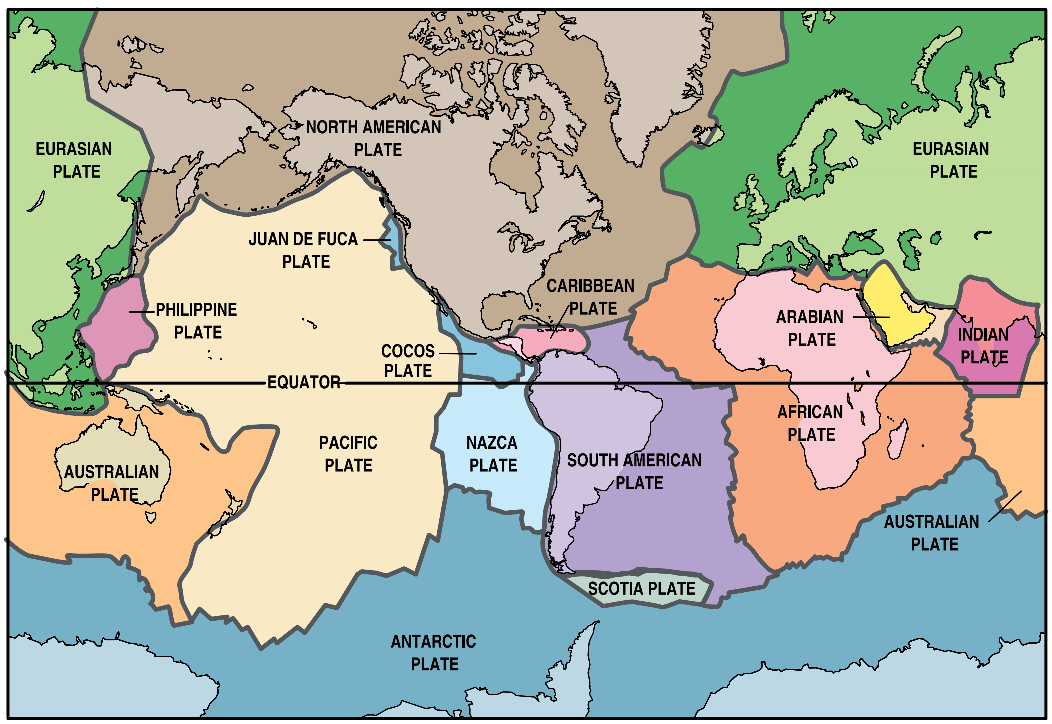


Figure 3-6. The Major Tectonic Plates of the Earth.
(Source: USGS Map, "This Dynamic Earth")

Magma continuously wells upward at the mid-oceanic ridges, producing currents of magma flowing in opposite directions below the lithosphere, which generates the forces that pull the sea floor apart at the mid-oceanic ridges. As the ocean floor spreads apart, cracks appear in the middle of the ridges, allowing molten magma to surface to form the newest ocean floor. As the ocean floor moves away from the mid-oceanic ridge, it eventually comes into contact with a continental plate and is subducted underneath the continent. These subduction zones are where the likelihood of undersea earthquakes, and hence tsunami generation, is highest. Figures 3-7a through 3-7d, from USGS Circular 1187, depict the process of tsunami generation via subduction where two tectonic plates collide.

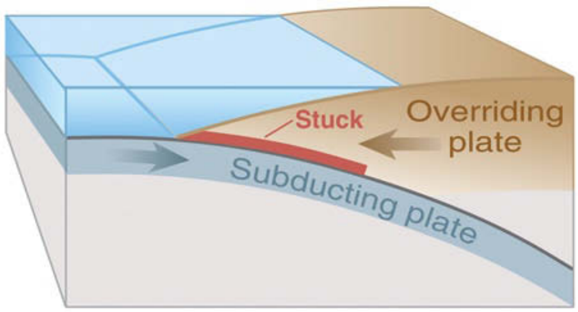


Figure 3-7a. Friction retards movement of the overriding plate in a subduction zone.

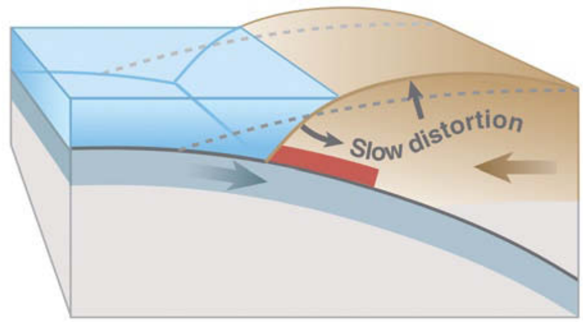


Figure 3-7b. The overriding plate is slowly distorted.

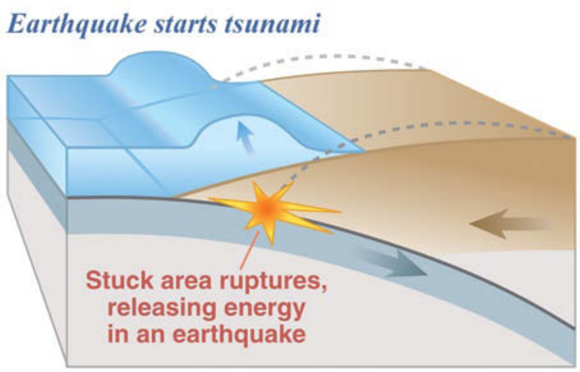


Figure 3-7c. The overriding plate rebounds and displaces ocean upwards.

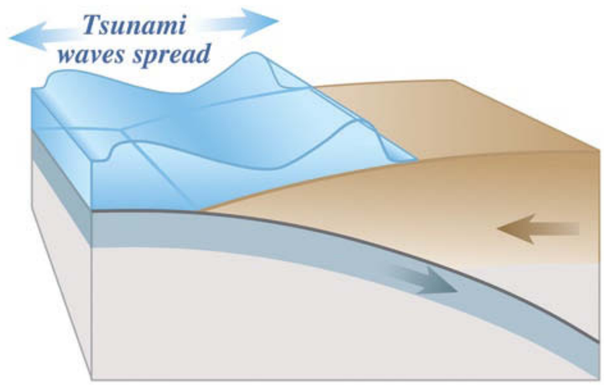


Figure 3-7d. Tsunami waves spread out from the source region.

Seismic Waves

While most of the plate-tectonic energy driving fault ruptures is taken up by static deformation, up to 10 percent may dissipate immediately in the form of **seismic waves**. A seismic wave can be distinguished by a number of properties, including the speed of travel, the direction it moves particles as it passes, and where the wave does and does not propagate.

The first two wave types, P and S, are called **body waves** because they travel or propagate through the body of the Earth (Figure 3-8, a and b). The latter two types, L and R, are called **surface waves** because they travel along Earth's surface and their amplitude decreases with depth into the Earth.

Tip

S waves travel at only about **60 to 70** per cent the speed of **P waves**

The mechanical properties of the rocks that body waves travel through quickly organize the waves into two types. Compressional waves, also known as primary or P waves, travel fastest, at speeds between 1.5 and 8 kilometers per second in the Earth's crust. They propagate by alternately compressing and expanding the rock. The rock particles move in the same direction as the wave is propagating. When P waves travel through the air, they are called "sound waves". Shear waves, also known as secondary or S waves, travel more slowly, usually at 60 to 70 percent of the speed of P waves. S waves can travel only in solids, and the particles vibrate at right angles to the direction of propagation of the wave.

P waves shake the ground in the direction they are propagating, while S waves shake perpendicularly or **transverse** to the direction of propagation, as shown in Figure 3-8.

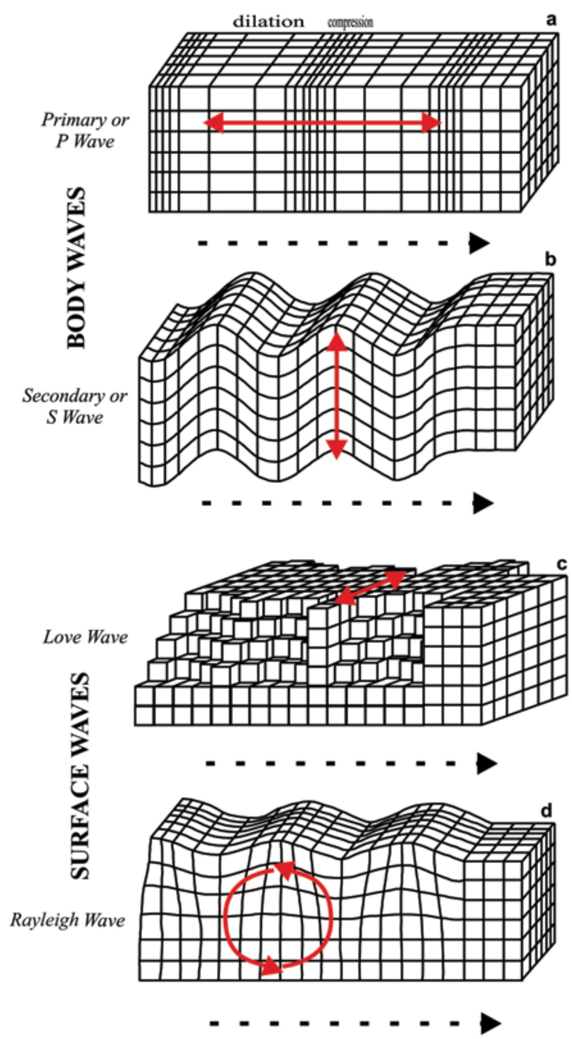


Figure 3-8. Particle Motion (in Red) Associated with Seismic Wave Types
(Source: S. Baxter, Delaware Geological Survey Publication Number 23 – Earthquake Basics)

Table 3-1. lists all four waves that are created by earthquakes, and their characteristics.

Table 3-1. Seismic Waves

Wave Type (and names)	Particle Motion	Typical Velocity	Other Characteristics
P, Compressional, Primary, Longitudinal	Alternating compressions ("pushes") and dilations ("pulls") which are directed in the same direction as the wave is propagating (along the ray path); and therefore, perpendicular to the wavefront.	V_P ~ 5–7 km/s in typical Earth's crust; >~ 8 km/s in Earth's mantle and core; ~1.5 km/s in water; ~0.3 km/s in air.	P motion travels fastest in materials, so the P-wave is the first-arriving energy on a seismogram. Generally smaller and higher frequency than the S and Surface-waves. P waves in a liquid or gas are pressure waves, including sound waves.
S, Shear, Secondary, Transverse	Alternating transverse motions (perpendicular to the direction of propagation, and the ray path); commonly approximately polarized such that particle motion is in vertical or horizontal planes.	V_S ~ 3–4 km/s in typical Earth's crust; >~ 4.5 km/s in Earth's mantle; ~ 2.5–3.0 km/s in (solid) inner core.	S-waves do not travel through fluids, so do not exist in Earth's outer core (inferred to be primarily liquid iron) or in air or water or molten rock (magma). S waves travel slower than P waves in a solid and, therefore, arrive after the P wave.
L, Love, Surface waves, Long waves	Transverse horizontal motion, perpendicular to the direction of propagation and generally parallel to the Earth's surface.	V_L ~ 2.0–4.4 km/s in the Earth depending on frequency of the propagating wave, and therefore the depth of penetration of the waves. In general, the Love waves travel slightly faster than the Rayleigh waves.	Love waves exist because of the Earth's surface. They are largest at the surface and decrease in amplitude with depth. Love waves are dispersive, that is, the wave velocity is dependent on frequency, generally with low frequencies propagating at higher velocity. Depth of penetration of the Love waves is also dependent on frequency, with lower frequencies penetrating to greater depth.
R, Rayleigh, Surface waves, Long waves, Ground roll	Motion is both in the direction of propagation and perpendicular (in a vertical plane), and "phased" so that the motion is generally elliptical—either prograde or retrograde.	V_R ~ 2.0–4.2 km/s in the Earth depending on frequency of the propagating wave, and therefore the depth of penetration of the waves.	Rayleigh waves are also dispersive and the amplitudes generally decrease with depth in the Earth. Appearance and particle motion are similar to water waves. Depth of penetration of the Rayleigh waves is also dependent on frequency, with lower frequencies penetrating to greater depth.

Source: Purdue University Website (http://web.ics.purdue.edu/~braile/edumod/waves/WaveDemo.htm)

Important Points to Remember about the Physical Forces that Generate Tsunamis

- Most tsunamis are generated by subduction-zone earthquakes at locations where tectonic plates converge on the sea floor.
- Most of the plate-tectonic energy driving fault ruptures is taken up by static deformation but up to 10 percent may dissipate immediately in the form of **seismic waves**.
- The two most important of the four seismic wave types are the P waves and the S waves.
- Compressional (or primary) P waves, travel fastest, at speeds between 1.5 and 8 kilometers per second in the Earth's crust.
- Shear (or secondary) S waves, travel more slowly, usually at 60 to 70 percent of the speed of P waves. S waves can travel only in solids, and the particles vibrate at right angles to the direction of propagation of the wave.

Locating Earthquake Epicenters and Hypocenters

Although seismic wave speeds vary by a factor of ten or more in the Earth, the ratio between the average speeds of a P wave and of its following S-wave is quite constant. This fact enables seismologists to estimate the distance (in kilometers) the earthquake is from the observation station by multiplying the difference (in seconds) between the two observations by the factor 8 kilometers per second (km/s), or

distance from observation = (S-P) * 8 km/s.

The dynamic, transient seismic waves from any substantial earthquake will propagate all around and entirely through the Earth. With a sensitive enough detector, it is possible to record the seismic waves from even minor events occurring anywhere in the world. The monitoring of nuclear test-ban treaties relies on our ability to detect a nuclear explosion anywhere if it is equivalent to an earthquake of Richter Magnitude 3.5. Seismic networks established specifically for this purpose can also be extremely valuable to tsunami warning programs.

Wave Travel Times

Charles J. Ammon, on the Penn State Earthquake Seismology website, uses the analogy of an automobile trip to conceptualize wave travel times. If you have to travel 120 miles and you drive 60 miles per hour, you will get to your destination in 2 hours; if you are forced to drive at 30 miles per hour, it will take you twice as long to arrive. The mathematical formula we use in this problem is

driving time = (distance of trip) / (driving speed)

Ammon further suggests that to apply this idea to earthquake studies, think of the earthquake location as the starting point for the trip and the seismometer as the place where the trip concludes. Faster waves will travel the distance quicker and show up on the seismogram first.

travel time = (distance from earthquake to seismometer) / (seismic wave speed)

Travel time is a relative time. It is the number of minutes, seconds, etc. that the wave took to complete its journey. The arrival time is the time when we record the arrival of a wave; it is an absolute time, usually referenced to Universal Coordinated Time (a 24-hour time system used in many sciences).

Seismic Wave Speed

Seismic waves travel fast, on the order of kilometers per second. The precise speed that a seismic wave travels depends on several factors, the most important being the composition of the rock. Because the speed depends on the rock type, scientists have been able to use observations recorded on seismograms to infer the composition or range of compositions of the planet. But the process is not always simple, because sometimes different rock types have the same seismic-wave velocity, and other factors also affect the speed, particularly temperature and pressure. Higher temperature tends to lower the speed of seismic waves, and higher pressure tends to increase the speed. Pressure increases with depth in Earth as the weight of the rocks above increases with increasing depth. In general, temperature also increases with increasing depth, effectively lowering the wave's velocity. Usually, the effect of pressure overshadows that of temperature and in regions of uniform composition, velocity generally increases with depth.

The two seismic wave types discussed below each include ranges of speed that is the range of values observed in common terrestrial rocks. The specific speed depends on composition, temperature, and pressure.

Compressional or P-Waves

P-waves are the first waves to arrive on a complete seismic record of ground shaking because they travel the fastest (the name derives from the abbreviation for primary [P], or the first wave to arrive). They typically travel at speeds of about 1 to 14 km/s. The slower value corresponds to a P-wave traveling in water, while the higher number represents the P-wave speed near the base of Earth's mantle.

The velocity of a wave depends on the elastic properties and density of a material. Elasticity is defined in terms of a material's modulus, which is a measure of how easy or difficult it is to deform the material. For example, the bulk modulus is a measure of how a material changes volume when pressure is applied. Foam rubber has a lower bulk modulus than steel. The shear modulus is the elastic modulus we use for the deformation which takes place when a force is applied parallel to one face of the object while the opposite face is held fixed by another equal force. The bigger the shear modulus the more rigid is the material since for the same change in horizontal distance (strain) you will need a bigger force (stress). This is why the shear modulus is sometimes called the modulus of rigidity.

If we let κ represent the bulk modulus of a material, μ the shear-modulus, and ρ the density, then the P-wave velocity, which we represent by α, is defined by:

$$\alpha = \sqrt{\frac{\kappa + \frac{4}{3}\mu}{\rho}}$$

P-waves are sound waves, although seismology is interested in frequencies lower than humans' range of hearing (the speed of sound in air is about 0.3 km/s). The vibration caused by P waves is a volume change, alternating from compression to expansion in the direction that the wave is traveling. P-waves travel through all types of media: solid, liquid, or gas.

Secondary or S-Waves

Secondary, or S waves, travel slower than P waves and are also called "shear" waves because they do not change the volume of the material through which they propagate; they shear it. S-waves are transverse waves because the particle motion is in the direction "transverse," or perpendicular, to the direction that the wave is traveling.

The S-wave speed, call it β, depends on the shear modulus and the density

$$\beta = \sqrt{\frac{\mu}{\rho}}$$

While slower than P-waves, S-waves move quickly. Typical S-wave propagation speeds are on the order of 1 to 8 km/s. The lower value corresponds to the wave speed in loose, unconsolidated sediment; the higher value occurs near the base of Earth's mantle.

An important distinguishing characteristic of an S-wave is its inability to propagate through a fluid or a gas, because fluids and gasses cannot transmit a shear stress, and S-waves are waves that shear the material.

In general, earthquakes generate larger shear waves than compressional waves, and much of the damage close to an earthquake is the result of strong shaking caused by shear waves.

Using P and S Waves to Locate Earthquakes

We can use the fact that P and S waves travel at different speeds to locate earthquakes. Assume a seismometer is far enough from the earthquake that the waves travel roughly horizontally, which is about 50 to 500 km for shallow earthquakes.

When an earthquake occurs, the P and S waves travel outward from the rupture with the P-wave arriving at the seismometer first, followed by the S-wave. Once the S-wave arrives, we can measure the time interval between the detection of P and S waves.

The travel time of the P-wave, Tp, is

distance from earthquake / (P-wave speed)

The travel time of the S-wave, Ts is

distance from earthquake / (S-wave speed)

The difference in the arrival times of the waves is

deltaT = Tp – Ts or

deltaT = [distance from earthquake / (S-wave speed)] –
[distance from earthquake / (P-wave speed)]

which equals

*distance from earthquake * (1 / (S-wave speed) - 1 /*
(P-wave speed))

We can measure that difference from a seismogram, and if we also know the speed that the waves travel, we could calculate the distance. For the distance range 50 to 500 km, the S-waves travel about 3.45 km/s and the P-waves around 8 km/s. The value in parentheses is then equal to about (1/3.45 - 1/8) or about 1/8. Thus the quick estimate of the distance between the earthquake and the seismometer for earthquakes in this distance range is about 8 times the difference in the arrival times of the S and P waves. The earthquake can be in any direction, but it must be located on a circle surrounding the seismometer, with a radius about 8 times the observed wave travel-time difference (in kilometers).

If we have two other seismometers that recorded the same earthquake, we could make a similar measurement and construct a circle of possible locations for each seismometer. Since the earthquake epicenter (location at the surface) must lie on each circle centered on a seismometer, we plot three or more circles on a map and find that the three circles intersect in the vicinity of a single location—the earthquake's epicenter. This is depicted in Figure 3-9, which shows that using seismometer readings at Berkeley, California; the Lamont-Doherty Earth Observatory in New York; and Rio de Janeiro, Brazil, the earthquake epicenter is indicated on the west coast of South America.

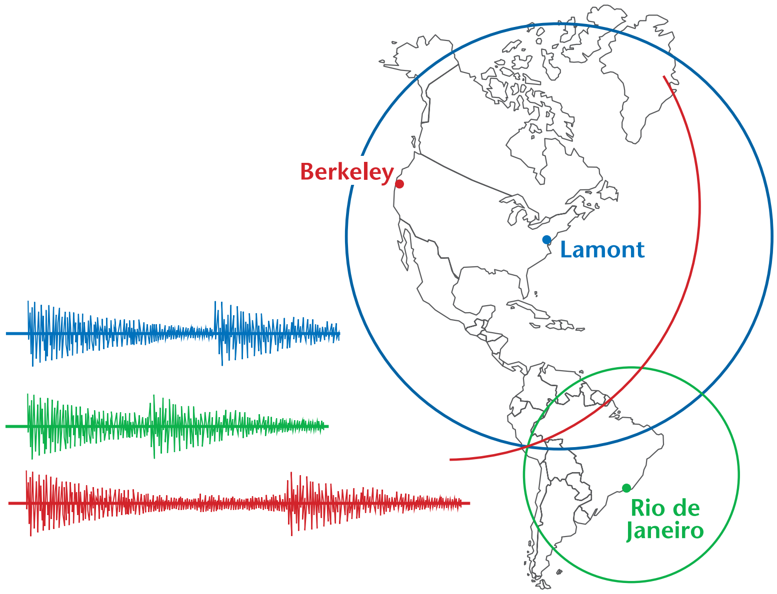


Figure 3-9. Locating Earthquake Epicenter

Along subduction zones, the often somewhat linear orientation of sensors can make it more difficult to accurately pinpoint the epicenter, as shown in Figure 3-10b below, compared to the more favorable instrument spacing in Figure 3-10a.

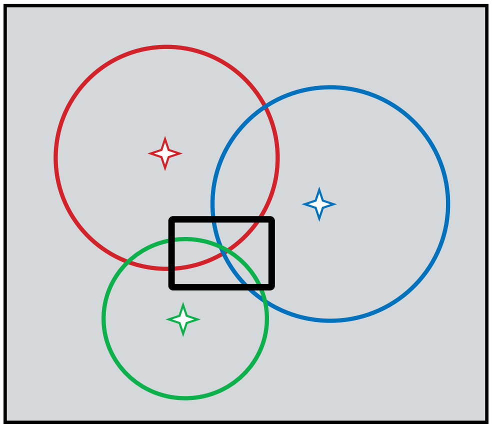


Figure 3-10a. Optimally placed sensors

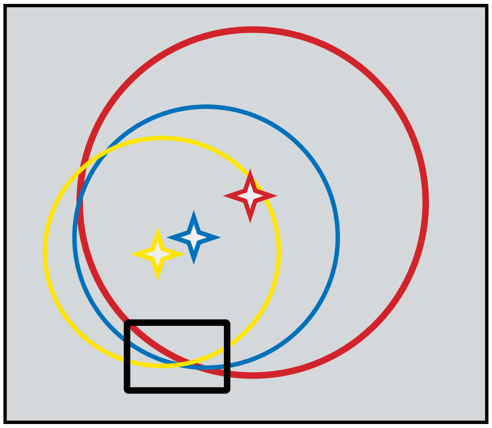


Figure 3-10b. Sensors on a subduction zone

In practice, seismologists use better estimates of the speed than the simple rule of thumb in the above example, and solve the problem using algebra and successive iteration routines on computers instead of geometry. They also can factor the earthquake depth (hypocenter) and the time that earthquake rupture initiated (called the "origin time") into the problem.

Some other methods of solving for the earthquake location include:

- Locating with P only. The location has four unknowns (t, x, y, z) so with 4+P arrivals, the problem can be solved. However, the P arrival time has a non-linear relationship to the location, so we can only solve numerically.
- Grid search. All locations on a grid are tested and the misfit mapped out, and the earthquake location is (at least in theory) where the minimum misfit is.
- Linearization (i.e., restructuring the problem so that the residuals are a linear function of the changes needed to the hypocentral distance). The most common approach assumes a starting location of the station with the earliest recorded arrival (i.e., the nearest station to the event) and assumes that small changes to this location will give the hypocenter. With this assumption we can reduce the required changes in location to a set of linear equations, which can be solved relatively easily. Having found the model adjustment needed to our first guess we now have a solution. However, we only have the approximate solution as we linearized the problem. So now we take the solution and use it as a new starting location and repeat the process. We continue to do this until there is little change between iterations. While we assume we have the solution, we cannot be certain whether we have found the true minimum or a local minimum of the solution.
- Single station method. If a network utilizes 3-component stations, an approximate location can be found from a single station. This is not just an interesting observation; rather, this method can be used to help constrain the search for multi-station location methods.

Determining the Earthquake Hypocenter

An earthquake's hypocenter is often located at some depth in the earth. The corresponding epicenter is the point at the earth's surface above the hypocenter. Figure 3-11 depicts the relationship between an earthquake epicenter and its hypocenter.

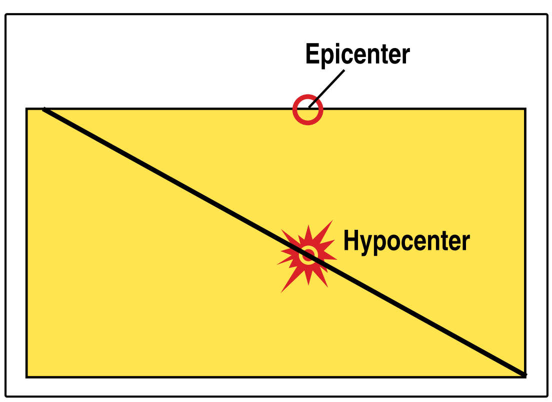


Figure 3-11. Earthquake Hypocenter and Epicenter

Mathematically, the hypocenter is determined by setting up a system of linear equations, one for each station. The equations express the difference between the observed arrival times and those calculated from the previous guess of (or initial) hypocenter location, in terms of small steps in the three hypocentral coordinates (latitude, longitude, and depth) and the origin time. We must also have a mathematical model of the crustal velocities (in kilometers per second) under the seismic network to calculate the travel times of waves from an earthquake at a given depth to a station at a given distance. The system of linear equations is solved by the method of least squares, which minimizes the sum of the squares of the differences between the observed and calculated arrival times. The process begins with an initial guessed hypocenter; performs several hypocentral adjustments, each found by a least squares solution to the equations; and iterates to a hypocenter that best fits the observed set of wave arrival times at the stations of the seismic network. This is the primary method that tsunami warning centers use to locate earthquakes. Other methods for locating the earthquake hypocenter include analysis of the phases of the P and S waves that are reflected by the earth's crust as discussed by Stein and Wysession in "An Introduction to Seismology, Earthquakes, and Earth Structure."

Important Points to Remember about Locating Earthquake Epicenters and Hypocenters

- Although seismic wave speeds vary by a factor of ten or more in the Earth, the ratio between the average speeds of a P wave and of its following S-wave is quite constant.
- We can use the fact that P and S waves travel at different speeds to locate the epicenter of an earthquake on the earth.
- By measuring the S-wave and P-wave arrival times at 3 or more stations, circles drawn around each station will overlap at a unique point, indicating the earthquake location.
- If a network utilizes 3-component stations, an approximate location can be found from a single station.
- An earthquake's hypocenter is often located at some depth in the earth. The corresponding epicenter is the point at the earth's surface above the hypocenter
- The depth of the earthquake is very important as deep earthquakes do not normally produce tsunamis.

Earthquake Intensity and Magnitude

Mercalli Intensity Scale

Earthquakes are measured by their intensity and by their magnitude. An earthquake's intensity readings are based on observed effects, for example, ground shaking and damage. An earthquake's intensity differs depending on the distance from the earthquake's epicenter. The ranking system used to measure seismic intensity is called the Modified Mercalli scale. Michele Stefano de Rossi and François-Alphonse Forel formulated the Rossi-Forel Scale, a simple 10-degree scale of earthquake intensity, in 1878. The Mercalli scale originated from the widely used Rossi-Forel scale, which was revised by Italian volcanologist Giuseppe Mercalli in 1883 and 1902.

In 1902, the 10-degree Mercalli scale was expanded to twelve degrees by Italian physicist Adolfo Cancani. It was later completely rewritten by German geophysicist August Heinrich Sieberg and became known as the Mercalli-Cancani-Sieberg (MCS) scale. This scale, in turn, was modified and published in English by Harry O. Wood and Frank Neumann, in 1931, as the Mercalli-Wood-Neuman (MWN) scale. It was later improved by Charles Richter, the father of the Richter magnitude scale. The scale is known today as the Modified Mercalli Intensity Scale.

The Modified Mercalli Intensity Scale (abbreviated MM or Io) assigns an intensity or rating to measure the effects of an earthquake at a particular location. The intensity of any one earthquake can be very different from place to place. This is because the amount of damage caused by an earthquake at a particular location depends on the geology of the location. The population density and the methods used to construct buildings near the location are also important in the Modified Mercalli scale.

Earthquake intensities are subjectively rated with Roman numerals ranging from I (not felt) to XII (buildings nearly destroyed). A full description of all twelve categories is given in Table 3-2. Although it is a qualitative measure of earthquake size, seismologists still mail questionnaires to local residents after an earthquake asking them to rate the effects of the earthquake at their home.

As you can see from Table 3-2, rating the intensity of an earthquake's effects does not require any instrumental measurements. Seismologists can use newspaper accounts, diaries, and other historical records to make intensity ratings of past earthquakes, for which there are no instrumental recordings. Such research helps promote our understanding of the earthquake history of a region, and estimate future hazards.

While the Modified Mercalli scale is effective for measuring the intensity of an earthquake in an inhabited area of a developed country, it is of no use in the middle of a desert or in any other place without trees, houses and railways. Descriptions such as "Resembling vibrations caused by heavy traffic" depend very much upon the observer having felt heavy traffic in the past. Even then, what one person in a small town considers to be "heavy" will most certainly differ from what a person living adjacent to a major urban road system would describe as "heavy."

While the Modified Mercalli scale is useful, something else is required in order to compare the magnitude of earthquakes wherever they occur. The intensity scale differs from the Richter Magnitude Scale in that the effects of any one earthquake vary greatly from place to place, so there may be many Intensity values (e.g., IV in one neighborhood, VII in another) measured for the same earthquake. Each earthquake, on the other hand, should have only one magnitude, although the various methods of calculating it may give slightly different values (e.g., 4.5 vs. 4.6).

Table 3-2. Modified Mercalli Intensity Scale

Intensity	Description
I	People do not feel any Earth movement.
II	A few people might notice movement if they are at rest and/or on the upper floors of tall buildings.
III	Many people indoors feel movement. Hanging objects swing back and forth. People outdoors might not realize that an earthquake is occurring.
IV	Most people indoors feel movement. Hanging objects swing. Dishes, windows, and doors rattle. The earthquake feels like a heavy truck hitting the walls. A few people outdoors may feel movement. Parked cars rock.
V	Almost everyone feels movement. Sleeping people are awakened. Doors swing open or close. Dishes are broken. Pictures on the wall move. Small objects move or are turned over. Trees might shake. Liquids might spill out of open containers.
VI	Everyone feels movement. People have trouble walking. Objects fall from shelves. Pictures fall off walls. Furniture moves. Plaster in walls might crack. Trees and bushes shake. Damage is slight in poorly built buildings. No structural damage.
VII	People have difficulty standing. Drivers feel their cars shaking. Some furniture breaks. Loose bricks fall from buildings. Damage is slight to moderate in well-built buildings; considerable in poorly built buildings.
VIII	Drivers have trouble steering. Houses that are not bolted down might shift on their foundations. Tall structures such as towers and chimneys might twist and fall. Well-built buildings suffer slight damage. Poorly built structures suffer severe damage. Tree branches break. Hillsides might crack if the ground is wet. Water levels in wells might change.
IX	Well-built buildings suffer considerable damage. Houses that are not bolted down move off their foundations. Some underground pipes are broken. The ground cracks. Reservoirs suffer serious damage.
X	Most buildings and their foundations are destroyed. Some bridges are destroyed. Dams are seriously damaged. Large landslides occur. Water is thrown on the banks of canals, rivers, lakes. The ground cracks in large areas. Railroad tracks are bent slightly.
XI	Most buildings collapse. Some bridges are destroyed. Large cracks appear in the ground. Underground pipelines are destroyed. Railroad tracks are badly bent.
XII	Almost everything is destroyed. Objects are thrown into the air. The ground moves in waves or ripples. Large amounts of rock may move.

Full descriptions are from Richter, C.F., 1958. Elementary Seismology. *W.H. Freeman and Company, San Francisco, pp. 135-149; 650-653*

Earthquake Magnitude Scales

Earthquake magnitude is a measure of energy released by an earthquake. There are many magnitude scales; all are logarithmic, but each is calculated using different types of seismic waves and constants. All of the magnitude scales are extensions of the original Richter magnitude scale (M_L) designed for southern California. Some of the more common scales are listed in Table 3-3. The choice of the most appropriate scale depends on what will be done with the data. For example, M_L is popular with engineers because it calculates the magnitude using a period of wave that is similar to the resonance frequency of most buildings, so it is closely related to the amount of damage caused by the earthquake.

Table 3-3. Earthquake Magnitude Scales

	Term	Type of Wave	Period Range
ML	Local magnitude (Richter scale)	Regional S and surface waves	0.1–1 sec
Mj	JMA (Japan Meteorological Agency)	Regional S and surface waves	5–10 sec
mb	Body wave magnitude	Teleseismic P waves	1–5 sec
Ms	Surface wave magnitude	Surface waves	20 sec
Mw	Moment magnitude	All waves	Any (depends on quake size)
Mwp	P-wave moment magnitude	Long-period P waves	10–200 sec
Mm	Mantle magnitude	Teleseismic surface waves	> 200 sec

The Richter Magnitude Scale

The Richter scale is designed to allow easier comparison of earthquake magnitudes, regardless of the location. It was originally developed by Charles Richter and Beno Gutenberg to make more quantitative measurements of the relative sizes of earthquakes in southern California. Today, modified versions of the scale are used to measure earthquakes throughout the world.

C.F. Richter was a geologist living and working in California, U.S.A., an area subjected to hundreds of earthquakes every year. He took the existing Mercalli scale and tried to add a "scientific" scale based on accurate measurements that could be recorded by seismographs (instruments used to measure vibration) regardless of their global location. By measuring the speed, or acceleration, of the ground when it suddenly moves, he devised a scale that reflects the "magnitude" of the shock, which is related to the earthquake's energy release. An earthquake detected only by very sensitive people registers as 3.5 on his scale, while the largest earthquake ever recorded reached 8.9 on the Richter scale.

The Richter scale of earthquake magnitude is logarithmic. This means that each whole-number step represents a tenfold increase in measured amplitude. Thus, a magnitude 7 earthquake is 10 times larger than a 6, 100 times larger than a magnitude 5, and 1000 times larger than a 4 magnitude. This is an open-ended scale, since it is based on measurements and not descriptions.

To understand the forces of an earthquake, it can help to concentrate just upon the upward movements. Gravity is a force pulling things down toward the earth. This accelerates objects at 9.8 meters per second per second (m/s/s). To make something, such as a tin can, jump up into the air requires a shock wave to hit it from underneath accelerating *faster* than 9.8 m/s/s. This roughly corresponds to 11 (very disastrous) on the Mercalli Scale, and 6.5 or above on the Richter scale. In everyday terms, the tin can must be hit by a force greater than you would experience if you drove your car into a solid wall at 35 kilometers (22 miles) per hour.

The Richter magnitude is related to the maximum amplitude of the S-wave measured from the seismogram. Because there is a great range in the sizes of different earthquakes, the Richter scale uses logarithms. Thus, a magnitude 7 (M 7) earthquake has wave amplitudes 10 times as large as a magnitude 6 earthquake, and releases over 30 times more energy. A comparison of the Modified Mercalli scale with the Richter scale is given in Table 3-4.

As noted by J. Louie of the University of Nevada Reno Seismology Department (**http://www.seismo.unr.edu/**), the equation for Richter Magnitude is:

$$ML = \log_{10}A(mm) + (\text{Distance correction factor})$$

Here A is the amplitude, in millimeters, measured directly from the photographic paper record of the Wood-Anderson seismometer, a special type of instrument. The distance factor comes from a table found in Richter's (1958) book *Elementary Seismology*. The equation behind this nomogram, used by Richter in Southern California, is:

$$M = \log_{10}A(mm) + 3\log_{10}[8\Delta t(s)] - 2.92$$

Thus, after wave amplitude is measured, its logarithm is scaled according to the distance of the seismometer from the earthquake, estimated by the S-P time difference. The S-P time, in seconds, makes Δt.

Seismologists try to get a separate magnitude estimate from every seismograph station that records the earthquake, and then calculate the average. This accounts for the usual spread of around 0.2 magnitude units reported from different seismological labs right after an earthquake. Each laboratory calculates the averages from the different stations that it has access to, and it can take several days before the different organizations come to a consensus on what was the best magnitude estimate.

Table 3-4. Mercalli Scale comparison with Richter Scale

Richter Magnitude	Energy (joule)	Mercalli Degree
< 3.5	< 1.6 E+7	I
3.5	1.6 E+7	II
4.2	7.5 E+8	III
4.5	4 E+9	IV
4.8	2.1 E+10	V
5.4	5.7 E+11	VI
6.1	2.8 E+13	VII
6.5	2.5 E+14	VIII
6.9	2.3 E+15	IX
7.3	2.1 E+16	X
8.1	> 1.7 E+18	XI
> 8.1	.	XII

The Moment Magnitude Scale

For very large earthquakes (magnitude greater than 7), most magnitude scales saturate as higher frequency energy is registered at a similar level for a magnitude 8 as, for example, a magnitude 7 event. This is because larger quakes rupture for a longer time and generate longer period waves that are not taken into account by magnitude scales such as M_L, mb, and Ms.

For these larger events, seismologists use a different measure of the earthquake size, called the moment magnitude. The moment magnitude comes from the seismic moment. It is directly related to the size of the earthquake rupture area or fault plane, and does not saturate for large events. For smaller events, the Richter and moment magnitudes are similar.

Seismic Moment

Seismic moment has been the standard measure for earthquake magnitude for the last 20 years or so. It is a physically meaningful number, unlike the magnitudes scales. Seismic moment is related to the area of the fault plane that slips, the amount of slip, and the rigidity of the fault.

To get an idea of the seismic moment, consider the elementary physics concept of torque. A torque is a force that changes the angular momentum of a system. It is defined as the force times the distance from the center of rotation. Earthquakes are caused by internal torques, from the interactions of different blocks of the earth on opposite sides of faults. After some rather complicated mathematics, it can be shown (J. Louie, 9 Oct. 1996, **http://www.seismo.unr.edu**) that the moment of an earthquake is simply expressed by:

$$(\mathit{Moment}) = (\mathit{Rock\ Rigidity}) \times (\mathit{Fault\ Area}) \times (\mathit{Slip\ Distance})$$

$$M_0 = \mu A d$$

$$(\mathit{dyne{-}cm}) = \left[\frac{\mathit{dyne}}{\cancel{\mathit{cm}^2}}\right] \times (\cancel{\mathit{cm}^2}) \times (\mathit{cm})$$

The formula above, for the moment of an earthquake, is fundamental to seismologists' understanding of how dangerous faults of a certain size can be.

Imagine a chunk of rock on a lab bench. The rigidity, or resistance to shearing, of the rock is a pressure in the neighborhood of a few hundred billion dynes per square centimeter (cm^2). (Scientific notation makes this easier to write.) The pressure acts over an area to produce a force, and as shown in the equation below, the cm-squared units cancel. Now if it is estimated that the distance over which the two parts grind together before they fly apart is about a centimeter, then the moment, in dyne-cm can be calculated:

$$M_0 = (3\times10^{11}\,\frac{dyne}{\cancel{cm^2}})(10\,\cancel{cm})(10\,\cancel{cm})(1\ cm)$$

$$M_0 = (3\times10^{11})(10^2)(dyne-cm)$$

$$M_0 = 3\times10^{13}\ dyne-cm$$

Again it is helpful to use scientific notation, since a dyne-cm is a very small amount of moment.

J. Louie also provides an excellent example to illustrate this concept. He considers a second case, the Sept. 12, 1994, Double Spring Flat earthquake, which occurred about 25 km southeast of Gardnerville, Nevada, USA. The first requirement is to convert the 15-kilometer length and 10-km depth of that fault to centimeters. Because 100,000 centimeters equal 1 kilometer:

$$1\ km = 10^5\ cm \qquad\qquad 1 = \frac{10^5\ cm}{km}$$

Because multiplying by 1 does not change the value, kilometer units are changed into centimeter units by:

$$M_0 = (3\times10^{11}\,\frac{dyne}{\cancel{cm^2}})(10\,\cancel{km})\left[\frac{10^5\,\cancel{cm}}{\cancel{km}}\right](15\,\cancel{km})\left[\frac{10^5\,\cancel{cm}}{\cancel{km}}\right](30\ cm)$$

$$M_0 = 1.1\times10^{25}\,dyne-cm$$

Using scientific notation, it is evident that this earthquake, the largest in Nevada in 28 years, had 2×10^{12}, or 2 trillion, times as much moment as breaking the rock on the lab table.

There is a standard way to convert a seismic moment to moment magnitude. The equation is:

$$M_w = \frac{2}{3}\left[\log_{10} M_0\ (dyne-cm) - 16.0\right]$$

This equation (meant for energies expressed in dyne-cm units) can be used to estimate the magnitude of the tiny earthquake made on a lab table:

$$M_0 = 3\times10^{13}\ dyne\text{–}cm$$

$$M_w = \frac{2}{3}\left[\log_{10}(3\times10^{13}\,dyne\text{–}cm) - 16.0\right]$$

$$M_w = \frac{2}{3}\left[\sim13.5 - 16.0\right]$$

$$M_w \sim \frac{2}{3}\ (-2.5)$$

$$M_w \sim -1.7$$

Negative magnitudes are allowed on Richter's scale, although such earthquakes are certainly very small.

Take the moment found for the Double Spring Flat earthquake and estimate its magnitude:

$$M_0 = 1.4\times10^{25}$$

$$M_w = \frac{2}{3}\left[\log_{10}(1.4\times10^{25}\,dyne\text{–}cm) - 16.0\right]$$

$$M_w = \frac{2}{3}\left[\sim25.2 - 16.0\right]$$

$$M_w \sim \frac{2}{3}\ (9.2)$$

$$M_w \sim 6.1$$

The magnitude 6.1 value is about equal to the magnitude reported by the University of Nevada Reno Seismological Lab, and by other observers.

Seismic Energy

Both the magnitude and the seismic moment are related to the amount of energy that is radiated by an earthquake. Richter, working with Dr. Beno Gutenberg, early on developed an equation to express the relationship between magnitude and energy. The relationship is:

$$\log E_S = 11.8 + 1.5M$$

giving the energy E_S in ergs from the magnitude M. Note that E_S is not the total "intrinsic" energy of the earthquake, transferred from sources such as gravitational energy or to sinks such as heat energy. It is only the amount radiated from the earthquake as seismic waves, which ought to be a small fraction of the total energy transferred during the earthquake process.

Dr. Hiroo Kanamori at the California Institute of Technology derived a relationship between seismic moment and seismic wave energy:

$$\text{Energy} = (\text{Moment})/20{,}000$$

For this equation, the moment is in units of dyne-cm, and energy is in units of ergs. (Dyne-cm and ergs are unit equivalents, but have different physical meaning.)

Look at the seismic wave energy yielded by the two examples, in comparison to that of a number of earthquakes and other phenomena. For this we'll use a larger unit of energy, the seismic energy yield of quantities of the explosive TNT (We assume 1 ounce of TNT, exploded below ground, yields 640 million ergs of seismic wave energy):

Richter Magnitude	TNT for Seismic Energy Yield	Example (approximate)
-1.5	6 ounces	Breaking a rock on a lab table
1.0	30 pounds	Large construction site blast
1.5	320 pounds	
2.0	1 ton	Large Quarry or Mine Blast
2.5	4.6 tons	
3.0	29 tons	
3.5	73 tons	
4.0	1,000 tons	Small Nuclear Weapon
4.5	5,100 tons	Average Tornado (total energy)
5.0	32,000 tons	
5.5	80,000 tons	Little Skull Mtn NV Quake 1992
6.0	1 million tons	Double Spring Flat NV 1994
6.5	5 million tons	Northridge, CA Quake, 1994
7.0	32 million tons	Hyogo-Ken Nanbu Japan 1995
7.5	160 million tons	Landers, CA Quake, 1992
8.0	1 billion tons	San Francisco, CA Quake, 1906
9.2	5 billion tons	Anchorage, AK Quake, 1964
9.5	32 billion tons	Chilean Quake, 1960
10.0	1 trillion tons	(San Andreas-type fault circling Earth)
12.0	160 trillion tons	Fault Earth in half through center, or Earth's daily receipt of solar energy

160 trillion tons of dynamite is a frightening yield of energy. Consider, however, that the Earth receives that amount in sunlight every day.

Practical Ways of Estimating Magnitude

Most seismologists prefer to use the seismic moment to estimate earthquake magnitudes. Finding an earthquake fault's length, depth, and its slip can take several days, weeks, or even months after a big earthquake. Geologists' mapping of the earthquake's fault breaks, or seismologists' plotting of the spatial distribution of aftershocks, can give these parameters after a substantial effort. But some large earthquakes, and most small earthquakes, show neither surface fault breaks nor enough aftershocks to estimate magnitudes the way we have above. However, seismologists have developed ways to estimate the seismic moment directly from seismograms using computer processing methods. The **Centroid Moment Tensor Project** (CMT) at Harvard University has been routinely estimating moments of large earthquakes around the world by seismogram inversion since 1982.

Moment magnitude is the most commonly reported, because is relates the size of the earthquake to the seismic moment. The problem with moment magnitude is that it takes a few tens of minutes to calculate as it uses long-period surface waves recorded at large distances. This is no problem for academics, but for tsunami warnings and other hazard mitigation uses, this time can be a big problem.

P-wave Moment Magnitude

The determination of the tsunamigenic potential of an earthquake as quickly as possible is the paramount concern of tsunami warning centers. The broadband moment magnitude from P-waves (Mwp) can be calculated shortly after the arrival of the first P waves, which is very important for timely tsunami warnings.

Tip

Mw from P-waves is preferred by tsunami warning centers because it can be computed soon after the arrival of the first P-waves from an earthquake.

Mwp was originally developed by Tsuboi et al. (1995), and has been shown to give quick and accurate size estimates for both regional and teleseismic earthquakes for any depth, and distances up to 100 degrees. Mwp is calculated from P-waves recorded on the vertical component of broadband seismometers. The P-wave section of the displacement seismogram, including the pP (reflection phase) contribution, is integrated. The first peak, or the first peak and trough, of this integrated seismogram is used to determine the seismic moment from the formula

$$M_o = \mathrm{Max}\,(\,|\,p_1\,|,\,|\,p_1 - p_2\,|\,)\,(4\pi\rho\alpha^3 r)\,/\,F^P \qquad (1)$$

Where M_o is the seismic moment, p_1 and p_2 are the first peak and trough values on the integrated displacement seismogram, ρ and α are the density and P-wave velocity along the propagation path (ρ = 3.4 x 10^3 kilograms/meter^3, α = 7.9 km/s), r is the epicentral distance, and F^P is the radiation pattern. Mwp is computed from (1) by using the standard moment magnitude formula,

$$Mw = (\log M_o - 9.1)/1.5 \qquad (2)$$

Where M_o is in Newton meter ($N \cdot m$) instead of dyne cm (as used earlier), and adding 0.2 (to account for the radiation pattern F^P as explained by Tsuboi et. al.) to the average Mw to obtain Mwp.

Whitmore et. al. (2002) found a definite trend when Mwp calculations using the above technique were compared to 416 earthquakes assigned Mw by the highly accurate, but slow, Harvard CMT Mw. The study showed only minor Mwp deficit trends when compared to epicentral distance or hypocentral depth. However, Mwp was shown to have a magnitude-dependent bias when compared to CMT Mw. In general, Mwp is higher than CMT Mw for earthquakes less than magnitude 6.8, and lower for those over 6.8. Results were considered consistent enough to add a linear correction. This gives the equation shown in (3):

$$Mwp_{\text{corrected}} = (Mwp_{\text{initial}} - 1.03)/0.843 \tag{3}$$

It should also be noted that there are some problems with the Mw from P-waves (Mwp) technique for earthquakes larger than about 8.0. However, for earthquakes above this magnitude, the decision to warn is often almost automatic.

Important Points to Remember about Earthquake Intensity and Magnitude

- An earthquake's **intensity** is based on observed effects, for example, ground shaking and damage. An earthquake's intensity differs depending on the distance from the earthquake's epicenter. The ranking system used to measure seismic intensity is called the Modified Mercalli scale.
- Earthquake **magnitude** is a measure of energy released by an earthquake. There are many magnitude scales; all are logarithmic, but each is calculated using different types of seismic waves and constants. They are designed to allow easier comparison of earthquake magnitudes, regardless of the location.
- Most seismologists prefer to use the seismic moment to estimate earthquake magnitudes.
- The seismic moment can be estimated directly from seismograms using computer processing methods. The **Centroid Moment Tensor Project** (CMT) at Harvard University has been routinely estimating moments of large earthquakes around the world by seismogram inversion since 1982.
- However, the CMT method takes too much time to be of use in tsunami warnings.
- The broadband moment magnitude from P-waves (Mwp) can be calculated shortly after the arrival of the first P waves, which is very important for timely tsunami warnings.
- Thus, the moment magnitude from P-waves is generally used by tsunami warning centers because it is quick and fairly accurate.

Instruments Used to Detect Seismicity

Various types of instruments are used to detect seismicity. This section describes seismometers and considerations for their proper installation. Special emphasis is placed on broadband sensors since they are preferred by most tsunami warning systems.

Seismometers

Seismometers are instruments that measure ground motion (caused by seismic waves) at a specific location. The ground motion caused by earthquakes includes a wide range of amplitudes, from a few millimicrons to several meters. It can be vertical (moving up and down) and horizontal (moving east to west or north to south). Because of this variability, different kinds of seismometers have been developed over the years that will record specific frequency bands. In addition, many sensors can be configured (or programmed) to constrain response to specific frequencies and amplitude ranges. Seismologists often use three kinds of seismometers: short-period, broadband, and strong-motion sensors.

- **Broadband** seismometers can detect motion over a wide range (or band) of frequencies and usually over a large range of amplitudes (the dynamic range). Broadband sensors respond to frequencies from 0.01 hertz (Hz) to 50 Hz. These are the sensors most used by tsunami warning programs.

Tip

Tsunami warning centers usually rely on **broadband** seismometers.

- **Short-period** seismometers measure signals mainly above 1 Hz (cycles/second). These sensors are used to measure local earthquakes and P waves from teleseisms.
- **Strong-motion sensors** are designed to measure the large-amplitude, high-frequency seismic waves typical of large local earthquakes. These seismic waves result in the strong ground motion we feel during a large earthquake. Strong ground motion is often to blame for the structural damage that occurs during an earthquake. The data seismologists record with strong-motion sensors is used to improve the design of earthquake-resistant buildings and to understand earthquake-induced geologic hazards like liquefaction and landslides. The range of motions of interest for strong motion applications includes accelerations from 0.001 to 2 times the gravitational force (g), and frequencies from 0 to 100 Hz. Strong motion sensors are a type of seismometer used to record the strong ground motion typical of large earthquakes (> 5.0 in magnitude). These sensors are specifically designed to stay on-scale during the strongest ground motion possible.

There are two basic types of seismic sensors:

- Inertial seismometers, which measure ground motion relative to an inertial reference (a suspended mass)
- Strainmeters or extensometers, which measure the motion of one point of the ground relative to another

Since the motion of the ground relative to an inertial reference is in most cases much larger than the differential motion within a vault of reasonable dimensions, inertial seismometers are generally more sensitive to earthquake signals. However, at very low frequencies, it becomes increasingly difficult to maintain an inertial reference, and for the observation of low-order free oscillations of the Earth, tidal motions, and quasi-static deformations, strainmeters may outperform inertial seismometers. Strainmeters are conceptually simpler than inertial seismometers, but their technical realization and installation may be more difficult. This section is concerned with inertial seismometers only. For a more comprehensive description of inertial seismometers, recorders, and communication equipment, see the book *Instrumentation in Earthquake Seismology* by Havskov and Alguacil (2002).

An inertial seismometer converts ground motion into an electric signal, but its properties cannot be described by a single scale factor, such as output volts per millimeter of ground motion. The response of a seismometer to ground motion depends not only on the amplitude of the ground motion (how large it is) but also on its time scale (how sudden it is). This is because the seismic mass has to be kept in place by a mechanical or electromagnetic restoring force. When the ground motion is slow, the mass will move with the rest of the instrument, and the output signal for a given ground motion will therefore be smaller. The system is thus a high-pass filter, e.g. one that passes high frequencies well but attenuates frequencies below a certain level, for the ground displacement. This must be taken into account when the ground motion is reconstructed from the recorded signal.

Site selection for a permanent station is always a compromise between two conflicting requirements: infrastructure and low seismic noise. The noise level depends on the geological situation and on the proximity of sources, some of which are usually associated with the infrastructure. A seismograph installed on solid basement rock can be expected to be fairly insensitive to local disturbances, while one sitting on a thick layer of soft sediments will be noisy even in the absence of identifiable sources. As a rule, the distance from potential sources of noise, such as roads and inhabited houses, should be very much larger than the thickness of the sediment layer. Broadband seismographs can be successfully operated in major cities when the geology is favorable. In unfavorable situations, such as in sedimentary basins, only deep mines and boreholes may offer acceptable noise levels.

Installation Considerations for a Typical Broadband Seismometer Station

This section describes important considerations in the installation of a broadband seismometer inside a building, vault, or cave (the seismic station). The two aspects of the installation that have the most influence on the overall performance of the broadband seismometer are the construction of the seismic pier (the concrete base that serves as the foundation for the instrument), and the application of thermal insulation around the sensor and pier.

Much of the following discussion comes from *Guidelines for Installing Seismic Broadband Stations* (**http://seismo.berkeley.edu/bdsn/instrumentation/guidelines.html**) and *Seismic Sensors and Their Calibration* by Erhard Wielant (Nov 2002) (**http://jclahr.com/science/psn/wielandt/**). For more complete information, refer to the *International Handbook of Earthquake and Engineering Seismology*, Academic Press, ed. W. H. Lee et al., July 2003.

Construction of the Seismic Pier

The first step in constructing the seismic pier is to mark the orientation of the sensor. This is best done with a geodetic gyroscope, but a magnetic compass will do in most cases. The magnetic declination must be taken into account. Since a compass may be deflected inside a building, the direction should be taken outside and transferred to the site of installation. A laser pointer may be useful for this purpose. When the magnetic declination is unknown or unpredictable (such as at high latitudes or in volcanic areas), the orientation should be determined with a sun compass.

Typically, the broadband seismometer is capable and responsive to nanoradian tilts. As a practical matter, a human hair placed under the corner of a level football field would cause such a tilt. Thus, site selection on low-porosity hard rock is critical. Any unconformity beneath or within the pier will add to the ambient noise. Clay soils, which swell in contact with moisture, or micrometer air pores within sand are capable of causing tilts. While construction or structural piers are often built upon compacted gravel, sand, or dirt, these underlying materials are capable of causing the seismic pier to reactively tilt, and thus increase ambient noise.

Considering that the seismic pier bears less than 20 kilograms (kg) seismometer mass, and encompasses a cubic meter of volume, strength and costs are not of concern. The primary concern is that the pier affects neither the response of the earth nor the seismometer. The concrete pier should simply hold, and grossly level the seismometer. The concrete mixture should be as homogeneous as possible. Steel reinforcement (re-bar), wire mesh, and rock aggregates all have different coefficients of thermal expansion and should not be used in a seismic pier. To ensure that no other concrete (either the vault floors or walls) comes into contact with the pier, a 4-inch gap should be maintained around the perimeter of the pier. This gap is needed to minimize any contact with the pier that could potentially induce tilts.

Thermal Insulation of the Broadband Seismometer

Prior to installing the seismometer to the pier, small glass plates should be cemented under the feet of the pier to isolate the seismometer from stray currents. After installation, the seismometer should be tested, and wrapped with a thick layer of thermally insulating material. The type of material is not critical, although alternate layers of fibrous material and heat-reflecting blankets appear to be most effective.

Proper thermal insulation has perhaps the biggest impact on the overall performance of the seismometer and is inexpensive and easy to install. This is key to achieving a thermal time constant of sufficient length to significantly attenuate the diurnal thermal signature.

Tip

The most important considerations for installation of a broadband seismometer are:

- **Location**
- **Pier construction**
- **Insulation**

Insulating just the seismometer with a 4-inch-thick foam box will result in a thermal time constant on the order of 1000 seconds, limited ultimately by heat conduction through the pier. Insulating the entire exposed portion of the pier with a 4-inch foam box will achieve a longer time constant.

Typical broadband seismometers dissipate 1 to 2 watts of heat, and typical accelerometers dissipate a few milliwatts of heat. Owing to their low power dissipation, they can be heavily insulated without an excessive rise in the operating temperature. If the seismometer is insulated to high R values (greater than about 80), either the temperature will need to be monitored, or the theoretical temperature rise for the pier and insulation geometry must be calculated to insure that the seismometer will not be subjected to temperatures in excess of its normal operating range.

Tip

The Imperial unit for R-value is: $ft^2 \cdot {}^\circ F \cdot h/Btu$

The SI unit for R-value is: $K \cdot m^2/W$

The temperature sensitivity of a 24-bit resolution data logger is typically about 2 percent as large as the temperature sensitivity of a broadband seismometer. Thus, temperature stability is not as critical for the data logger as it is for the broadband seismometer.

Sensor and Seismograph

There are several electronic and communications components that must be installed once the pier is in place. While the actual sensor may vary from installation to installation, the basic components are often the same. Information in this section comes mainly from the University of Washington's Pacific Northwest Seismic Network website (**http://www.pnsn.org/SMO/INSTALL/smoinstall.html**).

Sensor

The ground motion sensor is often a 3-component force balance accelerometer. It can be configured to have a 4-g full scale reading. The digitizer is located in the sensor housing. The power supply and internet communications hardware are enclosed in a separate housing. The sensor needs to be bolted to a level concrete floor or placed outdoors in a small vault.

Optimal signals are those not affected by the response of structures. Thus, the best locations for the sensors will be either away from buildings or located within buildings of only 1 or 2 floors with a footprint smaller than 6000 square feet. The sensor should be located in a basement or ground floor.

An additional consideration is noise. The unit should be located away from existing or potential vibrational sources. It should not be located near devices such as motors, fans, compressors, and generators. Natural vibration, such as wind noise, can also be a problem. The unit should not be located near tall trees or poles. Indoor installations are ideally in a room without loose items (such as chairs or desks) that will move around during an earthquake and contaminate the recording of the ground motion.

Digitizer

The analog signal produced by the accelerometer will be digitized by the seismograph. The seismograph will send logical data packets out through an RS-232 port. A low-voltage serial cable connects the digitizer to the internet communications hardware, a terminal server, enclosed in the power supply housing.

The sensor and digitizer has two external connections:

- Global Positioning System (GPS) receiver
- serial data

The power supply will be installed indoors, near internet connections, even when the sensor is installed in an outdoor vault. Cabling to vaults must be buried in rigid conduit.

Component Technical Needs

GPS Antenna

- Mounted outside, usually on exterior wall close to roof line
- Cable routed from antenna to seismograph
- Cable length must be no longer than 65 feet.

Sensor/Seismograph

- Installed in external vault, or
- Mounted inside building
  - Bolted to level concrete floor
  - Located in basement or ground floor of a 1- or 2-story building
  - Located in a seismically quiet area (no motors, fans, pumps, etc. nearby)

Internet Interface

- Internet protocol (IP) address should be assigned prior to installation
- RJ-45 type 10Base-T Ethernet connection
- AC power

Data Acquisition

- Access through firewalls to specified IP address and port number
- Data are acquired on computers dedicated to seismic data acquisition and are maintained at a high security level

Important Points to Remember about Seismic Instruments

- There are two kinds of seismometers: inertial sensors and strain meters. Tsunami warning programs use inertial sensors.
- There are three basic types of inertial seismometers: short-period, strong-motion, and broadband sensors. Tsunami warning programs utilize broadband seismometers because these instruments can detect over a large range of frequencies and a large range of amplitudes (dynamic range).
- The three most important considerations for seismometer installation are:
  - Location away from ambient shaking sources, including the ocean.
  - Seismic pier placed on solid bedrock whenever possible.
  - Thermal insulation to shield instruments from large ambient temperature fluctuations.

Seismic Network and Processing Requirements for Tsunami Warning Centers with a 5-Minute Response Need

To produce accurate moment magnitudes, NTWCs and RTWPs require reliable, broad-frequency, low-noise, high dynamic-range, digital seismic data in real time. The timeliness of the data is crucial to issuing an initial bulletin within 5 minutes of an earthquake. This is especially important for centers with local tsunami sources. Seismic network data density and timing requirements are as follows:

- Twelve evenly distributed seismometers within 900 km (2-minute P-wave travel time) of all coastal source areas.
- Assume 80 percent data availability (9 to 10 sites operating at a time)
- Up to 30 seconds of data latency
- Above conditions will provide 9 to 10 P-wave observations within 2½ minutes after the earthquake occurrence or O-time. With an adequate processing system, a correct hypocenter location can be produced at this time.
- 60 seconds further to record the P-wave will provide data with which to compute a moment magnitude.
- Moment magnitude and hypocenter available at 3½ minutes after O-time.
- 30 seconds for experienced professional analyst review.
- 60 seconds to compose and send bulletin

> **Tip**
>
> Anticipate that about **20 percent** of gages will be out of service at all times.

The above procedure results in 5 minutes total since O-time.

Seismic network data quality requirements include:

- Digital, broadband seismic data for data processing
- Seismometers should have flat velocity responses from 0.1 seconds to 130 seconds for accurate magnitude results.
- The seismic network cannot be reliant on one external network for all data feeds.
- The network must be maintained with at least 80 percent up-time.
- In any 900-km radius, at least 8 stations must be operating.
- Seismic data latency cannot exceed 30 seconds.

Seismic data processing capabilities include:

- Process seismic data to produce P-wave arrival times and appropriate magnitude parameters.
- Trigger alarms based on strong ground shaking at a single station or pair of stations.
- Produce immediate hypocenter locations given sufficient number of P arrivals (5 to 7 arrivals).
- Support a graphical user interface which allows analyst to review and alter data in real time and support relocation of events interactively.
- Compute moment magnitude within 60 seconds of P-arrival for a given station.
- Interact directly with product generation software to produce bulletins with minimal analyst effort.
- The USGS Earthworm seismic data processing system should be used as the base processing architecture for interoperability with other tsunami warning centers, availability of source code, and easy sharing of modules and processes.

Data Redundancy

Observational Networks

The process of locating earthquake hypocenters has advanced considerably from the old days of drawing intersecting arcs on a globe or wall map to find an epicenter. Today, the task of locating earthquakes relies on computers with sophisticated programs. From the knowledge of seismograph station positions and measured arrival times of an earthquake's seismic waves, the point in time and space from whence the waves originated—the hypocenter—may be calculated.

The certainty and accuracy of a computer program's capability to determine an earthquake hypocenter depends on many factors. The number of seismograph stations recording an event and their distribution around the event are critical to accurately locating a hypocenter. Thus, an earthquake that occurs within a network will have a more accurately determined position than one that occurs outside and away from the network. Moreover, the configuration of operating seismograph stations changes as the network grows, as stations are moved to new locations, and as stations are temporarily out of service.

Seismic station outages of the Global Seismic Network (GSN), as measured at the Pacific Tsunami Warning Center (PTWC) and the West Coast/Alaska Tsunami Warning Center (WC/ATWC), average about 10 to 25 percent of the network at any time. For this reason, **an NTWC or RTWP should not be reliant on a single seismic network in any critical region, and should strive for redundancy.**

Each network (local or global) should strive to have multiple communications paths for interrogation of individual seismic sites, and transmission of real-time data. If a network uses the internet or a satellite as the primary method of data transmission, then a telephone dial backup capability should be considered only if other alternate means are not available, e.g. dedicated circuits, alternate Internet Service Providers (ISP), etc.

It is also desirable to design networks with an approximate 20 percent outage reality in mind, i.e., network design should provide sufficient density to make the network effective even with one-fifth of the gages out at any one time.

Observational Platforms

Full redundancy of individual seismometers is usually not practical from a budgetary standpoint. Whether or not this is the case, serious consideration of redundant or alternate interrogation communications methods should be considered. Whenever possible, some form of backup power to sites is also highly desirable.

Important Points to Remember about Seismic Network Requirements

- The USGS Earthworm seismic data processing system should be used as the base processing architecture for interoperability with other centers, availability of source code, and easy sharing of modules and processes.
- In any 900-km radius, at least 8 seismic stations must be operating at all times.
- Centers should assume that about 20 percent of the gages in any network will be unavailable at all times.
- A warning center requires access to multiple networks via multiple communications paths to ensure that a seismic event is never missed.
- Seismometers should have flat velocity responses from 0.1 seconds to 130 seconds for accurate magnitude results.

Sea Level Data Requirements for Tsunami Detection

A tsunami, in the ocean or other body of water, is a wave train generated by a vertical displacement of the water column. Earthquakes, landslides, volcanic eruptions, explosions, and even the impact of cosmic bodies such as meteorites can generate tsunamis. Where they impact a coastline, tsunami waves can cause loss of life and severe property damage.

Tsunamis may have wavelengths in excess of 100 km and periods of minutes to over an hour, depending on the generation mechanism. As a result of its long wavelength compared to the water depth, a tsunami behaves like a shallow-water wave and propagates at a speed that is equal to the square root of the product of the acceleration of gravity (9.8 meters per second squared) and the water depth. In a typical ocean depth of 4,000 meters, a tsunami travels at about 200 meters per second, or over 700 km per hour.

Because the rate at which a wave loses its energy is inversely related to its wavelength, tsunamis not only propagate at high speeds, they can also travel great distances without loss of energy. Tsunamis are only about a meter high, at the most, in the open ocean. However, where they impact the coast, amplitudes are significantly higher and can be as large as 10 meters (30 meters in extreme cases). Wave refraction, caused by segments of the wave moving at different speeds as the water depth varies, can cause extreme amplification in localized areas.

The ability to warn a vulnerable population of the approach of a tsunami depends on a variety of measurements, initially seismic network data, but also on a network of tide gages to monitor the progress of the wave and thereby forecast the time of arrival at a distant coast. Real-time data transmission without any significant time delays is essential because of the high speed at which a tsunami wave propagates and the time needed by a tsunami warning center to implement decision-making and mitigation procedures before a warning is issued to the relevant authorities.

Numerous international sea level monitoring networks provide essential real-time data that can be accessed by NTWCs and RTWPs. Many of these networks are coordinated by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Education, Scientific, and Cultural Organization (UNESCO).

The most extensive and notable is the Global Sea Level Observing System (GLOSS), conducted under the auspices of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the World Meteorological Organization (WMO) and the IOC.

In some instances; however, these international networks may not meet a tsunami warning center's requirements for rapid detection and warning of **local tsunami events**.

Tip

Local tsunamis are caused by near shore earthquakes with little time for action!

For example, NTWCs may require more sea level gages than the RTWPs in order to more rapidly detect and evaluate locally generated tsunamis, as well as to more finely monitor impacts along their coast from distant tsunamis. In these cases, a center will need to establish and maintain gages that augment the available international networks.

- Tsunami warning centers should strive to deploy gages that meet international requirements and recommendations since the data will also be useful to other NTWCs and RTWPs, researchers, and other user groups.
- Local network data should be made readily available to all interests, both in real time, and as historical datasets, which are valuable for improving and fine-tuning models.

There are two basic types of sea level gages: coastal tide gages and open ocean buoys. Tide gages are generally located at the land-sea interface, usually in locations somewhat protected from the heavy seas that are occasionally created by storm systems. Tide gages that initially detect tsunami waves provide little advance warning at the actual location of the gage, but can provide coastal residents where the waves have not yet reached an indication that a tsunami does exist, its speed, and its approximate strength.

Open ocean buoy systems equipped with bottom pressure sensors are now a reliable technology that can provide advance warning to coastal areas that will be first impacted by a teletsunami, before the waves reach them and nearby tide gages. Since the tsunami waves will not yet be modified by local bathymetry, open ocean buoys often provide a better forecast of the tsunami strength than tide gages at distant locations.

Important Points to Remember about Sea Level Data

- Sea level data are needed to adjust and cancel warnings, via both observed values for real-time verification and as input to models as an event unfolds.
- Sea level data come from tide gages and from DART buoys in the open ocean.
- International sea level gage networks can be accessed by tsunami warning centers as a source of sea level data. In some instances, international networks may not meet a tsunami warning center's requirements for rapid detection and warning of **local tsunami events**. In these cases a tsunami warning center may need to establish and maintain gages that augment the available international networks.
- Real-time data collection by robust and reliable communications channels is essential to the success of a tsunami warning program.

Causes of Sea Level Variations and Detection of the Tsunami Wave Signal

Sea level measurement has many different facets and requires significant technical expertise and experience. Data must be carefully calibrated, checked and evaluated. Measurements should be tied to local benchmarks that in turn are integrated within a country's national leveling network as well as the global network using modern geodetic techniques. Recorded data must be archived, documented, and protected for future studies. Sea level data that are managed in this manner serve as a valuable resource for a wide range of studies from refining tsunami models to monitoring impacts of global climate change.

Variations in sea level are caused by a combination of physical factors that are usually distinguished by their period. The various components of sea level include:

- Surface gravity waves with periods of 1 to 20 seconds
- Seiches and tsunamis with periods of minutes to over an hour
- Tides centered around 1/2 and 1 day
- Meteorological effects of several days
- Interannual and decadal variability
- Long-term trends in the mean level caused by geological and climatological effects

The magnitudes of these components vary enormously:

- Surface gravity waves can have amplitudes up to 30 meters.
- Tsumanis tend to be less than 1 meter in the deep ocean but may be several meters near the coast.
- Tides are relatively small in the ocean but may be 10 meters near the coast.
- Storm surges may be on the order of a few meters in shallow seas.

As noted by UNESCO in Manuals and Guides 14, IOC Manual on Sea Level Measurement and Interpretation, Volume IV: An Update to 2006, any instantaneous measurement of sea level in a series may usually be considered the sum of three component parts:

Observed Sea Level = Mean Sea Level + Tide + Meteorological Residuals

Each of these component parts is controlled by separate physical processes, and the variations of each part are essentially independent of the variations in the other parts. There are many ways of defining these components. An acceptable set of definitions is:

- **Tides** are the periodic movements of the seas which have coherent amplitudes and phase relationships to some periodic geophysical force.

- The dominant forcing is the variation in the gravitational field on the surface of the earth due to the regular movements of the earth-moon and earth-sun systems. These cause **gravitational tides**.
- There are also weak tides generated by periodic variations of atmospheric pressure and on-shore off-shore winds which are called **meteorological tides**.

- **Meteorological residuals** are the non-tidal components that remain after removing the tides by analysis. They are irregular, as are the variations in the weather.
  - Sometimes the term **surge residual** is used, but more commonly **surge** is used to describe a particular event during which a very large nontidal component is generated.
- **Mean sea level (MSL)** is the average level of the sea, usually based on hourly values taken over a period of at least a year; for geodetic purposes, the mean level may be taken over several years. The frequency with which different observed hourly levels occur over a long period of observation has a definite pattern. Where semidiurnal tides are dominant, the most frequent levels are near to Mean High and Mean Low Water Neap levels. Figure 3-12 shows some examples of tidal characteristics at different locations.

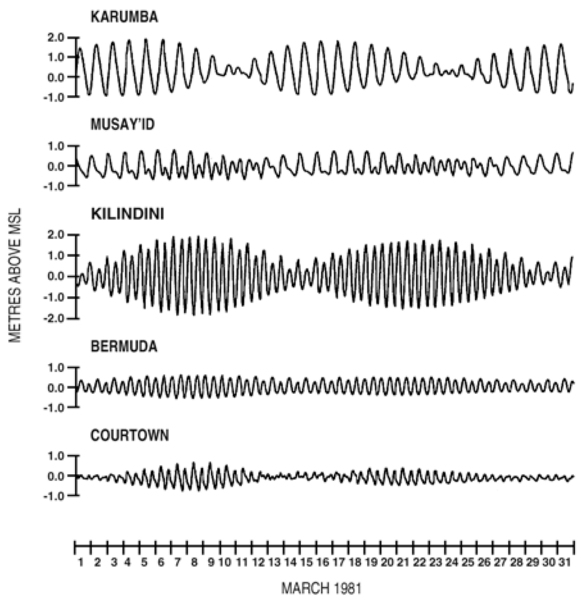


Figure 3-12. Tidal Characteristics at Five Stations Showing Different Regimes
(Source: UNESCO Manual of Sea Level Measurement and Interpretation Vol. 1 – Basic Procedures, 1985)

Figure 3-12 shows five different patterns of tidal characteristics at different locations: diurnal, at Karumba, Australia; mixed, at Musay'id in the Persian Gulf; semi-diurnal with strong spring-neap modulation at Kilindini in the Indian Ocean; semidiurnal with weather modulation at Bermuda, in the North Atlantic Ocean; and gross shallow water distortions at Courtown, in the Irish Sea.

Tides are calculated from the hydrodynamic equations for a self-gravitating ocean on a rotating, elastic Earth. The driving force is the small change in gravity due to motion of the moon and sun relative to Earth. Small variations in gravity arise from two separate mechanisms related to the rotation of the moon about the Earth. These mechanisms include the following:

- The moon and Earth rotate about the center of mass of the Earth-moon system. This gives rise to a centripetal acceleration at Earth's surface that drives water away from the center of mass and toward the side of Earth opposite the moon (point C in Figure 3-13).
- At the same time, mutual gravitational attraction of mass on Earth and the moon causes water to be attracted toward the moon (point A in Figure 3-13).

If the Earth was an ideal ocean planet with no land, and if the ocean was very deep, the two processes would produce a pair of bulges of water on Earth, one on the side facing the moon, one on the side away from the moon (Figure 3-13). (The figure assumes an ocean of uniform depth, with negligible friction between the ocean and the underlying planet.)

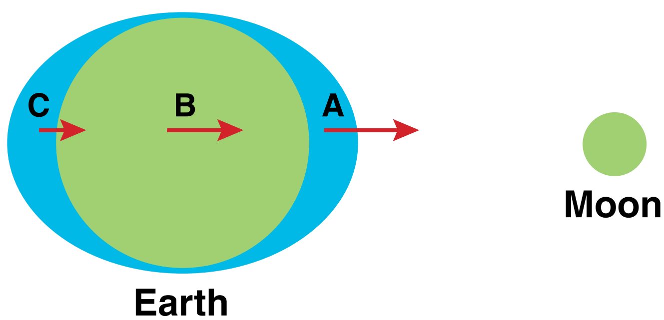


Figure 3-13. Model of Gravitational Attraction on a Planet Completely Covered by Ocean *(Source: University of Tennessee website,* **http://csep10.phys.utk.edu/astr161/lect/time/tides.html***)*

The realistic situation is considerably more complicated, as a result of the following conditions:

- The Earth and moon are not static, as depicted in Figure 3-13, but instead are in orbit around the common center of mass for the system.
- The Earth is not covered with oceans, the oceans have varying depths, and there is substantial friction between the oceans and the Earth.

One additional complication of a realistic model of gravity's effects on the Earth's tides is that not only the moon but other objects in the solar system influence the Earth's tides. Most of their tidal forces are negligible on Earth, but the differential gravitational force of the sun does influence our tides to some degree. The effect of the sun on Earth tides is less than half that of the moon.

Particularly large tides are experienced in the Earth's oceans when the sun and the moon are lined up with the Earth at new and full phases of the moon. These are called *spring tides* (the name is not associated with the spring season). The degree to which Earth's tides are enhanced is about the same whether the sun and moon are lined up on opposite sides of the Earth (full lunar phase) or on the same side (new lunar phase). Conversely, when the moon is at first quarter or last quarter phase (meaning that it is located at right angles to the Earth-sun line), the sun and moon interfere with each other in producing tidal bulges and tides are generally weaker; these are called *neap tides*. Figure 3-14 illustrates spring and neap tides.

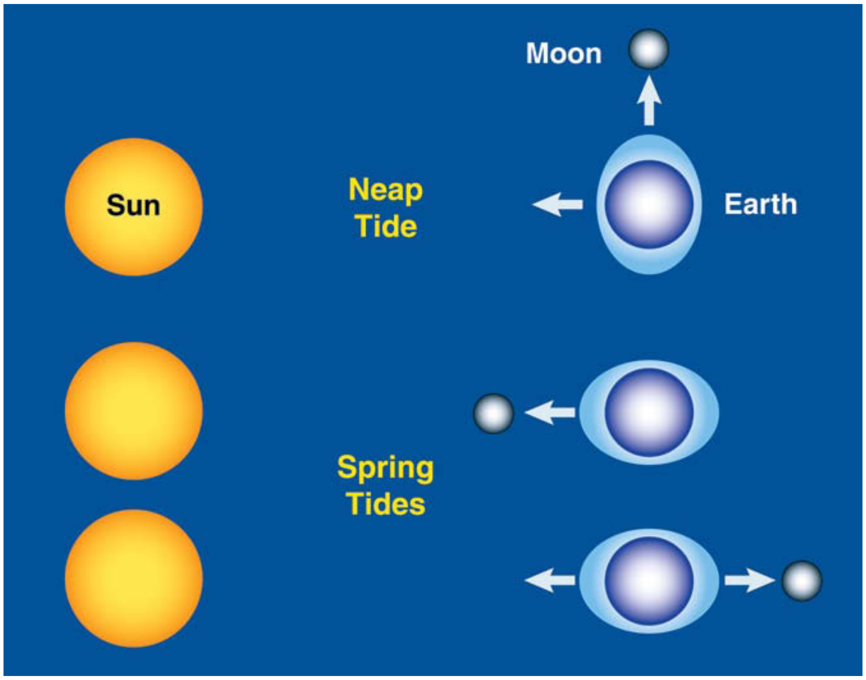


Figure 3-14. Competition Between the Sun and Moon in Producing Tides
(Source: University of Tennessee website, **http://csep10.phys.utk.edu/astr161/lect/time/tides.html***)*

A tsunami creates a fourth component that is not normally present in the observed sea level. Fortunately for tsunami warning center watch standers, the signature of tsunami waves at sea level gages is generally quite distinctive, as illustrated in Figure 3-15.

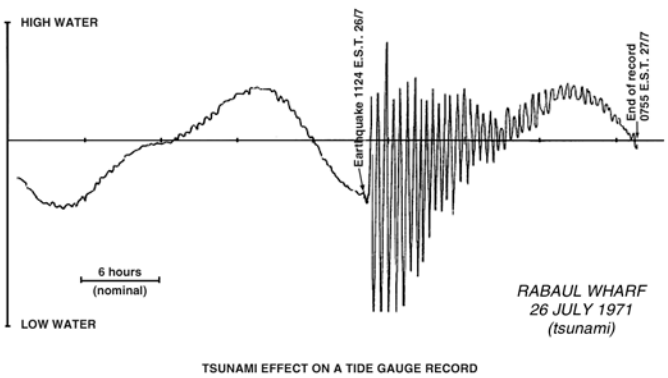


Figure 3-15. Tsunami Signal
(Source: UNESCO Manual of Sea Level Interpretation Vol. 4, 2006)

Important Points to Remember about Causes of Sea Level Variations

- Variations in sea level contain contributions from different physical sources that are usually distinguished by their period. Components include:
  - Surface gravity waves with periods of 1 to 20 seconds
  - Seiches and tsunamis with periods of minutes to over an hour
  - Tides centered around 1/2 and 1 day
  - Meteorological effects of several days
  - Interannual and decadal variability
  - Long-term trends in the mean level caused by geological and climatological effects
- A tsunami creates a component that is not normally present in the observed sea level. Fortunately, the signature of tsunami waves at sea level gages is generally quite distinctive and thus recognizable.

Using Tide Gages to Measure Changes in Sea Level

Four basic types of tide gages are used to measure changes in sea level. These are discussed extensively in the 2006 update to the UNESCO publication Manuals and Guides 14, Intergovernmental Oceanographic Commission, Manual on Sea Level Measurement and Interpretation Volume IV, and will be summarized in this section.

In addition, there are direct measuring devices based on resistance or capacitance rods, but these have found less widespread use because of their lack of robustness in harsh climates. Recent advances in technologies, such as GPS reflection methods, have led to other elaborate ways of measuring sea level, which are now being deployed in some areas.

Most systems for measuring sea level have a precision approaching 1 cm, given sufficient care and attention. This value is adequate for the measurement of most of the hydrodynamic processes. This level of precision does not, however, imply sufficient accuracy for adequate measurement of the mean sea level, which also depends on the long-term stability of the measuring system. Fortunately for tsunami warning systems, such high accuracy is not a priority because what is most important is the **change** that occurs in water level as the tsunami waves arrive.

There are practical constraints that govern the choice of an instrument for a particular application. These include:

- Cost
- Degree of difficulty of installation
- Ease of maintenance and repair
- Availability of support facilities or services

The installation of a highly complex electronic instrument with sophisticated software control would be unwise without technical support staff who possess the ability to maintain its operation. Another important consideration in the choice of an instrument is its suitability for the site at which it is to be located.

Traditionally, permanent sea level stations around the world have been primarily devoted to tide and mean sea level applications. This has been the main objective of the Global Sea Level Observing System (GLOSS). Because of this focus, not only are wind waves filtered out from the records by mechanical or mathematical procedures, but any oscillation between wind waves and tides (e.g. seiches, tsunamis etc.) has not been considered a priority; in fact, these phenomena are not properly monitored, owing to the standard sampling time of more than 5 to 6 minutes. If this range of the spectrum should be covered from now on, it would be necessary to consider this when choosing a new instrument and designing the sea level stations.

Tip

GLOSS is an international program conducted under the auspices of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the World Meteorological Organisation (WMO) and the Intergovernmental Oceanographic Commission (IOC).

Groups such as the Permanent Service for Mean Sea Level (PSMSL) and the GLOSS Technical Committee can provide advice on the design and installation of tide gages. An important consideration is the correct installation and a thorough knowledge, by the maintenance technicians, of the problems that any particular sensor can present and how to avoid them with adequate operation.

Stilling Well and Float Gage

A stilling well gage is probably the most common of all sea-level recording systems on a worldwide basis. These gages were at one time employed at every port installation and were the primary technology by which sea level records were compiled. Recent stilling well installations are less common, since they require a considerable amount of costly engineering work, so that they have often been superseded by one of the other technologies discussed later in this section. In some circumstances it may not be possible to install a well, e.g. on a shelving beach, and other methods have to be adopted.

The function of a well is to filter out, or to "still," the wave activity, so that the tides and longer-period processes can be recorded accurately. A stilling well usually consists of a float gage in the well that drives a pen-and-chart recorder or, in more recent years, a shaft encoder such that the readings of sea level height can be digitized automatically. It is not uncommon for other types of instrument, such as a pressure sensor, to also be placed in the well. The well itself is a vertical tube about 1 meter (m) in diameter constructed of concrete, coated steel, or plastic, with a hole or, less frequently, a pipe connection to the sea. The ratio of the hole diameter or pipe length and diameter to that of the well gives it the characteristics of a low-pass mechanical filter (Noye 1974a, b, c). Care has to be exercised in trying to measure processes such as tsunami waves, as the frequency response is not 100 percent for periods less than or equal to 4 hours. The stilling well suffers from amplitude attenuation and a phase lag at shorter periods, which are critically dependent on the design of the well and sometimes difficult to change. A schematic diagram of a float gage in a stilling well is shown in Figure 3-16, below. The float wheel is shown driving a pen recorder, but the same pulley could equally drive a digital shaft encoder or a potentiometer, which can then be recorded by a local data logger or interfaced to a telemetry system. The well is shown with a conical inlet at its base, since this is the most common configuration and is to some extent self-cleaning. Many other configurations of the inlet are acceptable, and although the conical orifice does restrict the inflow relative to the outflow, this does not appear to have a significant effect on the records even in the presence of waves.

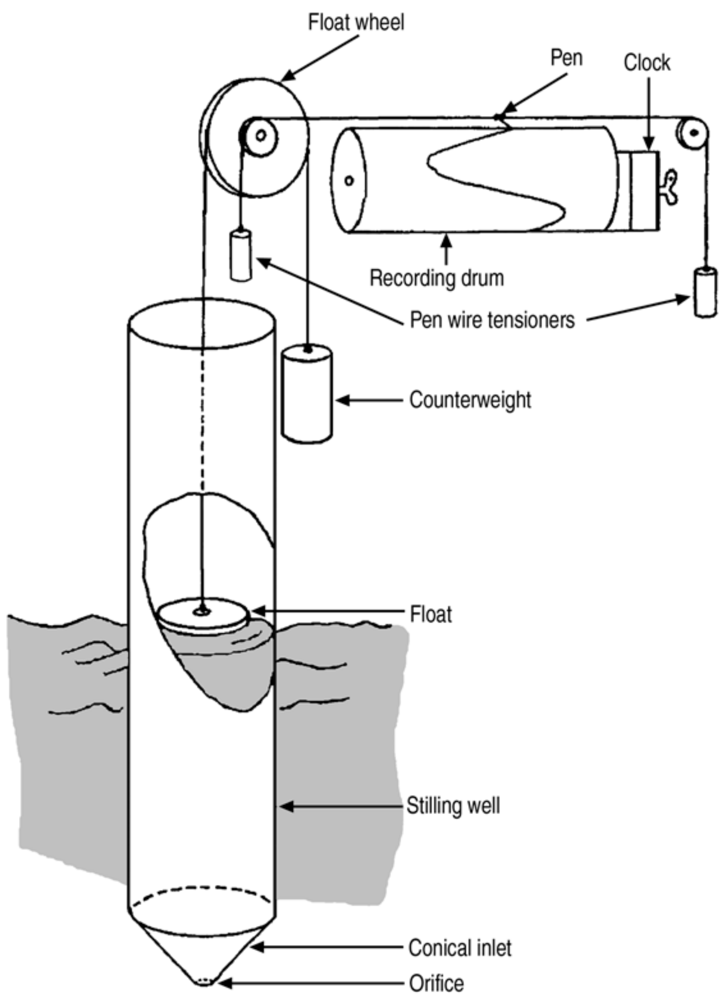


Figure 3-16. Basic Float-Operated Tide Gage in a Stilling Well.
(Source: IOC Manual of Sea Level Measurement and Interpretation Vol. 4, 2006)

Pressure Systems

Instruments that measure subsurface pressure instead of sea level directly have found widespread use. Knowledge of seawater density and gravitational acceleration is required to make the conversion from pressure to sea level, but in spite of this, the instruments have many practical advantages as sea level recorders. The most commonly used types are the pneumatic bubbler gages and pressure sensor gages, in which sensors are mounted directly in the sea. The two types have much in common and a choice of which type is suitable is usually based on practical considerations at a proposed site.

The **pneumatic bubbler** tide gage has been successfully used worldwide for several decades. It replaced many of the float-operated harbor gages as the primary standard for sea level measurement in countries such as the US and the United Kingdom, although in the US they have been superseded by acoustic gages.

Figure 3-17 shows the basic essentials of a bubbler system. Air is passed at a metered rate along a small-bore tube to a pressure point fixed underwater, well below the lowest expected sea level. The pressure point normally takes the form of a short vertical cylinder with a closed top face and open at the bottom. A small bleed hole is drilled about halfway down its length, and metered air is entered through a connection on the top surface.

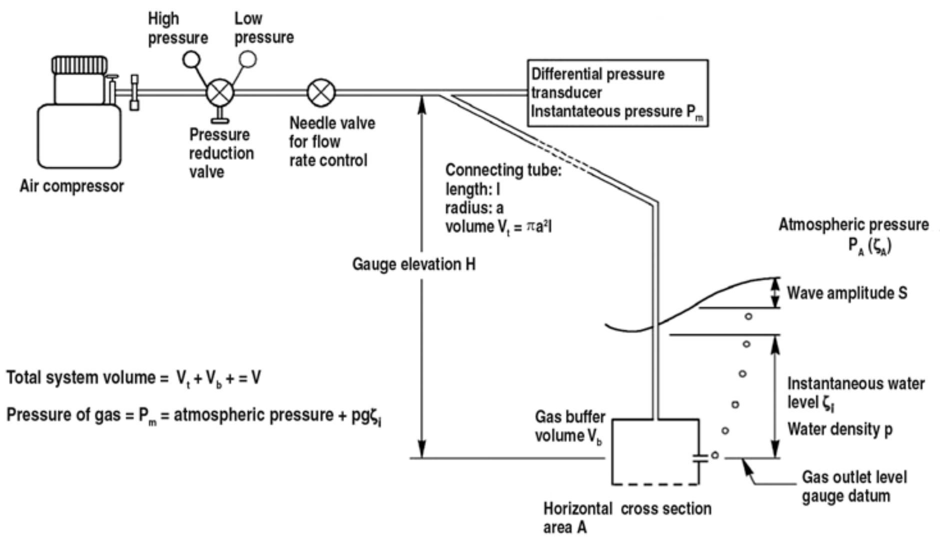


Figure 3-17. Components of a Bubbler System
(Source: IOC Manual of Sea Level Measurement and Interpretation, Vol. 4, 2006)

As air from the tube enters the pressure point, it becomes compressed and pushes the water down inside the chamber until the level of the bleed hole is reached, at which time the air bubbles out through the hole and back to the surface. Provided that the rate of air flow is low and the air supply tube is not unduly long, the pressure of air in the system will equal that of the pressure due to the depth of the sea water above the bleed hole coupled with atmospheric pressure. A pressure-recording instrument connected into this supply tube at the landward end records the changes in water level as changing pressures, according to the law:

$$h = (p-pa)/(\rho g)$$

where h = height of sea level above the bleed hole

p = measured pressure

pa = atmospheric pressure

ρ = seawater density

g = gravitational acceleration

Most pneumatic instruments use a pressure sensor as part of the recording equipment to monitor the changes in pressure and hence sea level. It is common to use a sensor operating in the differential mode, sensors being so constructed that the system pressure is opposed by atmospheric pressure. Hence, the resultant pressure experienced by the sensor becomes (p–pa), making the measured pressure directly proportional to the sea level height. Knowledge of the seawater density (ρ) is important. This is normally obtained from separate water sampling, and, where the water is well mixed, can be considered constant. In estuarine locations, the density may change during a tidal cycle or seasonally, and density corrections will have to be included in the data processing. Several other effects on the measured pressure have to be considered. These include a "static" effect, which is a function of the height of the gage above sea level, and a "dynamic" effect, which results from the dynamics of gas flow. The latter can be calculated in terms of tube length and radius and the minimum air-flow consistent with preventing water from entering the system.

The effect of waves on the system is to introduce a positive bias during storm conditions (i.e. sea level is measured too high). These effects can perturb the sea level measurements at the sub-centimeter level during average conditions, but measurements may be incorrect by several centimeters under extreme waves. In common with all pressure measuring systems, there is a need to establish a datum for the observed time series. This datum can be achieved in several ways including:

- From a knowledge of the exact depth of the pressure point bleed hole during installation, combined with accurate calibration of the pressure transducer
- Using datum level switches similar to those for stilling wells, which trigger at a known sea level
- Having a parallel system, called a B gage, with a second and more accessible pressure point fixed near mean sea level

Comparison of the differences between the two bubbling systems when both are submerged gives an accurate measure of the datum, so the third method is the most accurate.

Air is normally supplied to a bubbler from a compressor to afford continuous operation of the installation. In the event of electrical supply failure, a reserve air capacity capable of sustaining the system for at least several days is necessary. For sustained operation under fault conditions, an alternative low-power backup system in the form of a pressure transducer mounted directly in the sea is necessary. Transducers, compressors, data loggers etc. can be purchased from the major gage manufacturers with ready-to-go packages. An all-bubbler system has an advantage in that most components are underwater and all components are both robust and, if damaged, relatively inexpensive to replace.

Pressure sensors can be fixed directly in the sea to monitor subsurface pressure in a similar fashion to the bubbler gage. The sensor is connected by a cable that carries power and signal lines to an onshore control and logging unit. In the sea, the active sensor is usually contained within a copper or titanium housing, with the cable entering through a watertight gland. Material used for the housing is chosen to limit marine growth.

The assembly is contained in an outer protective tube to provide a stable fixation to a sea wall or rock outcrop, as depicted in Figure 3-18a and b. Where this is not possible, the pressure sensor may be placed securely on the sea bed, but this method has disadvantages, as deployment and maintenance usually require a diving team.

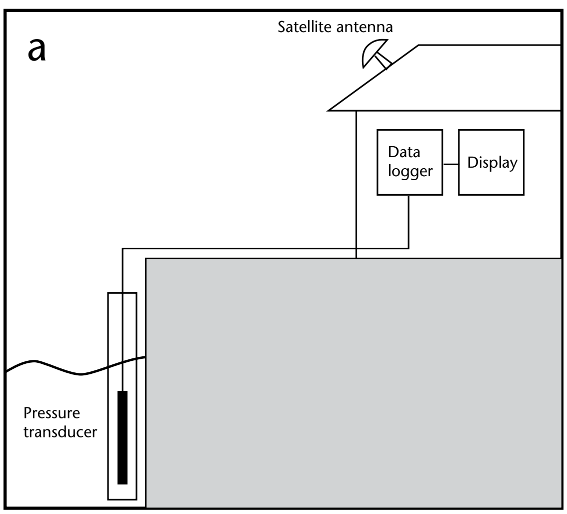


Figure 3-18a. Pressure Gage Mounted Directly in the Sea

(Source: IOC Manual of Sea Level Measurement and Interpretation, Vol. 4, 2006)

Figure 3-18b. Pressure Gage Attached to a Pier in Port Stanley Harbor

(Source: IOC Manual of Sea Level Measurement and Interpretation, Vol. 4, 2006)

Pressure-based instruments can be operated from batteries for periods of a year or more, as they consume a very small amount of power. This can be advantageous even where electrical supplies are available but subject to long periods of failure. Therefore, they have been used extensively in remote areas, such as oceanic islands, where access is limited. In polar regions, pressure-based instruments to measure sea level offer the best alternative if the area is ice covered or if the gage is to be left unattended for long periods. The main disadvantage is the lack of a fixed datum level, which has to be found by alternative means. Pressure sensors are available in two varieties that provide either an absolute or a differential signal. If an absolute transducer is employed, the sensor provides a measurement of the total pressure including sea level and atmosphere. Therefore, a separate barometer is required, usually in the form of an identical transducer open to the atmosphere. Both sensors are synchronized to the same clock so they can readily be subtracted to yield sea level (with subsequent correction for density and acceleration due to gravity). Differential pressure transducers have a vented cable in which the reference side of the transducer is open to the atmosphere. Vented systems are known to suffer from occasional blockage and are used less frequently in hazardous environments. In addition, a record of barometric pressure is valuable for oceanographic studies, so the two-transducer option is most frequently employed.

Acoustic Systems

Acoustic tide gages depend on measuring the travel time of acoustic pulses reflected vertically from the sea surface. This type of measurement can theoretically be made in the open with an acoustic transducer mounted vertically above the sea surface, but in certain conditions the reflected signals may be lost. To ensure continuous and reliable operation, the sensor is located inside a tube that provides some degree of surface stilling and protects the equipment. Some sensors even constrain the acoustic pulses within a narrow vertical tube which is contained inside the previous one. This outer tube does not completely filter out wave action but, by averaging a number of measurements, the desired filtering is achieved. The velocity of sound in air varies significantly with temperature and humidity (about 0.17 percent per °C), and some form of compensation is necessary to obtain sufficient accuracy. The simplest method is to measure the air temperature continuously at a point in the air column and use this to calculate the sound velocity. To account for temperature gradients in the air column, temperature sensors may be required at a number of different levels. A more accurate method of compensation is by use of an acoustic reflector at a fixed level in the air column. By relating the reflection from the sea surface to that from the fixed reflector, direct compensation for variation in sound velocity between the acoustic transducer and the fixed reflector can be achieved; however, this still does not account for any variation in sound velocity between the fixed reflector and the sea surface. To achieve full compensation would require, in principle, a number of fixed reflectors covering the full tidal range, but none of the known acoustic sensors has this possibility.

Acoustic Gages with Sounding Tubes

The U.S. National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS) initiated a multi-year implementation of a Next-Generation Water Level Measurement System (NGWLMS) over a decade ago, both within the U.S. national tide-gage network and at selected sites around the world (Gill et al. 1993). These systems were operated alongside existing (float or bubbler) tide gages at many stations for a minimum period of 1 year to provide datum ties and data continuity. Dual systems were maintained at a few stations for several years to provide a long-term comparison. Tide gages using the same technology have been deployed in a number of other countries, such as Australia, where they are known as SEAFRAME systems (Lennon et al. 1993). The NGWLMS tide gage uses a sensor that sends a shock wave of acoustic energy down a 1/2-inch-diameter PVC sounding tube and measures the travel time for the reflected signals from a calibration reference point and from the water surface. Two temperature sensors give an indication of temperature gradients down the tube. The calibration reference allows the controller to adjust the measurements for variations in sound velocity due to changes in temperature and humidity. The sensor controller performs the necessary calculations to determine the distance to the water surface. The sounding tube is mounted inside a 6-inch-diameter PVC protective well that has a symmetrical 2-inch-diameter double cone orifice to provide some degree of stilling. The protective well is more open to the local dynamics than the traditional stilling well and does not filter waves entirely. In areas of high velocity tidal currents and high-energy sea swell and waves, parallel plates are mounted below the orifice to reduce the pull-down effects (Shih and Baer 1991). Figure 3-19 is a schematic of a typical NGWLMS installation.

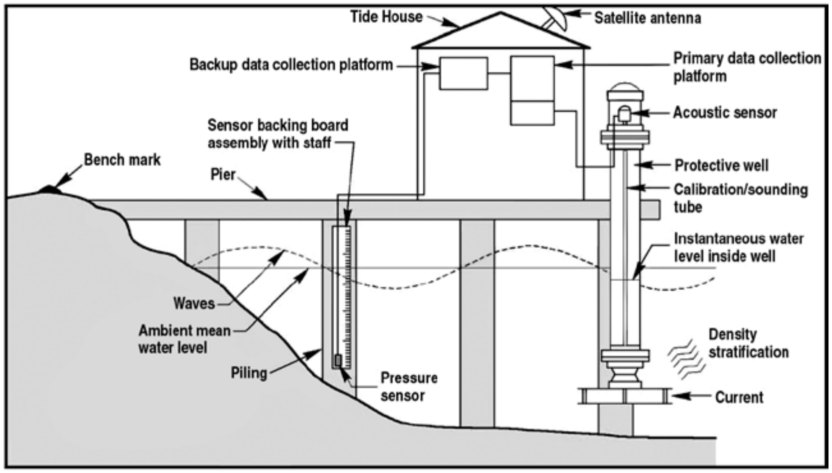


Figure 3-19. NOAA/NOS NGWLMS Tide Gage
(Source: IOC Manual of Sea Level Measurement and Interpretation, Vol. 4, 2006)

To obtain the best accuracy, the acoustic sensor is calibrated using a stainless steel tube of certified length, from which the zero offset is determined. The NGWLMS gages have the capability of handling up to 11 different ancillary oceanographic and meteorological sensors. The field units are programmed to take measurements at 6-minute intervals, with each measurement consisting of 181 1-second-interval water level samples centered on each tenth of an hour. Software in the instrument rejects outliers, etc., which can occur as a result of spurious reflections. Measurements have a typical resolution of 3 millimeters (mm). The instrument contains the necessary hardware for telephone and satellite communications. Most comparisons with conventional stilling well gages show small differences, on the order of a few mm, for the various tidal and datum parameters, which are generally within the uncertainty of the instrumentation. Such differences are very small when compared to typical tidal ranges and even seasonal and interannual sea level variations. NGWLMS systems are considered sufficiently accurate for mean sea level studies. A modern version of the NGWLMS is called a Sea Ranger, which is claimed to have a number of advantages over the earlier technology, including self calibration (IOC 2004).

Acoustic Gages without Sounding Tubes

Several acoustic instruments have been produced that operate without a sounding tube. These gages are normally located inside an existing stilling well or inside a plastic tube some 25 cm in diameter. Some of them may operate in the open air, but are not normally employed for high-quality sea level measurements. These acoustic instruments operate at a frequency of 40 to 50 kilohertz (kHz) and have a relatively narrow beam width of 5°. The manufacturer's measurement range is approximately 15 m with an overall accuracy of 0.05 percent.

Contradictory experiences have been experienced with this type of acoustic sensor, from problems in achieving the stated accuracy under all environmental conditions to the high-quality and continuous operation of 15 tide gages in the REDMAR network (Spain), most of them installed in 1992 and still in operation. A crucial aspect of this type of sensor is the dependence of the velocity of sound on the environmental conditions, such as the air temperature. On the other hand, tubes tend to increase the temperature-gradient between the instrument and the sea surface unless special precautions are taken to ensure that the air is well mixed in the tube. A complementary and necessary method is to compensate for sound velocity variations using a reflector mounted at a suitable distance below the transmitter, as is the case for the Sonar Research and Development (SRD) gages employed in the REDMAR network. A careful design of the installation, avoiding different ambient conditions along the tube and following the maker's requirements about the minimum distance to the water surface, become crucial for the final accuracy of the data.

The performance of one of these SRD sensors over an existing stilling well inside a hut or small building in Santander, Spain, has been nearly perfect and continuous over 15 years. The conditions of this installation are probably ideal, perhaps because the temperature inside the building is rather homogeneous. Data from this acoustic sensor have in fact helped to correct malfunctions of the float gage that operates inside the same stilling well. Studies of mean sea levels from 12 years of data in Spain, comparing this type of acoustic sensor (SRD) with the traditional float gages, has shown their high quality and has even helped to identify reference jumps in the older float gages. Nevertheless, because the success of the SRD sensors in the REDMAR system appears unique, it seems likely that radar gages will replace this type of acoustic sensor everywhere, in the near future.

Radar Systems

Radar tide gages have become available during the last few years from several manufacturers. Although this technology is relatively new, radar gages are being purchased and installed by a number of agencies as replacements for older instruments or for completely new networks. The reason is that they are as easy to operate and maintain as acoustic sensors, without their main disadvantage: their high dependence on the air temperature. Radar gages have a relatively low cost, and the engineering work necessary to install them is relatively simple compared to other systems. The instruments are supplied with the necessary hardware and software to convert the radar measurements into a sea-level height. In addition, the output signals are often compatible with existing data loggers or can be interfaced to a communication network. Like many modern systems, they can be set up using a portable computer.

The active part of the gage is located above the water surface and measures the distance from this point to the air-sea interface. A diagram and photograph are shown in Figure 3-20a and b, respectively. The gage has to be mounted in such a way that there are no restrictions or reflectors in the path of the radar beam, between the gage mounting and the sea surface. It has to be positioned above the highest expected sea level and preferably above the highest expected wave height, so as to prevent physical damage.

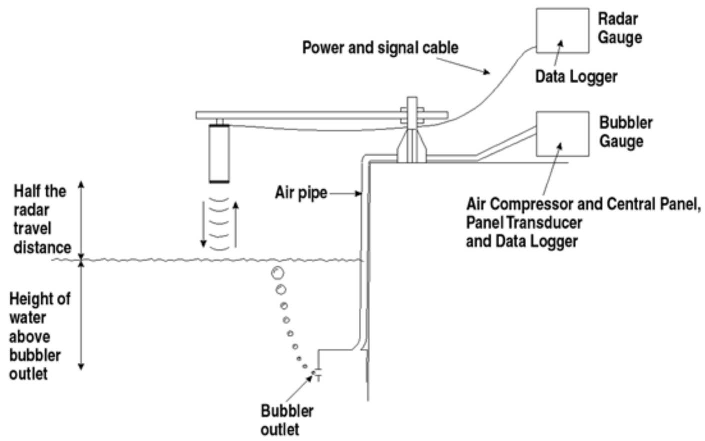


Figure 3-20a. Comparison of a Radar and a Bubbler Gage
(Source: Woodworth and Smith 2003)

Figure 3-20b. OTT Kalesto Radar Tide Gage at a Test Installation, Liverpool, England
(Source: IOC Manual of Sea Level Measurement and Interpretation, Vol. 4, 2006)

A radar gage has many advantages over traditional systems in that it makes a direct measurement of sea level. The effects of density and temperature variations, even in the atmosphere, are unimportant. The main constraint is that the power consumption may be relatively large in radar systems if used on a continuous basis in a rapid sampling mode. Averages are typically taken over periods of minutes. This may limit its use in some applications (e.g. tsunami warning) where observations are required on a continuous high-frequency (e.g. 15-second) basis. In such areas, pressure gages may be more appropriate, although work and research is still being done concerning this particular application. The WC/ATWC notes that averages can be specified by the user. WC/ATWC utilizes 15-second data samples at radar gages and considers the radar gages ideal for high-frequency usage.

Radar gages fall into two categories: (1) those that transmit a continuous frequency and use the phase shift between transmitted and received signal to determine sea level height (frequency modulated continuous waves [FMCW]), and (2) those that use pulsed transmissions and time-of-flight measurement. The OTT Kalesto, Miros and Radac instruments use the FMCW method, and the VEGA and SEBA systems are examples of the pulsed-transmission type. Both types of gages have undergone initial tests and inter-comparisons by various agencies in different countries. Details of these tests can be found in IOC Workshop Report No 193. In principle, the instruments are self calibrating as far as a datum value is concerned; however, to provide confidence that the datum remains constant over long time periods, alternative means are being investigated. These take the form of a reflector that can be placed in the radar beam at appropriate intervals. The reflector is placed at a known distance below the contact point of the installation for a short period. Over a period of a year or more, the datum value can be verified and used to adjust the measurements, if necessary.

Initial indications suggest that these instruments can provide acceptable measurements for the purposes of GLOSS. As with all tide gages, practical considerations related to a particular application often dominate other considerations. For example, they may have very limited application in polar regions. They have not yet been used extensively in extremely hostile environments, such as on remote islands where extreme waves may overtop the gage by several meters. However, for a normal application in which a stilling well or bubbler gage is presently in use, they appear to operate satisfactorily. The WC/ATWC has used a radar gage at Shemya, Alaska (a very hostile environment) for more than 4 years. Waves overtop the gage several times a year. WC/ATWC reports that the radar gage is far superior to traditional stilling well installations in difficult environments.

Multiple-Use Platforms

The University of Hawaii Sea Level Center (UHSLC) has been providing high-frequency tide gage data for tsunami warning to the Pacific Tsunami Warning Center (PTWC) for 25 years. This has led to an emphasis on multiple-use platforms that have the stability and accuracy to measure long-term sea level variability and trends, and the range, durability, and sampling capability to monitor tsunamis. Serving this dual purpose has resulted in a robust system, where (1) station malfunctions can be detected and addressed quickly given the immediate access to the data, and (2) ongoing maintenance in support of sea level monitoring ensures the sustainability of the stations between infrequent tsunami events.

The basic configuration used by the UHSLC for a tide gage station that can also be used for tsunami warning includes the following:

- **Sensors** – No single sensor provides optimal measurements of both mean and high amplitude fluctuating components of sea level. A combination of sea level sensors should be used. The primary sea level sensor is a pulsed radar, with sampling fast enough (3 minute averages or shorter) to serve also as a secondary tsunami sensor. The primary tsunami sensor is a vented pressure transducer reporting 1 minute or shorter averages. The pressure time series, converted to water level, is usually adequate to fill any short gaps that may occur in the radar record. In many cases, a station with a preexisting float gage is also retrofitted for tsunami monitoring. In these situations the float gage is maintained as a third sensor that provides a backup for sea level monitoring. Water level switches and a tide staff are also included to monitor the stability of the data over time.
- **Power** – All UHSLC stations rely on batteries charged by solar panels for power. At many remote sites, local power is not an option. More importantly, local power is susceptible to failure in the event of a local earthquake or tsunami inundation event, in which case it is advantageous to be isolated from the power grid. Most of the UHSLC stations are at low to mid latitudes, making solar a viable option. This may not be the case at high-latitude sites.

- **Siting** – Because tide gages require a stable platform, most of the UHSLC stations are located on piers or docks within harbors or atoll lagoons. In terms of tsunami monitoring, this has the disadvantage of not sampling the wave signal in an open coast setting. Tsunami amplitudes and frequencies within a protected harbor are likely to be significantly different than along an unprotected coast. This is of particular concern for tsunami modelers who may be trying to assimilate tide gage data. On the other hand, unprotected sites tend to be exposed to swell and low frequency wave energy that may in some cases mask a small tsunami event or limit the early detection of a larger event. In addition, the station is less likely to be destroyed during a tsunami if it is situated in a harbor. For these reasons, siting a station within a harbor is a better option if the main concern is to determine whether a tsunami threat is present.
- **Communications** – The UHSLC tsunami monitoring experience in the Pacific has been in the context of a basin-wide warning system. Given that the Pacific is such a large area, transmitting data from the station to the warning center within an hour or so of collection is typically sufficient for monitoring the basin-wide extent of a tsunami event. As a result, the UHSLC uses the Geostationary Operational Environmental Satellite (GOES) satellite in the Pacific, with the transmission of 2- to 4-minute averages every hour.
  - Following the December 2004 tsunami, UHSLC is transitioning to 1-minute averages transmitted every 15 minutes for basin-wide monitoring. This transmission rate has been accomplished using the Japanese Meteorological Agency (JMA) and European Meteorological Satellite (EUMETSAT) geostationary satellites in the Indian Ocean, and the GOES in the Pacific.
  - For stations located within a 1-hour travel time of a known tsunami generation site, 15-second sampling with a 5-minute transmission cycle is under consideration. At present, this may be feasible on the GOES system but not for stations using either the JMA or EUMETSAT downlinks. For these stations, and in support of partners installing national tsunami warning systems, UHSLC plans to use the International Mobile Satellite Organization Broadband Global Area Network (INMARSAT BGAN) system. This application is currently under development in the Indian Ocean.

Important Points to Remember about Tide Gages

- Four types of tide gages are commonly used to measure sea level variations. These types are:
  - **Stilling well and float:** in which the filtering of the waves is done through the mechanical design of the well.
  - **Pressure systems:** in which subsurface pressure is monitored and converted to height based on knowledge of the water density and local acceleration due to gravity. Such systems have additional specific application to ocean circulation studies in which pressure differences are more relevant than height differences

- **Acoustic systems:** in which the transit time of a sonic pulse is used to compute distance to the sea surface.
- **Radar systems:** similar to acoustic transmission, but using radar frequencies. Early results suggest that these systems will dominate in the future as they perform well in harsh environments.

- **Multiple-use** platforms have the stability and accuracy to measure long-term sea level variability and trends, and the range, durability, and sampling capability to monitor tsunamis. Serving this dual purpose can ensure the **sustainability** of the stations/networks between infrequent tsunami events.

Coastal Tide Gage Network and Processing Requirements

Several decades of experience at a number of national and regional centers have led to the determination of requirements for density, quality, and processing capabilities of sea level gage network(s) to adequately support a tsunami warning program. These guidelines were developed by the GLOSS program based on science principles, and also the compelling requirement to issue time-critical products to protect life and property. The following sections are based on the very different needs of teletsunami and local tsunami warning programs.

Each nation or jurisdiction will have to assess its needs in terms of early warning requirements. As the subregional and national sea-level data messages are available for immediate retransmission to the PTWC and the JMA using WMO's GTS facilities, they can be used by these and other tsunami warning centers to help confirm the existence of a major tsunami, or to cancel a tsunami watch or warning.

> **Tip**
>
> Warn on seismic data, and update or cancel on sea level data.

It cannot be overemphasized that the free and open real-time data exchange and the use of sea-level data to verify forecast models is the most beneficial path for all countries to follow. Sea-level data are invaluable to efforts to reduce false alarm rates by detecting small tsunamis. With this in mind, there is a compelling need to establish performance standards for the installation and maintenance of sea level gages.

Coastal Tide Gage Network Requirements

NTWCs may require more tide gages than RTWPs in order to more rapidly detect and evaluate locally generated tsunamis as well as finely monitor impacts from distant tsunamis along their coast.

Additionally, it is recommended that, when possible, these sites be configured within existing multipurpose coastal sea level stations (for sustainability) and into the core network of sea-level stations being developed worldwide under the Indian Ocean Tsunami Warning System

> **Tip**
>
> **MULTI-USE** equals Sustainability

initiative. To this end, the following station performance standards are recommended for both subregional and national *in situ* sea level stations:

- Independent power and communications, i.e., solar and satellite
- Fault-tolerant redundant sensors (multiple sensors for tsunami, tides, and climate)
- Local logging and readout of data (local backup of data)
- Warning center event trigger (ramping up of sampling and transmission on event detection)
- Establishment of a system of surveying benchmarks (tides, engineering, and climate)
- Locating gages in protected areas that are responsive to tsunamis, such as harbors (sustainability and filtering)

The use of multiple-use water level stations maximizes the likelihood of continuous operation of the sea-level measurement network. The specifications for these stations should be designed for long-term sea level monitoring and configured for a sub-regional and national tsunami monitoring system.

Coastal Tide Gage Data Quality

Data recovered from a tide gage always provide time series with a particular sampling interval. Even analogue charts are digitized to provide levels at regular points in time. Until recently, most data acquired this way have been archived and distributed by data assembly centers (DAC) in a quality controlled (QC) and fully documented form. This results in "delayed-mode" data sets. Such QC methods are well established.

Sea level data are required for many purposes, and in many applications, no time is available to perform a full QC. For example, during the World Ocean Circulation Experiment (WOCE), the UHSLC was established as the "fast delivery" DAC, with the British Oceanographic Data Centre (BODC) as the "delayed mode" DAC. The UHSLC was tasked with the assembly, QC, and distribution of sea level data from WOCE gages within several weeks, comparable to the delay, at the time, in the delivery of satellite altimeter data. Meanwhile, BODC had the task to assemble and supply sea level data from the WOCE network to the full extent of QC within 18 to 24 months from data collection. More recently, there has been an emphasis on making as many GLOSS gages as possible deliver data in near real time, typically within an hour. This requirement has arisen for several reasons. First, with real-time data, it is immediately obvious when problems with a gage have occurred. Second, the data become available for many other applications within operational oceanography, e.g. for flood warning or for assimilation of sea level data into ocean circulation models. The data are also then useful for tsunami warning systems in certain areas. The GLOSS program has defined the UHSLC as the "GLOSS Real-Time Center" in addition to its existing role as the "Fast Center," responsible for producing hourly values for monitoring and models.

If sea level data are used in near-real-time applications, then the operational system has to be robust enough to not be perturbed when bad data are recorded (e.g. data spikes). One way to guard against bad data is to have continuous human oversight of the data stream (such as occurs in the UK Storm Tide Forecasting Service for flood warning). Real-time quality control (RTQC) software is now being developed by several groups; for example, in Europe, the Spanish Ports Authority (Puertos del Estado) has developed an automatic QC of sea level data for detection of spikes, gaps, etc. before data is displayed on the public webpage and assimilated into a storm surge forecasting system. Information about this software and the algorithms for spike detection can be obtained through GLOSS.

Coastal Tide Gage Processing Requirements

The current specifications for the basin-wide (regional) in situ sea level component of tsunami warning systems requires data collection and transmission standards that include "sampling of 1-minute averages and a continuous 15-minute transmission cycle via the World Meteorological Organization's (WMO) Global Telecommunications System (GTS) to the JMA, PTWC, and other appropriate warning centers/watch providers." These guidelines were developed in consultation with existing tsunami warning center scientists and technicians from PTWC and JMA, and with JMA and EUMETSAT geostationary satellite operators.

IOC has been following these guidelines in establishing or enabling sea level stations for the IOTWS core stations. However, subsequent Intergovernmnetal Core Group (ICG) meetings in Europe, and the Caribbean and U.S. IOTWS Program team meetings identified the need for subregional and national data collection and transmission standards.

The proposed standards from the ICGs require:

Subregional sites within 1 hour travel time of the tsunamigenic zones:

- Sampling of 15-second averages, and a continuous transmission cycle of 5 minutes.
- Immediate transmission via WMO's GTS to JMA, PTWC, and other appropriate warning centers. (However, it is noted that the European and Japanese geostationary meteorological satellites cannot be used since they are limited to a 15-minute transmission cycle.)

National sites within 100 km of tsunamigenic areas:

- Sampling of 15-second averages, and a continuous or 1-minute transmission cycle for sites within 100 km of the tsunamigenic zones.
- Immediate transmission via WMO's GTS to JMA, PTWC, and other appropriate warning centers and regional watch providers.
- Standards should include data reports that cover a greater time period than the transmission frequency, i.e., redundant data transmission.

Coastal Tide Gage Processing Software

The software package TideTool provides end users with the ability to decode, display, and manipulate sea level data broadcast over the WMO's GTS. The software utilizes the Tcl/Tk software package, specifically the BLT extension. Tcl/Tk is an open source, platform-independent software package offering a powerful shell programming language and graphical toolkit.

Tip

Many tsunami warning centers use the software package "TideTool" to process coastal tide gage data.

The software application was developed by the PTWC to provide an operational tool for real-time continuous tsunami monitoring in the Indian Ocean. Its primary users would be national meteorological and hydrological services (NMHS), or other agencies with a downlink from the GTS or to a data file containing those data formatted in a similar manner. It has been tested under Linux, Windows 2000, and Windows XP environments in Indonesia and Malaysia. A manual providing information on its installation and use is available.

Important Points to Remember about Coastal Tide Gage Networks and Processing Requirements

- Various international sea level gage networks already exist and are available to NTWCs and RTWPs through the GTS.
- Sea level data are needed by tsunami warning centers in real time, with minimal delays.
- Free and open data exchange is critical.
- NTWCs may need more dense sea-level gage networks and more frequent data transmissions than RTWPs.
- Computer software called TideTool provides the ability to decode, display, and manipulate sea-level data broadcast over GTS.
- Multi-use gages are much more sustainable considering the infrequent occurrence of tsunamis in any one region.

Using Tsunameter Buoys to Detect a Tsunami Wave Signal

NOAA has placed Deep-ocean Assessment and Reporting of Tsunami (DART™) buoys at sites in the Pacific and Atlantic Oceans that have a history of generating destructive tsunamis that impact coastlines of the United States. The purpose of the DART buoy network is to ensure early detection of tsunamis, regardless of how the tsunami was generated (Bernard 2005), and to acquire data critical for real-time tsunami forecasting. NOAA has completed installation of 35 DARTs and plans to have completed a full network of 39 stations by April 2008. The current operational array is shown in Figure 3-21. Originally developed by NOAA's Pacific Marine Environmental Laboratory (PMEL) and operated by NOAA's National Data Buoy Center (NDBC), as part of the U.S. National Tsunami Hazard Mitigation Program, the DART Project is an effort to maintain and improve the capability for the early detection and real-time reporting of tsunamis in the open ocean.

> **Tip**
>
> **DARTs** are standardized:
>
> 1. All utilize the same type of pressure transducer, and
>
> 2. All transmit data using the same FORMAT

Coastal sea level tide gages are invaluable for refining tsunami warnings, but due to nearshore bathymetry, sheltering, and other localized conditions, they do not necessarily always provide a good estimate of the characteristics of a tsunami. Also, the first tide gages to receive the brunt of a tsunami wave do so without advance verification that a tsunami is under way. With these shortcomings in mind, the United States and several other countries have begun deployment of tsunameter buoys in the Pacific, Indian, and Atlantic Oceans and other tsunami-prone basins (Figure 3-21), creating an interoperable, standardized network. Sources of potentially damaging tsunamis are widespread, as are the coastal communities they threaten. With costs and budgets limiting the number of DART systems available to deploy and maintain, it is vital that they be positioned to provide high-quality observations at the earliest possible time. Site selection of the DART buoys must address the following:

- Optimization of site locations based on scientific considerations
- Logistical deployment needs and maintenance considerations
- Modeling and detection requirements imposed by potential sources of tsunamis
- Identification of at-risk coastal communities.

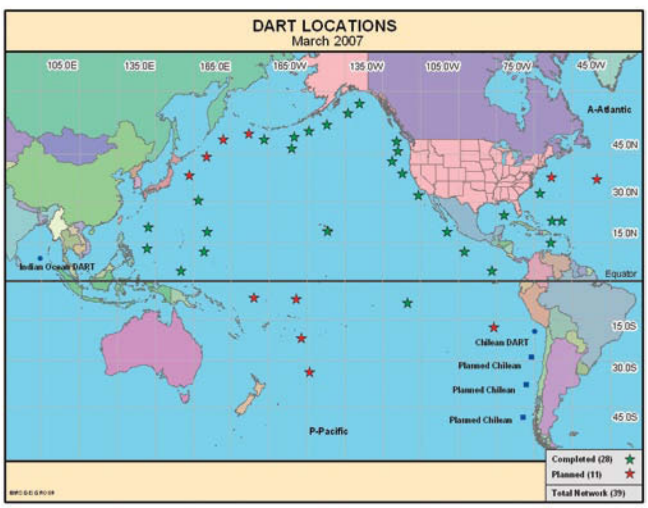


Figure 3-21. Current Operational Array of Tsunameter Buoys

When a tsunami event occurs, the first information available about the source of the tsunami is based only on the available seismic information for the earthquake event. As the tsunami wave propagates across the ocean and successively reaches the DART systems, these systems provide standardized reports of sea level information measurements back to the tsunami warning centers, where the information is processed and used in models to produce a new and more refined estimate of the tsunami effects. The result is an increasingly accurate forecast of the tsunami that can be used to issue watches, warnings, or evacuations, or prevent false alarms. DARTs also detect tsunamis that are generated by landslides, both above and below water, which may not be detected by the seismic network. Hence, the DART array fills in for deficiencies in the seismic array for tsunami warnings.

DART II System Overview

DART II, the second-generation DART system, consists of an anchored seafloor bottom-pressure recorder (BPR) and a companion moored surface buoy for real-time communications (Gonzalez et al., 1998). The BPR monitors water pressure with a resolution of approximately 1 mm of sea water, with 15-second averaged samples. An acoustic link transmits data from the BPR on the seafloor to the surface buoy. The moored system is shown Figure 3-22.

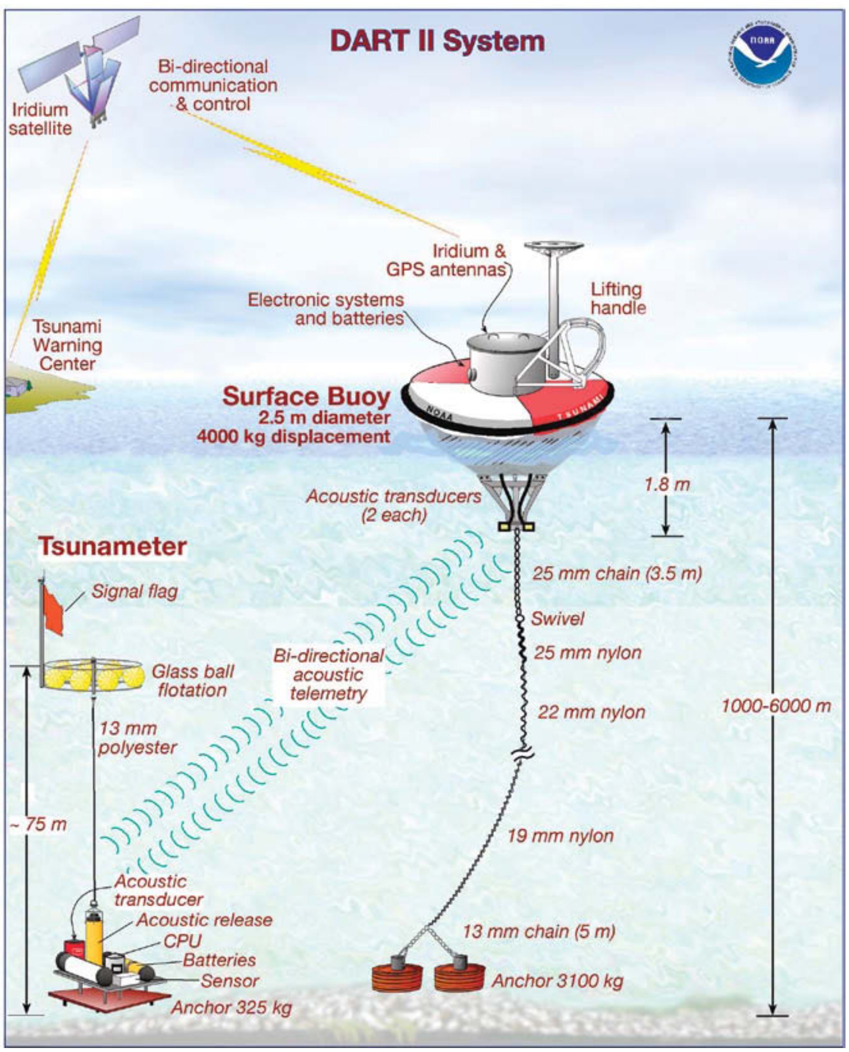


Figure 3-22. Components of DART System

The BPR collects temperature and pressure at 15-second intervals. The pressure values are corrected for temperature effects and the pressure converted to an estimated sea-surface height (height of the ocean surface above the seafloor) by using a constant 670 millimeters per square inch absolute (mm/psia).

The DART II system has two data reporting modes, standard and event. The system operates routinely in standard mode, in which four spot values (of the 15-second data) at 15-minute intervals of the estimated sea surface height are reported at scheduled transmission times. When the internal detection software (Mofjeld) identifies an event, the system ceases standard-mode reporting and begins event-mode transmissions. In event mode, 15-second values are transmitted during the initial few minutes, followed by 1-minute averages. Event mode messages also contain the time of the initial occurrence of the event. The system returns to standard transmission after 4 hours of 1-minute real-time transmissions if no further events are detected. For additional information on the message content, see the Data Formats section in Chapter 4.

A significant capability of DART II is the two-way communications between the BPR and the tsunami warning centers and NDBC using the Iridium commercial satellite communications system (Meinig *et al.*, 2005). The two-way communications allow centers to set stations in event mode in anticipation of possible tsunamis or retrieve the high-resolution (15-second intervals) data in 1-hour blocks for detailed analysis. DART II systems transmit standard mode data, containing 24 estimated sea-level height observations at 15-minute intervals, once every 6 hours. The two-way communications allow for real-time troubleshooting and diagnostics of the systems. NDBC receives the data from the DART II systems, formats the data into messages under the SXXX46 KWBC header, and then delivers them to the National Weather Service (NWS) Telecommunications Gateway, which then distributes the data in real time via NWS communications and nationally and internationally via the GTS.

Iridium uses a Motorola 9522 L-band trans-ceiver from NAL Research at 2400 baud.

GPS is a Leadtek model 9546 receiver

Buoy:

- Fiberglass over foam.
- Computer is 32-bit, 3.3 volt Motorola 68332
- System electronics use 2560 watt-hour D-cell battery pack.

Mooring is 19 mm 8-strandplaited nylon line with rated breaking strength of 7100 kg.

Acoustic modems on tsunameter and buoy:

- Benthos ATM-880 Telesonar with AT-421LF directional transducer.
- Powered by 1800 watt-hour batteries.

Tsunameter:

- Pressure sensor is a 0-10000 psi model 410K Digiquartz Paroscientific unit.
- Tilt sensor is Geometrics 900-45 to determine orientation.
- Uses Alkaline D-cell battery with 1560 watt-hour capacity.
- Uses same computer as buoy.

DART II Surface Buoy

The surface mooring is 2.5 m in diameter and made of fiberglass over foam disk buoy, with a gross displacement of 4000 kg. The mooring line is a 19-mm 8-strand plaited nylon line with a rated breaking strength of 7,100 kg and is deployed with a scope of 0.985. This maintains a tight watch circle to keep the buoy positioned within the narrow cone of the acoustic transmission. Two downward looking transducers are mounted on the buoy bridle at a depth of 1.5 m below the sea surface. A multilayered baffle system of steel, lead, and syntactic foam shields the transducers and cushions them with rubber pads for a soft mount. Deployed U.S. DART and Chilean Hydrographic and Oceanographic Service of the Chilean Navy (SHOA) buoys are shown in Figures 3-23a and 3-23b.

The DART II surface buoy relays information and commands from the tsunameter and the satellite network. The buoy contains two identical electronic systems to provide redundancy in case one of the units fails. The standard-mode transmissions are handled by both electronic systems on a preset schedule. The event-mode transmissions, due to their importance and urgency, are immediately transmitted by both systems simultaneously.

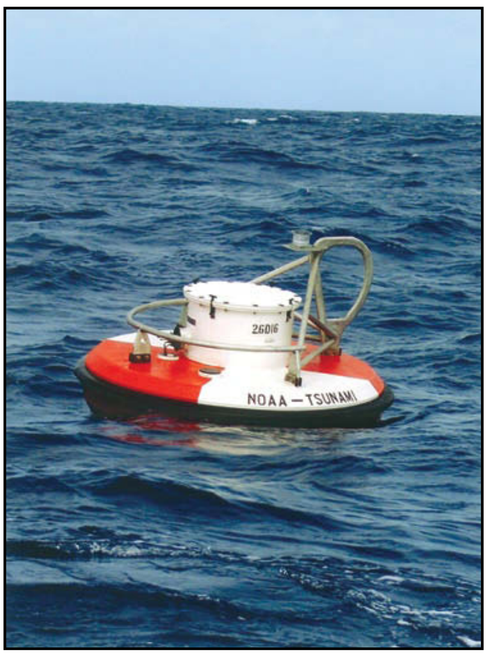


Figure 3-23a. U.S. DART II Buoy

Figure 3-23b. Chilean SHOA Buoy

Surface Buoy Modem and Acoustic Transducer

The Benthos Telesonar acoustic modems and transducers are the same as used in the tsunameter. To improve the reliability of data transmission, two identical systems are used on the buoy.

Surface Buoy Computer

The computer is the same type used in the tsunameter. It processes messages from both the satellite and the tsunameter.

Surface Buoy Iridium Transceiver

A Motorola 9522 L-Band Iridium transceiver from NAL Research provides data connectivity via the Iridium Satellite Network. The buoy computer connects to the transceiver using an RS232 serial port. Data is transferred at 2400 baud, similarly to the familiar dialup modem connections. A typical standard-mode report takes approximately 30 seconds, including the time it takes to complete the connection, transmit the data, and disconnect.

Surface Buoy GPS

A Leadtek model 9546 GPS receiver is used to maintain the buoy's computer clock's accuracy to within ~1 second of Greenwich Mean Time. Additionally, a GPS position is reported once per day to monitor buoy position.

Surface Buoy Batteries

The buoy's fiberglass well houses the system electronics and power supply, which is made up of packs of D-cell alkaline batteries. The computer and Iridium transceiver are powered by 2,560 watt-hour batteries; the acoustic modem is powered by 1,800 watt-hour batteries. These batteries will power the buoy for at least 2 years. The buoy is designed to mitigate the potentially dangerous buildup of hydrogen gas that is naturally vented from alkaline cells. Design features include: 1) hydrogen getters (such as those from HydroCap Corp); 2) pressure relief valves; and 3) spark-free components such as fiberglass or plastic.

DART II Tsunameter

The tsunameter includes a computer that reads pressure readings, runs a tsunami detection algorithm, and sends and receives commands and data to and from the buoy via an acoustic modem.

Pressure Sensor

The DART II pressure sensor is a 0- to 10,000-psi model 410K Digiquartz® unit manufactured by Paroscientific, Inc. The transducers use a very thin quartz crystal beam, electrically induced to vibrate at its lowest resonant mode. The oscillator is attached to a Bourdon tube that is open on one end to the ocean environment, as shown in Figure 3-24. The pressure sensor outputs two frequency-modulated square waves, proportional to the ambient pressure and temperature. The temperature data is used to compensate for the thermal effects on the pressure-sensing element. This pressure transducer is used in all DART II stations and also by the Japanese in their cabled observatories.

As a tsunami wave crest passes over the instrument, the increased pressure causes the Bourdon tube to uncurl, stretching the quartz crystal and increasing the vibrational frequency. Conversely, the passage of a tsunami trough reduces the pressure, allowing the Bourdon tube to curl more tightly, thereby compressing the quartz crystal and lowering the vibrational frequency. These quartz-crystal vibrational frequency changes can be measured very precisely by the electronics system of the tsunami gage, and the frequency changes are then converted into the corresponding changes in tsunami height. For periods greater than a minute or so, and for deployments at depths of 5000 m, the transducer is sensitive to changes in wave height of less than a millimeter.

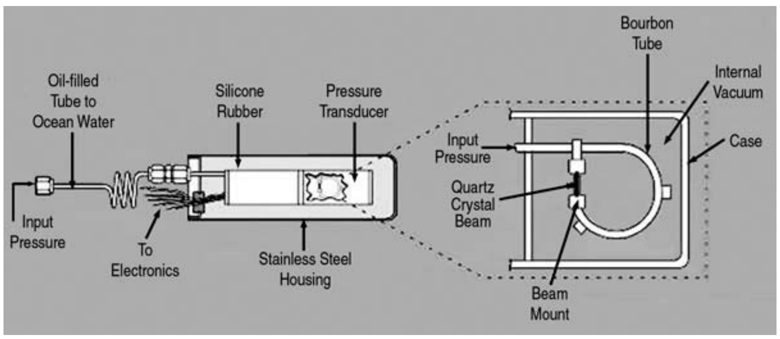


Figure 3-24. Bottom Components of DART II System

Reciprocal Counter

The high-resolution precision reciprocal counting circuit continuously measures the pressure and temperature signals simultaneously, integrating them over the entire sampling window, nominally set to 15 seconds. There is no dead period between the sampling windows. The circuit has a sub-millimeter pressure and sub-millidegree temperature least-count resolution. The reference frequency for the reciprocal counter is derived from a low-power, very stable, 2.097152-megaHertz (MHz), temperature-compensated crystal oscillator. A real-time calendar-clock in the computer also uses this reference for a time base. At the end of each sampling window, the computer reads the pressure and temperature data and stores the data in a flash memory card. A 15-second sampling period generates about 18 megabytes of data per year.

Computer

The embedded computer system in both the buoy and the tsunameter was designed around the 32-bit, 3.3-volt Motorola 68332 microcontroller, and was programmed in C. It was built to be energy efficient for long-term battery-powered deployment. The computer has 4 megabytes of flash memory, a 12-bit A/D converter with 8 input channels, two RS232 channels, a hardware watchdog timer, a real-time clock, and 512 bytes of RAM. The embedded computer implements and regulates the primary functions of the surface and seafloor units: transmitting data communications, running the tsunami detection algorithm, storing and retrieving water column heights, generating checksums, and conducting automatic mode switching.

Acoustic Modem and Transducer

A Benthos11 ATM-880 Telesonar acoustic modem with an AT-421LF directional transducer has a 40° conical beam that is used to transmit data between the tsunameter and the surface buoy. Modems transmit digital data via multiple frequency shift keying (MFSK) modulated sound signals with options for redundancy and convolutional coding. Transducers are baffled to minimize ambient noise from entering the receiver.

Tilt Sensor

Each tsunameter has a Geometrics 900-45 tilt sensor mounted in the base of one of the housings. This is used to determine the orientation of the acoustic transducer when the system has settled on the seafloor. If the tilt is greater than 10 degrees, the tsunameter can be recovered and redeployed. The watch circle of the surface buoy could carry it out of the acoustic projection cone from the tsunameter if the angle from the vertical is too great.

Batteries

The tsunameter computer and pressure measurement system uses an alkaline D-cell battery pack with a capacity of 1560 watt-hours. The acoustic modem in the tsunameter is powered by similar battery packs that can deliver over 2,000 watt-hours of energy. These batteries are designed to last for 4 years on the seafloor; however, this is based on assumptions about the number of events that may occur and the volume of data request from the shore. Battery monitoring is required to maximize the life of the system.

Tsunami Detection Algorithm

Each DART II tsunameter is designed to detect and report tsunamis autonomously. The Tsunami Detection Algorithm works by first estimating the amplitudes of the pressure fluctuations within the tsunami frequency band, and then testing these amplitudes against a threshold value. The amplitudes are computed by subtracting predicted pressures from the observations, in which the predictions closely match the tides and lower frequency fluctuations. If the amplitudes exceed the threshold, the tsunameter goes into event mode to provide detailed information about the tsunami.

Data Communications

This subsection describes all the messages that are sent and received to and from the DART II systems. *Telemetry* describes how the data is physically transported over the distance between the hardware components. *Content* refers to the information contained in the messages. *Format* describes how the message is formatted.

Workstation – to – Buoy

A DART II innovation is the ability to send messages from a workstation on land to the buoy and the tsunameter. This bi-directional communication enables commands to be sent to the DART II system.

Telemetry
The warning center issues commands that are queued in a server until the DART II buoy is in listen mode.

Content
Once the connection is established, the following commands can be sent:

- Turn on deployment mode for 30 minutes in the tsunameter
- Download 1 hour of high-frequency data (15-second data)
- Trip tsunameter into event mode
- Turn acoustic modem on or off
- Turn on event mode
- Turn off event mode
- Reboot tsunameter computer
- Change tsunami detection threshold (30- to 90-mm range)
- Reboot buoy computer
- Get engineering data from tsunameter

Tsunameter – to – Buoy

Telemetry
The Benthos Telesonar acoustic modems use the water itself as the medium for the transmission of acoustic signals. The acoustic modems on the DART II systems are configured to operate in the 9-to 14-kHz frequency band at 600 baud, using MFSK and error-correcting coding. The communication uses a modified x-modem protocol. Entire packets of data with many blocks are sent without requesting an acknowledgement from the receiver after each block. Missing or erroneous blocks are requested to be resent again as individual blocks. If the system is unable to connect, a maximum of two retries are attempted. Most importantly, the modified x-modem protocol greatly reduces power consumption, and efficiently supports high data throughput and integrity.

Content

Standard Mode
Normally, the tsunameter is in its low-power standard mode, and transmissions are made only once every 6 hours. Standard-mode messages contain the following data:

- Message ID, a sequential number
- Message status: C = corrupted, I = intact
- Date= month day year
- Time= hour minute second

- Main battery voltage, or error code
- Acoustic modem digital signal processor battery voltage
- Acoustic modem battery voltage
- Four values for water column height in mm, corresponding to 15-minute intervals
- Number of tries to deliver tsunameter data
- Checksum delimiter
- Checksum

Event Mode

When the tsunameter first detects an event and enters event mode, it immediately transmits an alert to the buoy, which causes it to turn on the Iridium transceivers for immediate transmission of data to the warning centers. The first event mode message contains the following data:

- The exact time that the event was detected
- A message ID
- The average water column height that triggered the event mode, along with three height deviations.
- Check sums and other data verification values that insure the integrity of the data transmission.

Following the initial message, the tsunameter sends messages on a predetermined schedule. The initial message contains 15-second height values. Ensuing messages are similar, but include 15 1-minute average height values, where the 1-minute values consist of the average of four 15-second height values. Once in event mode, the standard mode stops transmitting every 6 hours, and is replaced with an extended-reporting mode for additional data redundancy. This mode transmits messages that consist of 120 1-minute average values, which are transmitted every hour. After the Tsunami Detection Algorithm is in non-triggered status, standard mode is resumed, and extended reporting mode is stopped.

Format

The format of the messages is a space-delimited text string of values, followed by an asterisk, followed by a checksum. The deviation values are coded as four hexadecimal digits.

Buoy – to – Satellite

Telemetry

Each DART II buoy sends its data to the Iridium Satellite Network using an Iridium transceiver. The radio frequency transmission is in the 1565 to 1626.5 MHz range, and the data transmission rate is at 2.4 kilobits per second. The satellite communication also uses a modified x-modem protocol.

Content

Event Mode

In event mode, both communication systems relay the data from the tsunameter.

Standard Mode

In standard mode, that is, no tsunami detected, the surface buoy relays the data it receives from the tsunameter using both systems. These timed transmissions occur once every 6 hours. Receiving these timed water-column height data ensures that each DART II system is functioning properly. If data are not received from the tsunameter, the buoy sends GPS coordinates instead of water column height data. The reported position is checked to ensure that the buoy has not parted from its anchor.

Deployment Mode

The tsunameter will enter into deployment mode prior to deployment. This mode enables the user to verify that the system is working on the seafloor before leaving the site. Deployment mode will transmit data to the buoy every other minute for 4 hours. Once the buoy has received a few messages, it will transmit these messages through the Iridium system. The data will show the tilt of the tsunameter, a quality parameter of the acoustic modem channel, and four 15-second pressure measurements.

Listen Mode

The buoy listens for an Iridium call with a 20 percent duty cycle. The redundant systems will turn on their respective Iridium transceivers at alternate times for 3 minutes out of 15 minutes. This yields a maximum inaccessibility of only 6 minutes. This scheme is employed to control the buoy power requirements by decreasing the standby power draw of the Iridium transceivers.

Format

Data sent from the buoys to the satellite are formatted as text messages sent over a voice-grade telephone connection, just like a normal dialup link.

Satellite to Ground Stations

Telemetry

DART II makes use of the Iridium Satellite Network. Data from each DART II system is downloaded and stored on a server via the Iridium Gateway and Router-based Unrestricted Digital Interworking Connectivity Solution (RUDICS) server. The warning centers monitor this data stream in real time and are responsible for issuing warnings. In addition, the data is posted to a web server, and can be viewed by anyone with a browser.

Content

Normally, sea level or tide data are relayed from the satellite to ground stations, ensuring that the systems are working. Immediately after an event is detected, transmissions increase in frequency, and the data include both averages and deviations along with time stamps. Commands can be sent from workstations on the ground to both the buoys and the tsunameter's computer.

Format

No messages are stored in the satellite network; rather, messages are simply relayed from the buoy to servers or workstations. The format of the messages is text using transmission control protocol/internet protocol (TCP/IP).

Site Characteristics

To reliably send and receive the acoustic packets to and from the tsunameter, which might be submerged between 1,000 and 6,000 meters below the buoy, the tsunameter must be located on a relatively flat portion of the ocean floor. The buoy must be moored such that it stays within a 40-degree cone whose vertex is at the tsunameter, and whose base encompasses the buoy. Outside of this cone, the signal-to-noise ratio deteriorates rapidly, and data integrity will be compromised. The mooring needs to be strong enough to withstand harsh ocean conditions of wind, waves, currents, fish bites, and vandalism.

DART II Performance Characteristic/Specification Summary

Mandatory Characteristic	Specification
Measurement sensitivity	Less than 1 millimeter in 6000 meters; 2 * 10-7
Sampling interval, internal record	15 seconds
Sampling interval, event reports	15 and 60 seconds
Sampling interval, tidal reports	15 minutes
Two-way end-to-end communications	On demand, tsunami warning center trigger
Tsunami data report trigger	Automatically by tsunami detection algorithm
Data flow, BPR to warning center	Less than 3 minutes after triggered event

Desired Characteristic	Specification
Reliability and data return ratio	Greater than 80 percent
Maximum deployment depth	6000 meters
Minimum deployment duration	1 year
Operating Conditions	Beaufort 9
Theoretical Battery Life, buoy	Greater than 2 years
Theoretical Battery Life, tsunameter	Greater than 4 years
Maximum status report interval	Less than 6 hours

Important Points to Remember about Tsunameter Buoys

- NOAA developed the DART (Deep-ocean Assessment and Reporting of Tsunami) buoys to improve tsunami warnings via overcoming many of the shortcomings of tide gage data and seismic data in forecasting tsunami impacts.
- DART II, the second generation DART system, consists of an anchored seafloor bottom-pressure recorder (BPR) and a companion moored surface buoy for real-time communications.
- DART II sensors provide standardized reports of sea level information measurements back to the tsunami warning centers, where the information is processed and used in models to produce revised and more refined estimates of the tsunami, including what its effects are expected to be.
- Under normal conditions (no tsunami) the BPR sends data hourly comprising four 15-minute values that are single 15-second averages.
- If two 15-second water level values exceed the predicted values, the system will go into the tsunami response mode. Data will be transmitted for a minimum of 3 hours, giving high-frequency data on short intervals with 100 percent repeated data for redundancy for the first hour.
- A significant capability of DART II is the two-way communications between the BPR and the tsunami warning centers and NDBC using the Iridium commercial satellite communications system.
- The two-way communications allow centers to set stations in event mode in anticipation of possible tsunamis or retrieve the high-resolution (15-second intervals) data in 1-hour blocks for detailed analysis.

Chapter 4

Data and Information Collection

The collection of data and information from locally maintained and international earth data observation networks is a crucial function of National Tsunami Warning Centers (NTWC) and Regional Tsunami Watch Providers (RTWP). NTWCs and RTWPs have three basic data and information collection requirements. These requirements are:

- Collect seismic and sea-level observational data
- Receive event impact reports from national, state, and local agencies and the public
- Share data and information with other NTWCs and RTWPs

This chapter describes data and information collection requirements, in particular the communications systems for collecting seismic and sea level data needed to detect the occurrence of a tsunami (Figure 4-1).

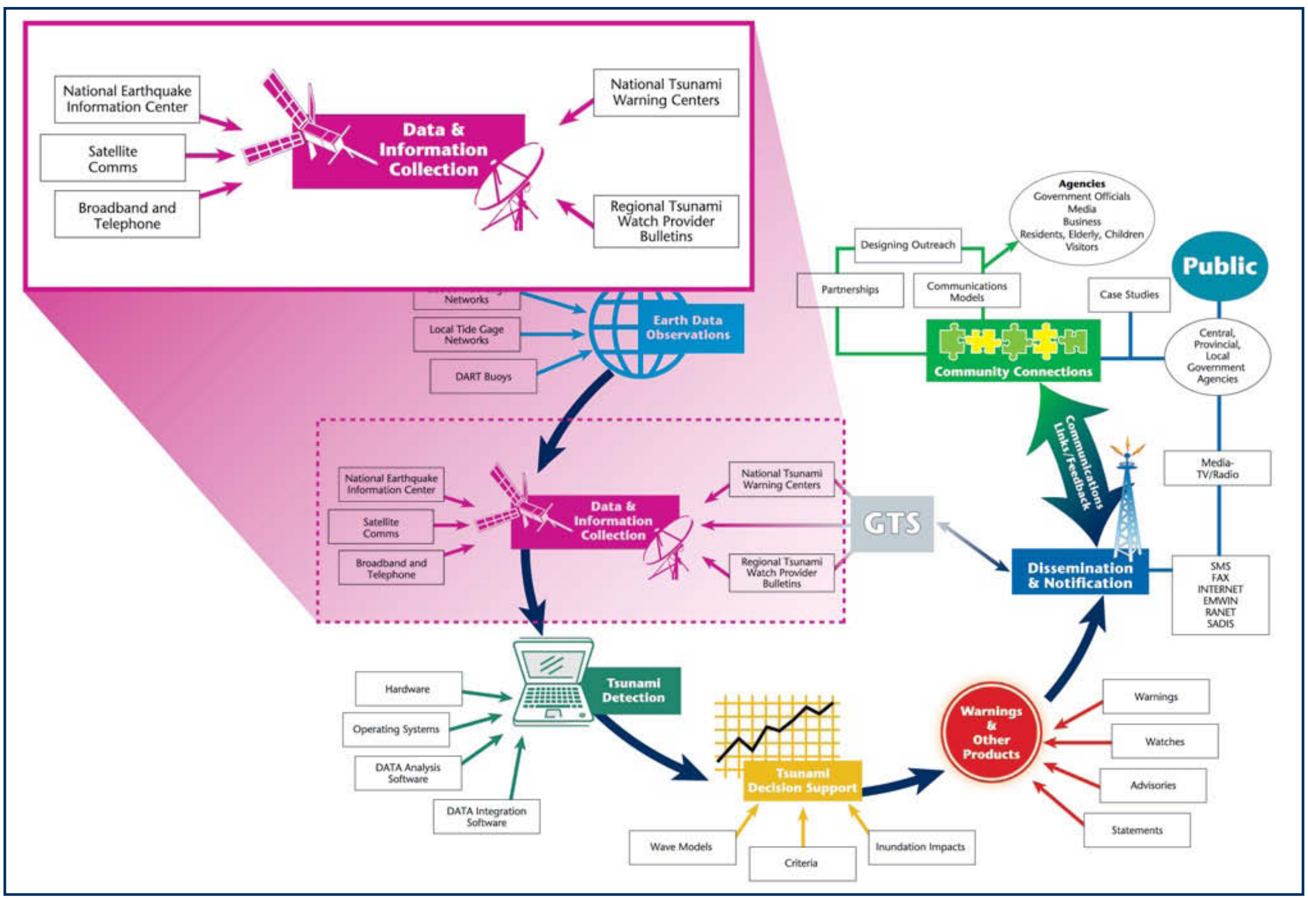


Figure 4-1. Components of a Tsunami Warning Center's Data and Information Collection Requirements

Several telecommunications connections are required to collect data and information needed to detect a tsunami. Some data, especially seismic and sea level data from international networks, are available in real time through the internet and satellite downlinks. Data from locally maintained networks often require alternate communications paths such as land lines, wireless telephone, or radio. This chapter should be read by persons who need to understand the types of communications methods necessary to collect and share data and information, and the importance of maintaining these communications programs and their backups.

How Do Data and Information Collection Fit into an End-to-End Tsunami Warning System?

Data and information collection systems are part of the hazard detection and forecast component of an end-to-end tsunami warning system. The rapid detection and characterization of tsunami-generating earthquakes provides the first indication of a potential tsunami in an end-to-end tsunami warning system. Initial seismic-based warnings based on data from networks of seismic gages are subsequently refined by the detection of tsunami-generated changes in sea level measured by tide gages and buoys. In both cases these data must be received at a center with as little delay as possible. Critical seismic and sea level data must be received rapidly at tsunami warning centers to be of any use in the warning process. Thus, data collection communications systems are crucial to the success of the warning system. Use of backup networks and backup communications paths are needed to ensure a robust program.

What Is in this Chapter?

This chapter contains sections that discuss the following topics:

- **Primary data and information collection through the Global Telecommunications System (GTS):** This section describes the World Meteorological Organization's (WMO) GTS, the primary earth data collection system, including general message formats, and the Message Switching System.
- **Other data and information collection communications channels:** This section briefly discusses methods other than GTS for retrieving earth observation data, including internet, telephone dial-up, etc.
- **Accessing international seismic networks:** This section discusses methods for accessing the Global Seismic Network and local seismic networks.
- **Accessing international tide gage networks:** This section discusses communications requirements for NTWCs and RTWPs to access the Global Sea Level Observing System, an international sea-level monitoring network.
- **Backup communications for data and information collection:** This section discusses the communications connections with other centers, and the importance of backup communications channels.
- **Data collection formats:** Tide gage data, Deep Ocean Assessment and Reporting of Tsunami (DART™) buoy, and seismic data formats are discussed in this section.

What Are the Most Important Points to Remember about Data and Information Collection for NTWCs and RTWPs?

- Critical seismic and sea level data must be received rapidly at tsunami warning centers to be of any use in the warning process.
- Seismic and sea level data from international networks are available in real time through the internet and satellite downlinks.
- Data from locally maintained networks often require alternate communications paths such as land lines, wireless telephone, or radio.
- Backup networks and backup communications paths are needed to ensure a robust program.

Primary Data and Information Collection through the Global Telecommunications System

The primary data collection pathway for NTWCs and RTWPs is the Global Telecommunications System of the World Meteorological Organization. The GTS distributes a wide range of earth data observations with standardized data formats and content. Data and information are routed using a message switching system (MSS) consisting of hardware and software systems. An overview of the GTS is given in Figure 4-2.

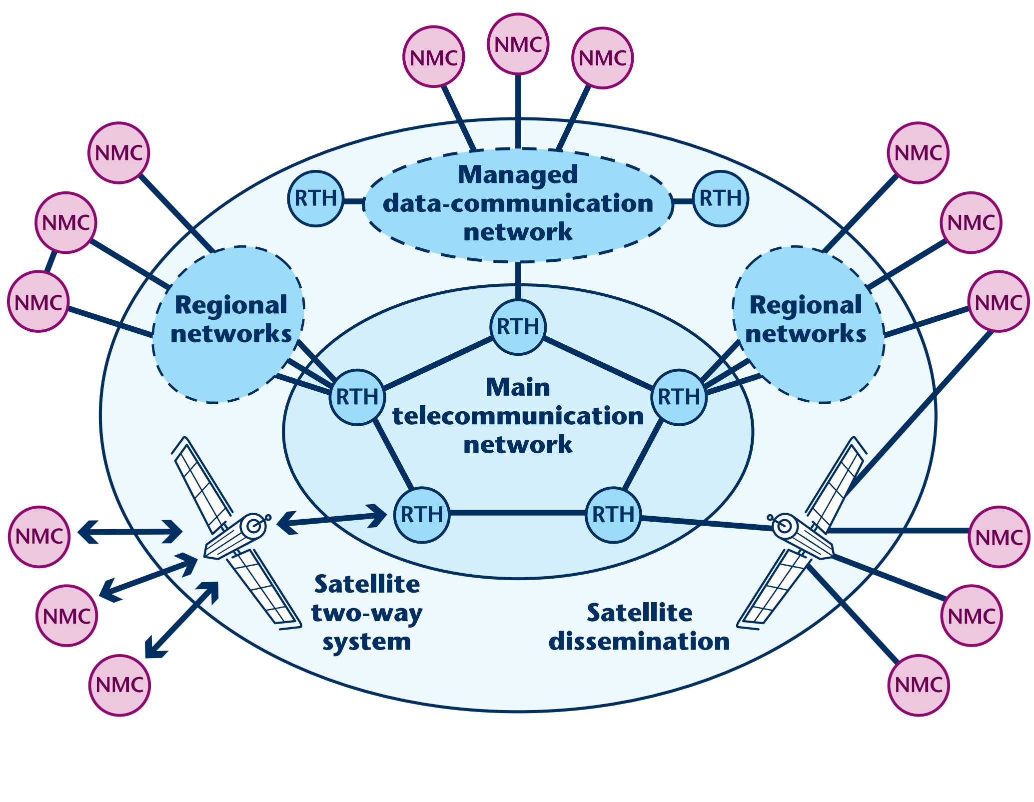


Figure 4-2. Basic Structure of the GTS

The GTS connects meteorological and other centers throughout the world. Its primary purpose is to distribute meteorological, hydrological, and other data, products, alerts, and warnings to the global meteorological community, composed of member nations of the WMO. The structure of the GTS makes use of terrestrial communications circuits to disseminate data, products, and bulletins over a tiered network. The three tiers of the GTS are the World Meteorological Centers (WMC), the Regional Telecommunications Hubs (RTH), and the National Meteorological Centers (NMC).

The three WMCs and the RTHs are interconnected through the Main Telecommunications Network (MTN). The NMCs are connected to the RTHs and other NMCs through numerous Regional Meteorological Telecommunications Networks (RMTN). The NMCs are connected to various in-country points through National Meteorological Telecommunications Networks (NMTN). In addition to the terrestrial network components, several satellite systems provide weather data and bulletins in various regions.

Some NMCs collect various observational data within their territory, such as upper air observations, surface temperature and winds, seismic sensor data, tide gage data, and ship and aviation reports, and produce various forecast and bulletin products. These data and messages are collated for distribution to the RTHs and WMCs via the GTS. Through a distributed set of routing catalogs at each tier (WMCs, RTHs, and the NMCs) of the GTS, data is routed across the GTS to every center requiring each data set and message. The formats and routing procedures are formally defined in WMO Manual 386, *Manual on the Global Telecommunication System*. There are other NMCs that receive data from GTS but do not yet contribute locally generated messages into GTS for distribution. It should be noted that at the present time, while sea level data is handled acceptably by GTS, the transmission of seismic data is probably beyond its scope and is better handled by other communications channels.

Data Formats and Contents

WMO Manual 386 defines the meteorological message format for transfer of information and data on the GTS. Information traversing the GTS may be in alphanumeric, binary, or pictorial form. The messages have a predefined structure consisting of a starting line, an abbreviated heading, the bulletin text, and an end-of-message line. This structure is illustrated in Figure 4-3, taken from WMO Manual 386.

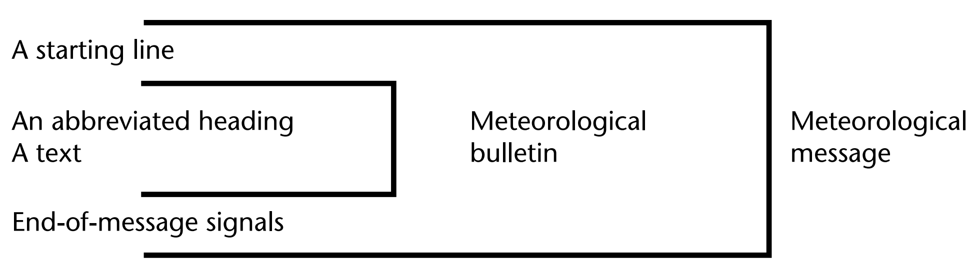


Figure 4-3. GTS Bulletin Structure

The starting line, abbreviated heading, and end-of-message line are alphanumeric using either the International Telegraph Alphabet No. 2 (ITA-2) or the International Alphabet No. 5 (IA-5). Messages containing information in binary representation are required to use IA-5 for these fields.

To the extent that the GTS is retained as the preferred means of transmitting tide gage data from their source (the gages) to the concerned data centers (notably, Permanent Service for Mean Sea Level (PSMSL), University of Hawaii Sea Level Center (UHSLC), and national sea level data centers), the necessary data format is contained in the WMO Manual on Codes at **http://www.wmo.int/pages/prog/www/ois/Operational_Information/ManOnGTS.html.** See Figure 4-10 for an example of a GTS message.

Message Switching Systems (MSS)

At the heart of the GTS routing mechanism reside hardware and software systems called the MSS. These systems are developed and deployed by various commercial firms and governmental agencies worldwide and must comply with the message structure and routing procedures called out in WMO Manual 386.

An MSS is essentially a store-and-forward data filtering application. A constant stream of data available on one or more incoming connections is monitored for the message header information, upon which the MSS makes routing and storage decisions based on user-configurable criteria. Messages are then typically stored in a database as well as forwarded to predetermined destinations, which could include, but are not limited to, local forecasting workstations, local storage devices, other organizations within the NMC's territory such as disaster management centers and national dissemination networks, and other MSSs on the GTS network. Routing of messages can occur several ways on a variety of circuit connections such as point-to-point over a local area network (LAN) or wide area network (WAN), dial-up, fax, email, Very Small Aperture Terminal (VSAT) satellite ground station, internet and file transfer protocol (FTP) services, etc.

Routing of data between RTHs and NMCs is done in accordance with GTS formatted routing catalogs accessed by, or resident on, the MSSs at each center. These routing catalogs consist of American Standard Code for Information Interchange (ASCII) files that can be imported into database applications. Therefore, the structure of the files is such that each line, or record, contains a discrete routing entry consisting of the 11-character abbreviated heading, the 4-character identifier of the GTS circuit from which the bulletin is received, and a series of one or more 4-character identifiers of the GTS circuit to which the bulletin is to be sent. The WMO stipulates that all centers make their routing catalogs available on FTP servers and that they be updated, at a minimum, every 3 months and preferably at least monthly. The prescribed format is a comma-separated value file, with the first record containing the last date of modification in the form YYYYMMDD. The functionality of an MSS varies based on location (WMC, RTH, or NMC) and in-country capabilities and requirements. Many MSSs are far more sophisticated and are linked with other software and hardware systems such as weather display, processing, and forecasting systems and disaster management systems.

Important Points to Remember about Data Collection through the GTS

- GTS can be used to:
  - Collect earth data observations.
  - Share data and information with other NTWCs and RTWPs.
- GTS is a three-tiered system, made up of World Meteorological Centers, Regional Telecommunications Hubs, and National Meteorological Centers.
- GTS uses message switching systems (MSS) to address, prioritize, and route products.
- Product formats required by GTS are specified in WMO Handbook 386.
- Sea level data can be monitored through the GTS, but primary access to seismic data should be via other means, notably the internet and dedicated circuits.

Other Data and Information Collection Communications Channels

Several other communications options, other than GTS, are available to collect data and information necessary for tsunami detection by NTWCs and RTWPs. These options include the internet, dedicated WANs, telephone and broadband links, and satellite systems. International seismic network and sea level network data can be obtained through the internet and GTS, respectively. In many cases, a tsunami warning center must collect national tide gage, buoy, and seismic data by telephone land lines or wireless technologies (such as cellular phone and radio links). Whenever possible, interrogation methods should be automated and capable of being easily modified during events.

Tip

Automate data collection, and make interrogation parameters easily modifiable during events.

Seismic Data Communications—Accessing International Seismic Networks

As noted in Chapter 3, in the section on seismic networks, NTWCs and RTWPs may access international seismic networks to receive crucial seismic data. This section describes methods for gaining access to the Incorporated Research Institutions for Seismology (IRIS) Global Seismic Network (GSN).

Incorporated Research Institutions for Seismology's Global Seismic Network

The IRIS GSN is made up of nearly 130 stations with affiliations to the U.S. Geological Survey (USGS), University of California San Diego's (UCSD) International Deployment of Accelerometers (IDA), GeoForshungsZentrums Potsdam (GEOFON), China Earthquake Administration (NCDSN), Institut de Physique du Globe de Paris

(GEOSCOPE), Germany's Federal Institute for Geosciences and Natural Resources (BGR), U.S. National Seismographic Network (USNSN), Berkeley Digital Seismic Network (BDSN), Air Force Technical Applications Center (AFTAC), and several other national and international networks.

The GSN was conceived as a network of digital seismographs arrayed uniformly around the globe, a configuration that yields a station spacing of about 18 arc degrees, or about 2000 km. Two decades after the birth of IRIS, there are about 126 stations installed and 12 more planned. These stations are distributed over all continental landmasses, several key island sites, and an ocean bottom location between Hawaii and the west coast of the United States. Of the installed stations, the USGS manages 73, and U.S. universities and affiliated institutions operate 53. When the GSN stations are combined with stations from the Federation of Digital Seismograph Networks (FDSN) and the International Monitoring System (IMS) of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization, the number of land-based stations exceeds that called for in the original GSN plan. Although the exact number of stations and their locations will continue to be subject to change due to the installation of a few additional stations and/or the possible closing of some stations, future perturbations to the existing system are expected to be small.

The IRIS GSN stations continuously record seismic data from very broadband seismometers at 20 samples per second (sps), and provide for high-frequency (40 sps) and strong-motion (1 and 100 sps) sensors where scientifically warranted. It is also the goal of the GSN to provide for real-time access to its data via internet or satellite. Most of the IRIS GSN stations meet this goal. Figure 4-4 shows the distribution of stations in the GSN network.

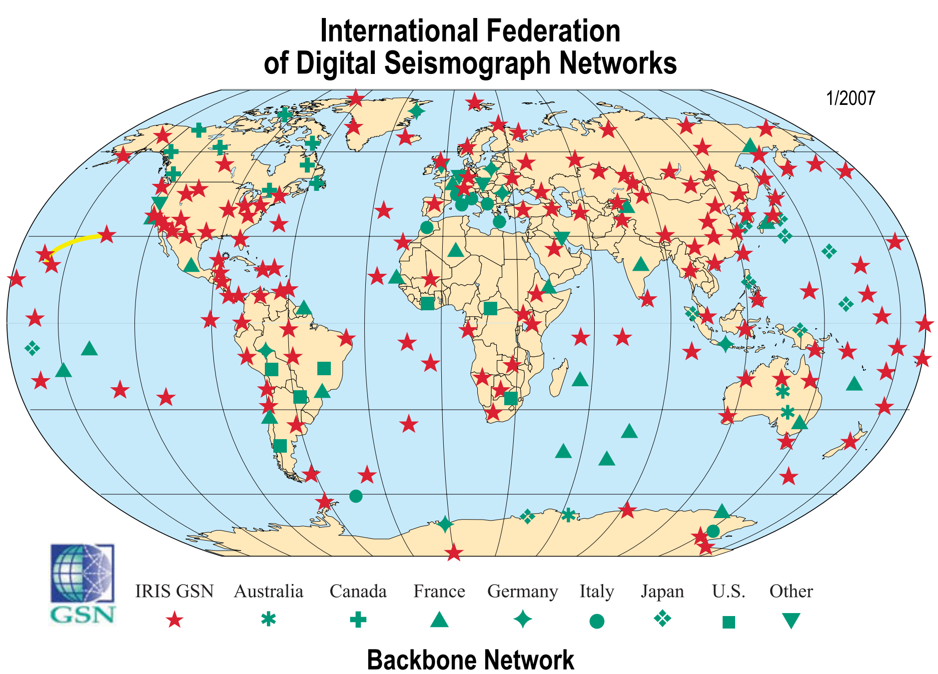


Figure 4-4. Global Distribution of Seismic Networks

Sensors Used in the IRIS GSN

The network uses a suite of sensors to capture the full range of geophysical information in the environment surrounding an IRIS GSN site. The sensors may be grouped into several broad categories:

- **Principal broadband seismometer.** At each IRIS International Deployment of Accelerometers (IDA) station, one of two seismometers (either the STS-1 very broadband seismometer manufactured by *G. Streckeisen AG* or a triaxial KS54000-IRIS manufactured by Geotech Instruments, LLC) is employed to accurately record very-long-period to mid-range seismic data.
- **Auxiliary seismometer.** Because the STS-1 and KS54000-I sensors do not record the higher frequency portion of the seismic spectrum with the sensitivity desired by the IRIS community, an auxiliary sensor is installed at many sites. The auxiliary sensor is either an STS-2, also made by *G. Streckeisen AG*, a CMG-3T by Guralp Systems Ltd., or a GS-13 also by Geotech Instruments, LLC.
- **Strong motion accelerometer.** The above seismometers will behave in a nonlinear fashion when subjected to high accelerations. In order to record acceleration up to 2g with fidelity, a strong motion instrument is installed at most sites. The instrument in use at IRIS/IDA stations is the FBA-23, made by Kinemetrics Inc.
- **Other instruments.** Because of the effect of air pressure on long-period seismic recordings and because geophysical phenomena such as volcanic eruptions generate pressure waves that are of interest to seismologists, it was decided to install microbarographs at GSN stations. The model used at IRIS/IDA stations is the 6016-B made by Paroscientific, Inc.

GSN Communications

Stations of the IRIS Global Seismographic Network are configured as nodes on the internet to facilitate access to the internet and its associated long-haul telecommunications infrastructure. By developing data acquisition and transmission around the internet's Transmission Control Protocol/Internet Protocol (TCP/IP) suite, the task of data collection from remote locations is reduced to one of bringing the internet to the station, a problem for which a multitude of off-the-shelf solutions exist.

Nodes at GSN stations shown in Figure 4-5 are connected to the internet over a variety of circuits including:

- LAN already on the internet
- Dedicated (leased) telecommunications circuit to an internet "point-of-presence"
- Dial-up telecommunications circuit to an internet "point-of-presence"
- Satellite circuit for those stations unreachable by existing telecommunications circuits

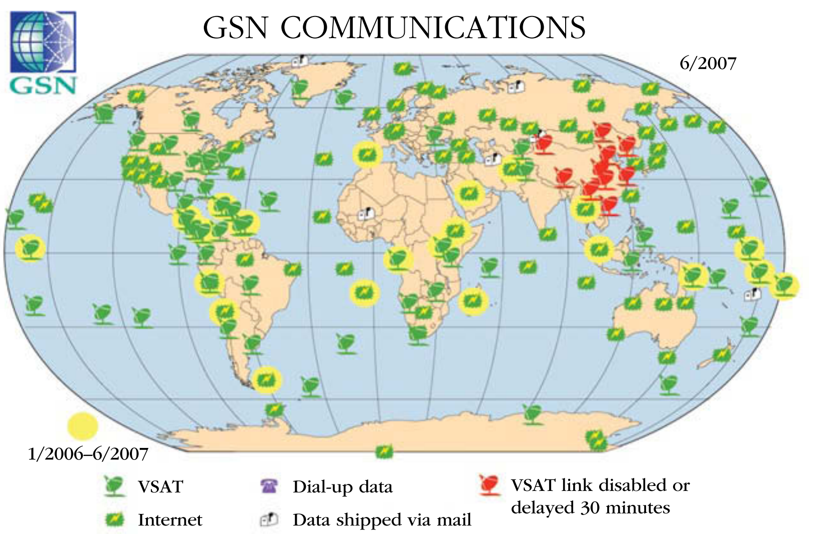


Figure 4-5. Communications Methods Used for GSN Sites

Data acquired via telemetry may be used for such diverse purposes as:

- **Tsunami warning:** Prompt transmission of the seismic data permits experts to locate earthquakes quickly, assess the likelihood they have generated a tsunami, and predict when the destructive wave will arrive. Such predictions have already saved numerous lives.
- **Emergency response:** Prompt and accurate location of earthquakes allows emergency personnel to better plan their response to disasters that occur in remote regions of the world.
- **Monitoring underground explosions:** Seismic methods are used increasingly to monitor adherence to nuclear test ban treaties. When a nuclear device is exploded underground, the resulting shock wave can be detected by seismic instruments over great distances.

In an effort to avoid huge losses in data resulting from an outage in a single network, centers should strive to receive seismic data from several different vendors. For example, the Pacific Tsunami Warning Center's (PTWC) suppliers for teleseismic waveform data are the National Earthquake Information Center (NEIC),Albuquerque Seismic Laboratory, West Coast/Alaska Tsunami Warning Center, IRIS/IDA, USGS Menlo Park, Cal. Tech, the University of Washington, and the University of Puerto Rico, Mayaguez.

Tip

Critical data should be collected from multiple networks via multiple communications methods.

Teleseismic waveform data flows to PTWC via two basic routes. One route is over the dedicated NEIC WAN, and the other is via the World Wide Web (WWW). In terms of programming, these differing routes can be treated the same; they have no differences as far as TCP/IP is concerned. Dedicated lines have a guaranteed bandwidth and are separate from the WWW. Data flowing through dedicated lines should make fewer hops than data flowing over the WWW, resulting in less latency. Furthermore, data flowing along dedicated paths are not as susceptible to WWW outages.

Sea Level Data—Accessing International Tide Gage Networks

As noted in Chapter 3, in the section on coastal tide gage networks, numerous tide gage networks exist around the world. Many of these networks are coordinated by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Education, Scientific, and Cultural Organization (UNESCO).

Global Sea Level Observing System

The most extensive and notable tide gage network is the Global Sea Level Observing System (GLOSS), conducted under the auspices of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the World Meteorological Organization (WMO) and the IOC. The main component of GLOSS is the Global Core Network (GCN) of over 290 sea level stations around the world for long-term climate change and oceanographic sea-level monitoring. The present definition of the GCN (the definition is modified every few years), called GLOSS02, is shown in Figure 4-6.

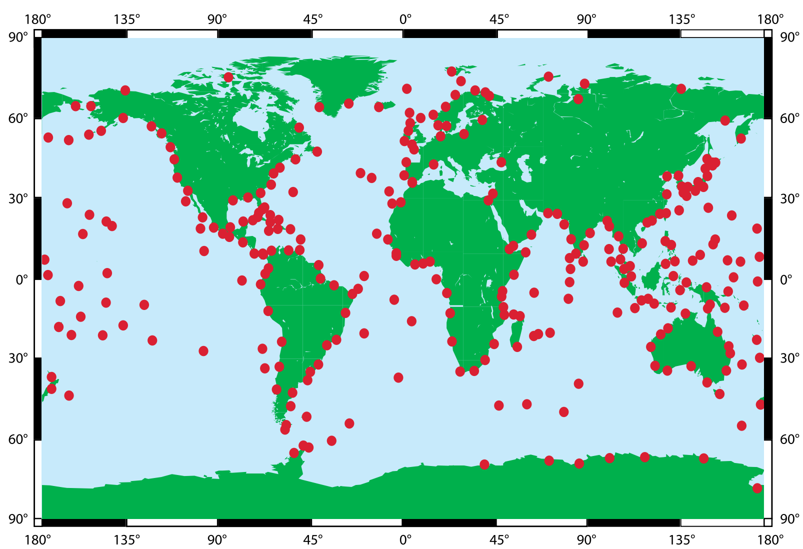


Figure 4-6. GLOSS Core Network Defined by GLOSS02

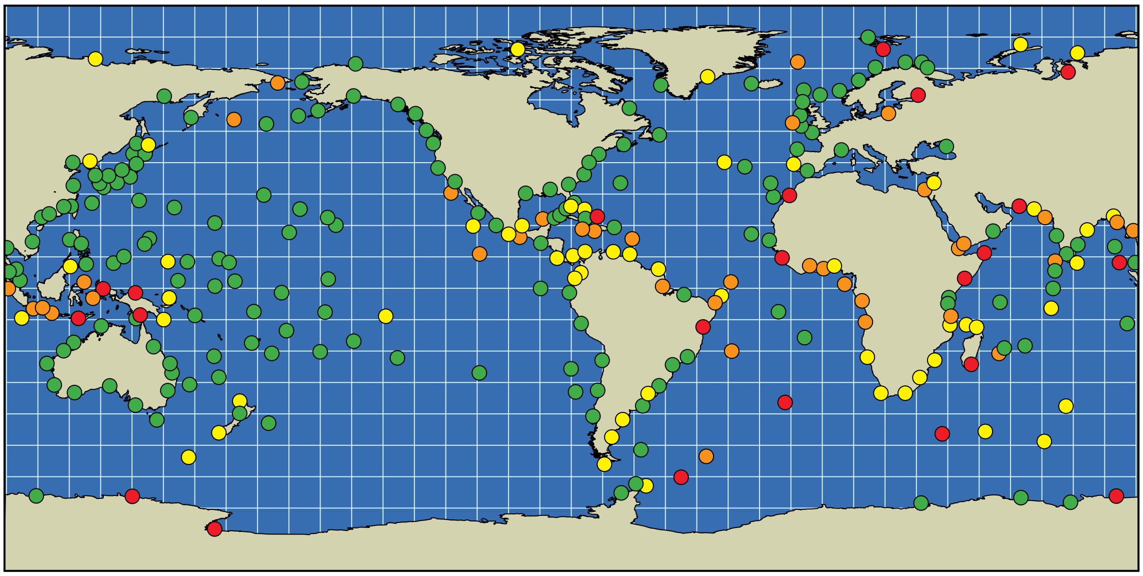
Permanent Service for Mean Sea Level

GLOSS data and data from numerous other networks are archived by the Permanent Service for Mean Sea Level (PSMSL). Since 1933, the PSMSL has been responsible for the collection, publication, analysis and interpretation of sea level data from the global network of tide gauges. It is based in Liverpool at the Proudman

Oceanographic Laboratory (POL), which is a component of the UK Natural Environment Research Council (NERC). The PSMSL is a member of the Federation of Astronomical and Geophysical Data Analysis Services established by the International Council for Science (ICSU). It is supported by the Federation, the IOC, and NERC. Figure 4-7 (a) and (b) shows the types of GLOSS stations in the PSMSL database, along with the Indian Ocean sea level network.

a.

GLOSS status within the PSMSL data set - October 2006



The PSMSL usually provides, each October, a summary of the status of the GLOSS Core Network (GCN) from its viewpoint. An "operational" station, from a PSMSL viewpoint, means that recent MSL monthly and annual values have been received and checked as far as possible, and have been included in the databank. For each of the GCN stations we have used the year of the last data entered into the databank, if any, to place the station into one of four categories:

- **Category 1:** "Operational" stations for which the latest data is 2002 or later.
- **Category 2:** "Probably operational" stations for which the latest data is within the period 1992-2001.
- **Category 3:** "Historical" stations for which the latest data is earlier than 1992.
- **Category 4:** "Stations for which no PSMSL data exist.

b.

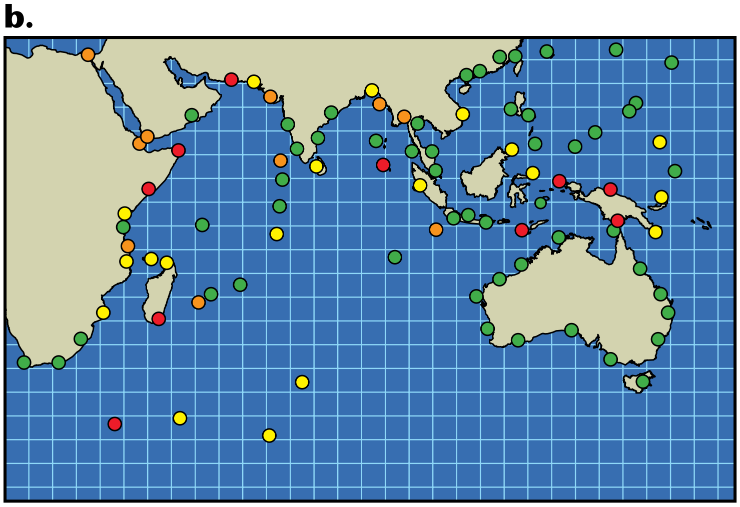


Figure 4-7a. GLOSS Station Status Within the PSMSL Archives as of October 2006
Figure 4-7b. GLOSS in the Indian Ocean Region as of October 2006

Communications

Sea level data acquired by a tide gage may be required in "real time," "near real time," or in "delayed mode," depending on the application. For example, a storm surge or tsunami warning system requires the data to be transmitted to the competent authorities in a very short time. On the other hand, for some scientific research, it is often only necessary to recover the data annually, in which case it can be stored locally and recovered during a site visit, either by downloading the data to a personal computer or by extracting and replacing a memory card. In any case, it is expedient to adopt such a local procedure, even if a communication link is in operation, to prevent loss of valuable data.

The Global Telecommunications System

As noted in the previous section, GTS is widely used by all the meteorological organizations for real-time transmission and interchange of environmental data (see **www.wmo.ch/web/www/TEM/gts.html**; and also **www.wmo.ch/web/www/ois/Operational_Information/WMO386/ManOnGTS.html**, which is the GTS Manual). Given the development by the IOC of an Indian Ocean Tsunami Warning and Mitigation System, GTS is being used more and more by the sea level community. GTS is the future for the GLOSS network, and in particular for the GLOSS Fast Data Center (GFDC).

The Indian Ocean Intergovernmental Coordination Group and other groups have adopted standards for core sea level stations for tsunami detection requiring data transmission within 15 minutes of being recorded at a tide gage (IOC Technical Series 71). A 1-minute sample, 5-minute cycle may be adapted for selected sites close to tsunamigenic source areas. The data would be composed of 1-minute samples to achieve the required resolution and would need to be made available on the GTS. This is in fact the actual recommendation for sea-level data transmitted for tsunami warning systems: making use of the GTS, which works well if geostationary meteorological satellites are used for data transmission. If this is not the case, arrangements with the national meteorological organizations may be needed for including and downloading sea level data from the GTS; automatic transmission by email or FTP will probably be required from the national sea level agency to the meteorological institute, GFDC, or Tsunami Alert System, for including the data in GTS.

Other Satellite Communications for Data Collection

The mission of meteorological satellites is generally twofold: collection of observational data such as infrared and visible imagery, and dissemination of this data as well as other products that are uplinked from the controlling meteorological service. Additionally, some of these satellites receive data from various Data Collection Platforms (DCP), such as tsunami buoys and tide gages. Often gage interrogation frequency can be increased, and time between transmissions shortened when tsunami warning center specified criteria are reached or exceeded.

There are several satellite systems that can be useful in supplementing GTS connectivity. These include:

- International Satellite Communications System (ISCS)
- Emergency Manager's Weather Information Network (EMWIN)
- EUMETCast, the UK Met Office's Satellite Distribution (SADIS)
- India's Satellite (INSAT) Distribution System
- Satellite-based data distribution systems like RETIM-Africa
- Radio and Internet for the Communication of Hydro-Meteorological and Climate-Related Information (RANET)
- Global Marine Distress and Safety System (GMDSS)

The above provide options for alternate and backup communications to ensure receipt of crucial data. The listed satellite systems are also capable of delivering warning and other products. They are discussed in detail in Chapter 8, in the section on dissemination. Overall there are now upward of 30 orbiting satellite systems in operation dedicated to data transmission, some on a global basis. Mobile satellite systems may be classified according to orbit altitude as follows:

GEO – geostationary earth orbit, approximate altitude: 35,000 km

MEO – mid-altitude earth orbit, approximate altitude: 10,000 km

LEO – low earth orbit, approximate altitude: <1,000 km

In all cases, when a tsunami warning center collects local seismic or sea level data via satellite, telephone services, or wireless links, the data should be properly coded and posted to the appropriate international databases for use by all NTWCs and RTWPs. A local gage reading may help the tsunami warning center determine the magnitude of a tsunami in its area of responsibility (AOR). The same data may assist a neighboring tsunami warning center in saving lives in its AOR.

Selecting a Communications System

The selection of a communication system for real time (RT) or near-real-time (NRT) data transmission is always a compromise among a number of constraints. The principal factors guiding a decision in the adoption of a system are:

- Data rate, data-rate profile in different operational modes (if more than one)
- Power availability (power from mains or autonomous/self-powered)
- Guarantee of data transmission (private network or shared data line)
- Location and availability of telecommunication infrastructure (satellites in field of view)
- Land or marine application (fixed or moving)
- Availability of funding.

Two-way communications with a tide gage can be advantageous. It can be used to update software or calibration values at the station, to interrogate the system for faults, to change the sampling rate and to carry out many house-keeping functions that would otherwise wait for a site visit. This allows the system to be flexible and improves overall reliability.

Tip

In the event of an earthquake, the first losses are often the PSTN network, mobile telephone links, and electrical power.

In adopting a communication system for a tide gage installation, one consideration has to be its reliability under severe environmental conditions. For example, for tsunami warning, some of the tide gages may have to be positioned in a tectonically active region to provide an acceptable early warning. In the event of an earthquake, the first losses are often the PSTN network, mobile telephone links, and electrical power. Under such circumstances, satellite links may be the only option. Additionally, some form of uninterruptible power supply (UPS) is necessary. This often takes the form of a battery back-up system with an adequate reserve capacity of several hours. A number of manufacturers, including tide gage and data logger manufacturers, produce relatively inexpensive ready-to-use communications systems suitable for tide gages. For a list, see the websites given on the PSMSL website: **http://www.pol.ac.uk/psmsl**.

The method of communication depends largely on the distance the data have to be transmitted. For short links (such as harbor operations), a radio link is often convenient. For countrywide links, subscriber trunk dialing or dedicated telephone lines of the Public Switched Telephone Network (PSTN) are an effective medium. Where fixed lines are not practical, the growth in the use of mobile phone links using General Switched Messaging (GSM) technology and General Packet Radio System (GPRS) protocols has extended the potential for long-distance communication. Both the fixed and mobile telephone systems give access to the internet through an Internet Service Provider (ISP), which can greatly enhance the transmission of data. For example, many of the GPS stations of the global network of the International Global Navigation Satellite System Service, which has some similarities to the global tide gage network in terms of number of sites and amount of data to be transmitted, report through the internet.

All the forms of telephony are merging into one, with telephone links provided by a supplier for which the connection method is transparent to the user. After the tsunami of December 26, 2004, India implemented a real-time coastal sea level data transmission by means of GPRS with continuous connection to internet, with much lower costs than previous experiments based on Short Messaging Service and Data Call Services.

The advantages of broadband technology are:

- Continuous two-way connection allowing high-speed data sampling and near-real-time data retrieval. Remote gage diagnostics and the ability to reprogram the system remotely are available.
- Timing drift and operator setup error eliminated by having accurate time available from Network Time Protocol servers on the internet.

- Data delivery costs are known up-front, because the subscription costs are paid monthly or yearly.
- Real-time data collection allows malfunctions to be found and fixed, more rapidly.
- Fixed-line broadband systems can also allow backup access through a dial-up modem.

The disadvantages of broadband technology are:

- A LAN interface is required; this is often difficult to add to existing tide gage systems. A land line is necessary for nonsatellite broadband systems.
- Serial port is generally not available, so interfacing is more difficult.
- Power requirement for broadband modems is quite high (~1 amp); this can create problems where main power is not available.

As already noted, for more remote areas, mobile satellite links provide a viable alternative. There are now upward of 30 orbiting satellite systems in operation dedicated to data transmission, some on a global basis.

Real-Time Transmission of Tsunameter Data

The real-time transmission of data from the tsunameter buoy varies depending on the operating mode of the bottom pressure recorder (BPR) (Figure 3-26). Transmission of real-time water level heights occurs when the Tsunami Detection Algorithm triggers a suspected event, when the tsunameter buoy is interrogated by the tsunami warning centers or the National Data Buoy Center,(NDBC) or at prescheduled intervals. The BPR transmits the messages to the surface buoy via underwater acoustics systems. The surface buoy is equipped with duplicate and independent communications systems to transmit data to the Iridium satellite and then on to the Iridium Gateway in Tempe, Arizona, where an Iridium Router-based Unrestricted Digital Internetworking Connectivity Solution (RUDICS) routes the data to the NDBC RUDICS Server at Stennis Space Center, Mississippi. RUDICS then routes the messages to a Data Acquisition Center server located at the Stennis Space Center, where NDBC attaches NOAA header information and message identifiers and sends the data to the National Weather Service's Telecommunications Gateway (NWSTG) in Silver Spring, Maryland for internet distribution via the global telecommunications operation center. The tsunami warning centers and NDBC pick up the data from the NWSTG broadcast. NDBC decodes and reformats the data for real-time web display and database storage. If the buoy is unable to establish the connection to the NDBC RUDICS Server, information does not move from the buoy's communication buffer.

A tsunami warning center or NDBC can initiate an interrogative data retrieval mode, or set the BPR in Event Mode; however, the Iridium receivers on board the surface buoys have a limited amount of receive time. Upon receipt of the command to retrieve high-frequency data, the BPR transmits 1 hour of 15-second pressure and temperature data. The data parameters are in a similar format as that written to the on-board memory card. NDBC will maintain a catalog of these data for possible archiving.

Important Points to Remember about Data Communications Channels

- Broadband interrogation methodology allows for faster real-time retrieval of time-critical data. However, broadband modems have a relatively large power requirement.
- Several satellite systems are available to serve as both primary data collection channels and as backups for GTS and other interrogation methods.
- Interrogation methods should be automated, and easy to modify. An example is two communications with local tide-gage networks where sampling rates can be changed during an event.
- Locally collected data should be properly coded and posted to the appropriate international databases for use by all NTWCs and RTWPs.

Backup Communications for Data and Information Collection

NTWCs and RTWPs should employ backup communications for data and information collection required to detect a tsunami. Two types of backup communications should be employed by tsunami warning centers: alternative communication paths within a center and backup communications by another center.

Alternate communication paths for data collection and product dissemination are needed within an NTWC or RTWP. In the event of the failure of one of a center's primary communication links, information can be rerouted through a secondary connection.

Center functionality backup by another center means that procedures are in place for an RTWP to assume the functions of one of its NTWCs if that national center has lost all communications links. Similarly, each RTWP must have agreements in place for another RTWP to take over in the event of a catastrophic event at the disabled regional center. Typically, a tsunami warning center should have connections to at least two other centers, and RTWPs to another regional provider to provide backup communications.

While commercial satellite systems do not directly support the GTS, it is important to take into consideration all of these systems since they may offer diverse dissemination mechanisms of tsunami warning information that may be able to supplement primary GTS connectivity. In this regard, a suitable commercially provided service could be used as further backup to GTS circuits.

Many other meteorological satellite systems are operated in polar orbits for observational data collection, and many perform additional functions of collecting data from DCPs such as buoys and tide gages. The role of implementing more than one satellite receiving system should be explored by an NTWC or RTWP to provide maximum overall system reliability. Although not common, unexpected outages of satellite systems do occasionally occur and can sometimes result in total loss of a satellite platform. Data reception from more than one satellite system will help ensure very high reliability in the unlikely, but possible occurrence of loss of one satellite service combined with a loss of terrestrial communications at a tsunami warning center.

Important Points to Remember about Backup Communications

- A center should have alternate communications paths to collect crucial seismic and sea-level data, and to disseminate warning and other products.
- To plan for possible total communications outages, each center must make arrangements for another center to take over. This requires careful planning, extensive coordination, and attention to numerous small details.

Data Collection Formats

Earth data observations are collected in a number of different data formats. Data formats from seismometers, tide gages, and tsunameters (DART buoys) vary in the data volume, transmission frequency, and format. NTWCs and RTWPs must be knowledgeable of and capable of handling these data formats.

Seismic Data

The NEIC component of the Advanced National Seismic System (ANSS) acquires data from foreign broadband stations in near-real-time. The NEIC automatically acquires over 2,000 data channels with an aggregate data volume of about 2.5 Gbyte per day. Of these data, about 860 Mbytes/day are archived (two copies each) onto optical storage (an aggregate of nearly 4 Tbytes to date). At the same time, the NEIC distributes data to the research community through an Automatic Data Request Manager (AutoDRM), autodrm@usgs.gov, and the IRIS Data Management Center (DMC). Real-time data are provided to ten Regional Seismic Networks including the Pacific and Alaska tsunami warning centers to augment regional and teleseismic monitoring.

All data, whether through the USGS CrestNet or internet, are transferred between data centers using the USGS Earthworm software, the *de facto* standard for seismic data and hypocenter parameter exchange. Seismic data transfer is quite complicated. The original data format is dependent on the manufacturer of the field equipment. Each brand has a different format, and sometimes multiple formats by the same vendor. The recording network (which is usually the operating network) is responsible for decoding the data. Within the tsunami warning center, data are converted to the Earthworm format and shared with other centers. Earthworm documentation is available at **http://folkworm.ceri.memphis.edu/ew-doc/**.

The primary seismic data archive for the seismic community is through the IRIS DMC. Information on the data and data formats is available from IRIS at: **http://www.iris.edu/manuals/DATutorial.htm**. The Standard for Exchange of Earthquake Data (SEED) manual can be found on the IRIS website at: **http://www.iris.edu/manuals/SEEDManual_V2.4.pdf**.

Tide Gage Data

In general, sea level data are digitized and sampled at the field station. Ideally, the data transmitted for tsunami monitoring will be 1-minute (or better) averaged data values that are transmitted at least every 15 minutes. Currently, many stations transmit every 10 to 60 minutes and data averages are at 1- to 4-minute sampling intervals. Data are transmitted over a number of different satellites to regional telecommunications hubs of the WMO, and onward to customers such as the Pacific Tsunami Warning Center, the Japan Meteorological Agency, and to any requesting national hydrological agency, as depicted in Figure 4-8.

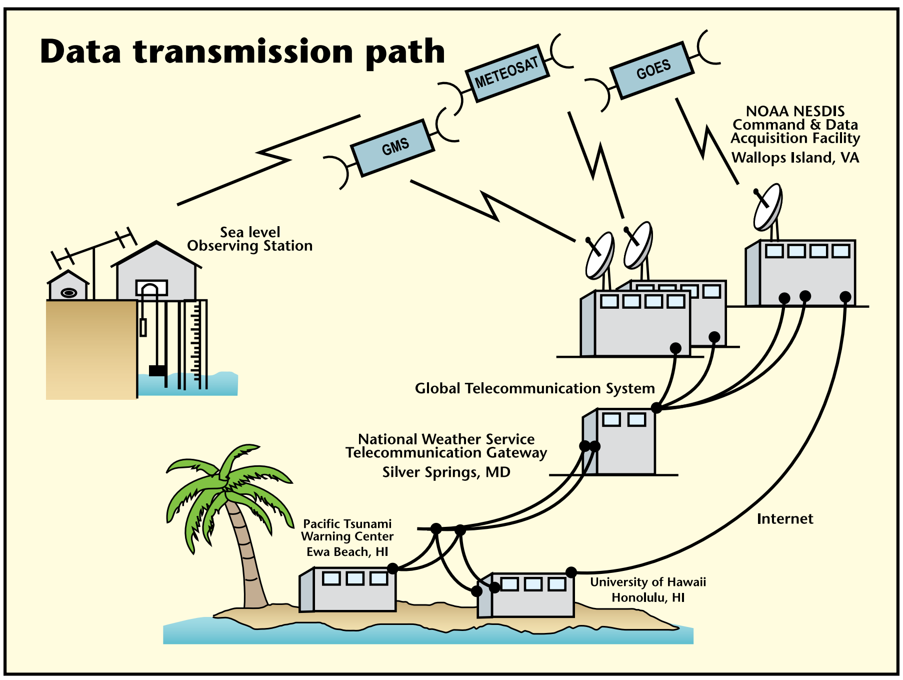


Figure 4-8. Data Transmission from Field Station to Tsunami Warning Centers
*Source. "Display and Decode of Sea Level Data Transmitted over the WMO Global Telecommunications System. Version 1.1, November 2005" (***http://www.ioc-tsunami.org/***).*

Sea Level Data Reported in WMO Code Form

The two primary WMO formats, Binary Universal Form for the Representation of meteorological data (BUFR), and Character form for the Representation and EXchange of data (CREX), offer great advantages in comparison with the traditional alphanumeric codes. The main features of the table-driven codes are self-description, flexibility, and expandability, which are fundamental in times of fast scientific and technical evolution. In addition, BUFR offers condensation (packing). The alphanumeric code CREX provides simple readability but no packing. BUFR has been used mainly, so far, for satellite, aircraft, and wind profiler observations, but also for tropical cyclone information and for archiving of all types of observational data. CREX is already used among meteorological centers for exchange of ozone data, radiological data, hydrological data, tide gage data, and soil temperature data. Ideally, BUFR should always be used to exchange observations internationally. CREX should be used only if binary transmission is not possible. It is thought that these two codes can satisfy all WMO needs for observation coding and are recommended for all present and future WMO applications.

Each station and its data transmission is described by a unique set of parameters, including Satellite Product Headers, Station Platform, method of transmission and transmission time, and file formats. Figure 4-9 shows an example of decoding a tide gage report in CREX format.

TIDE GAUGE DATA EXAMPLE

```
CREX++
T000101 A001 D06025++
RI010 1998 01 23 15 00 2761 00 00 30 -30
01407 1225 01384 1217 01382 1221 01395 1220 01473 1262 01502 1227+
CT010 1998 01 23 15 00 2781 01 00 30 -30
02024 1757 02043 1717 02124 1728 02177 1716 ///// //// 02259 1670++
7777
```

Interpretation of the example:

Line	Group	Meaning
1	CREX	Indicator of a CREX message
2	T000101	CREX Master Table Number 00, Edition 01, Version 01
	A0001	Data type 001: Surface data - sea
	D06024	Tide elevation series
3	RI010	Tide station RI010
	1998	Year: 1998
	01	Month: January
	23	Day: 23
	15	Hour: 1500 UTC
	00	Minute: 00
	2761	Sea/water temperature
	00	Tide station automated water level check: Good data
	00	Tide station manual water level check: Operational
	30	Time increment: time is now hour 1500, minute 30
	-30	Short time increment: increment is applied prior to each replication of two descriptors indicated by the group R02006, thus the time is now hour 1500, minute 00
4	01407	Tide elevation of 1407 mm at hour 1500, minute 00
	1225	Meteorological residual tidal elevation of 1225 mm at hour 1500, minute 00
	01384	Tide elevation of 1384 mm at hour 1400, minute 30
	1217	Meteorological residual tidal elevation of 1217 mm at hour 1400, minute 30
	01382	Tide elevation of 1382 mm at hour 1400, minute 00
	1221	Meteorological residual tidal elevation of 1221 mm at hour 1400, minute 00
	01395	Tide elevation of 1395 mm at hour 1300, minute 30
	1220	Meteorological residual tidal elevation of 1220 mm at hour 1300, minute 30
	01473	Tide elevation of 1473 mm at hour 1300, minute 30
	1262	Meteorological residual tidal elevation of 1262 mm at hour 1300, minute 00
	01502	Tide elevation of 1502 mm at hour 1200, minute 30
	1227	Meteorological residual tidal elevation of 1227 mm at hour 1200, minute 30
	+	End of report for station RI010
5	CT010	Tide station CT010
	1998	Year: 1998
	01	Month: January
	23	Day: 23
	15	Hour: 1500 UTC
	00	Minute: 00
	2761	Sea/water temperature: 276.1 K
	00	Tide station automated water level check: Good data
	00	Tide station manual water level check: Operational
	30	Time increment: time is now hour 1500, minute 30
	-30	Short time increment: increment is applied prior to each replication of two Descriptors indicated by the group R02006, thus the time is now hour 1500, minute 00
	602024	Tide elevation of 2024 mm at hour 1500, minute 00
	1715	Meteorological residual tidal elevation of 1715 mm at hour 1500, minute 00
	02043	Tide elevation of 2043 mm at hour 1400, minute 30
	1717	Meteorological residual tidal elevation of 1717 mm at hour 1400, minute 30
	02124	Tide elevation of 2124 mm at hour 1400, minute 00
	1728	Meteorological residual tidal elevation of 1728 mm at hour 1400, minute 00
	02177	Tide elevation of 2177 mm at hour 1300, minute 30
	1716	Meteorological residual tidal elevation of 1716 mm at hour 1300, minute 30
	/////	Tide elevation missing at hour 1300, minute 30
	////	Meteorological residual tidal elevation missing at hour 1300, minute 00
	02259	Tide elevation of 2259 mm at hour 1200, minute 30
	1670	Meteorological residual tidal elevation of 1670 mm at hour 1200, minute 30
	++	End of report for station CT010; also, end of Data Section
7	7777	End of CREX message

Figure 4-9. Decoded Example of WMO CREX Format

GTS coding requirements for sea level data can be found in the GTS Manual (WMO Publication 386) (**http://www.wmo.ch/web/www/ois/Operational_Information/WMO386/ManOnGTS.html**).

Sea Level Data Reported in Non-WMO Code Form

Sea level data from the GLOSS tide gage network and some other organizations use a non-WMO code form. The following example is the report received from the DCP in Colombo, Sri Lanka, collected via the Geostationary Meteorological Satellite at the Japan Meteorological Agency. The report is the 1-minute observation transmitted every 15 minutes. The message received at the Regional Telecommunications Hub via GTS for the report at 0430 coordinated universal time UTC on 29 March 2006 is shown in Figure 4-10.

```
SWIO40 RJTD 290430
:ENB 1 #1 M 3763 3761 3761 3759 3758 3758 3755 3754 3752 3750 3749
3746 3745 3744 3743 3743 3743 3742 3742 3742 3742 3741 3741 3741 3739
3739 3738 3737 3737 :ENC 0 #2 3269 3265 3263 3263 3260 3256 3250 3246
3247 3246 3245 3243 3244 3243 3242 3239 3237 3234 3233 3233 3232 3230
3232 3232 3233 3233 3232 3228 3229 3230 :BATTLOAD 0 12.83 :NAME=
```

Figure 4-10. Example of GLOSS Non-WMO Sea Level Gage Report Code

The first line of the message depicted in figure 4-10 is the abbreviated header (TTAAii CCCC YYGGgg) of the bulletin for identification and transmission on GTS. The date/time group YYGGgg given in the abbreviated header is 0430 UTC on the 29th of the month. The month and year (March 2006) are not reported in the message.

The latest observation time reported in this message is 0431 UTC, i.e. 0430 + 1 min. Twenty-nine tidal measurements at 1-minute intervals are included in the report, but 14 of the 29 observations have already been reported in the last bulletin. The observations are reported in **reverse** order.

Time	Data Value
0431	3763
0430	3761
0429	3761
0428	3759
0427	3758
.	.
.	.
.	.
0417	3743

(15 new observations)

0416	3743
0415	3743
0414	3742
0413	3742
.	.
.	.
.	.
0403	3737

(14 observations reported in previous bulletin and repeated in this bulletin)

Tsunameters (DART buoys)

DART provides internally stored high frequency data, triggered event data, and lower frequency data for system monitoring. Pacific Marine Environmental Laboratory (PMEL) engineers provide system enhancements through continued research and development efforts.

High frequency data consists of temperature and pressure averaged over 15-second intervals for the entire bottom package deployment period. Observations are stored on a flash card in the BPR until the bottom package is retrieved and the data recovered by NDBC. These data are retrospective and in addition to data transmitted in real time. In addition to internally recorded 15-second data, DART systems report a combination of 15-second data and 1-minute averages when triggered to do so by the detection of an event. These data provide the tsunami community with deep ocean tsunami observations essential for evaluating the potential risk to coastal communities. In addition, each DART system delivers spot pressure observations at 15-minute intervals in near-real-time for system monitoring.

Near-real-time bidirectional communication allows access to internally set system parameters and allows centers to manually trigger event-reporting mode. Additionally, bidirectional communication can be used to retrieve a 1-hour block of internally recorded pressure and temperature frequency counts from the flash storage card. A limited number of these after-the-fact requests are possible, due to battery life considerations. In order to maintain this capability for the deployment life of a given system, the tsunami warning centers must coordinate this activity among interested parties.

Interrogation Protocol

The tsunami warning centers coordinate DART trigger activation during events. Normally, if triggers are not activated by the earthquake or tsunami, a center can initiate an interrogative data retrieval mode, or set the BPR in Event Mode. However, the Iridium receivers on board the surface buoys have a limited amount of receive time. Upon receipt of the command to retrieve high-frequency data, the BPR transmits 1 hour of 15-second pressure and temperature data.

The tsunami warning centers perform after-the-fact interrogation of internally recorded 15-second data. Specific requests by interested agencies should be made no earlier than a day or two following an event, as tsunami warning center personnel will be focused on operations. Tsunami warning centers will advise appropriate agencies when data have been downloaded unrelated to specific requests.

Real-Time Transmission of Data—Iridium Transmissions and Time Series Data Formats

The real-time transmission of messages varies depending on the operating mode of the BPR, as described above. Transmission of real-time water level heights occurs when the Tsunami Detection Algorithm triggers a suspected event, when the buoy is interrogated by the tsunami warning centers, or at pre-scheduled intervals. The BPR transmits the messages to the surface buoy via underwater acoustics systems. In addition to the examples given below, see a slightly different presentation of current codes in the Description of Real Time DART System Messages, Revision 3.01 (2 August 2007), by Marie C. Elbe and Scott E. Stalin (a NOAA/PMEL publication).

Every Iridium transmission begins with a platform header followed by the message formats as described in this document. The format of the header is:

3f 3f 3f ck ck DARTxxxP/S

3f 3f 3f = three bytes to start the transmission (always 3f hex)

ck ck = two byte checksum

DART = Indicates tsunami buoy platform ID follows

xxx = three ASCII digit platform ID

P/S = P indicates transmission from Primary side; S for Secondary side.

Standard Mode Hourly Reporting

Standard-mode hourly reporting consists of water level height data. The reports consist of four discrete 15-minute water column height values, in millimeters, via acoustic modem each hour, and via Iridium every 6 hours if height data are available. In addition, a GPS Position Fix is transmitted once per day, or hourly if height data is not available.

Height Data (Transmitted via acoustic modem every hour, via Iridium every 6 hours if height data available)
<cr>D$1*C/I d*   ***ate time batv1 batv2 batv3 ht1 ht2 ht3 ht4 tries * checksum***   **<cr>D$1*C/I date time batv1 batv2 batv3 ht1 ht2 ht3 ht4 tries * checksum***   **<cr>D$1*C/I date time batv1 batv2 batv3 ht1 ht2 ht3 ht4 tries * checksum***   **<cr>D$1*C/I date time batv1 batv2 batv3 ht1 ht2 ht3 ht4 tries * checksum***   **<cr>D$1*C/I date time batv1 batv2 batv3 ht1 ht2 ht3 ht4 tries * checksum***   **<cr>D$1*C/I date time batv1 batv2 batv3 ht1 ht2 ht3 ht4 tries * checksum***   <cr> = 0x0D   D$1 = message id   *C/I* = message status, C = corrupted, I = intact   d*ate* = month day year   t*ime* = hour minute second   *batv1* = BPR battery voltage in 10ths of a volt, or error code   *batv2* = acoustic modem DSP battery in 10ths volts   *batv3* = acoustic modem battery in volts   *ht1 … ht4* = water column height in millimeters   *tries* = number of tries to deliver BPR data

* = = checksum delimiter checksum = exclusive OR of all characters preceding "*", 1-byte hexadecimal **Example:** D$1I 08/17/2006 12:15:00 1654147 5311813 5311758 5311703 5311652 1* 35 D$1I 08/17/2006 13:15:00 1654147 5311604 5311559 5311516 5311480 1* 34 D$1I 08/17/2006 14:15:00 1654147 5311445 5311414 5311389 5311369 1* 3C D$1I 08/17/2006 15:15:00 1654147 5311352 5311342 5311336 5311336 1* 36 D$1I 08/17/2006 16:15:00 1654147 5311341 5311353 5311366 5311385 1* 3A D$1I 08/17/2006 17:15:00 1654147 5311407 5311433 5311466 5311499 1* 32
GPS Position Fix (Transmitted once per day or hourly if height data not available)
D$0 N/S lat_deg E/W long_deg * checksum D$0 = message id date = month day year time = hour minute second lat_deg = latitude of buoy, DDMM.MMMM N/S = North or South long_deg = longitude of buoy, DDMM.MMMM E/W = East or West * = checksum delimiter checksum = exclusive OR of all characters preceding "*", 1-byte hexadecimal **Example:** D$0 08/17/2006 13:05:05 4857.0556 N 17816.8330 E* 5D

Figure 4-11. Examples of Standard-Mode Hourly Reports

Tsunami Event Mode Reporting

Examples of tsunami event-mode reports are shown in Figure 4-12. They consist of the following types:

First Event Mode Message (Message #0). Reports the water column height that triggered the event mode (in millimeters), along with three height deviations (15-second height values 0.75 minutes prior to the event trigger).

Second Event Mode Message (Message #1). Reports 15-second height values -0.75 to 3 minutes after event trigger.

Subsequent Event Mode Messages (Messages #2-14). Reports 15 1-minute average height values from the detection of the event until event mode has ceased.

First Event Mode Message (Message #0)

D$2 C/I msg# tt time ts begin height dev1 dev2 dev3 tries * checksum
D$2 = message id
C/I = message status, C = corrupted, I = intact
msg# = message number (0 for the first message)
time = time tsunami detected
begin = first data point time stamp
height = first data point water column height in millimeters
dev1...dev3 = deviation from height in millimeters, 2-byte hexadecimal
tries = number of tries to deliver BPR data
* = checksum delimiter
checksum = exclusive OR of all characters preceding "*", 1-byte hexadecimal
 	
Example:
`D$2I 00 tt 22:53:15 ts 22:52:30 3259892`
`00000044000001* 28`

Subsequent Event Mode Messages (Message #1 - #14(typically))

D$2 C/I msg# tt time ts begin height dev1 dev2 dev3......dev15 tries * checksum
D$2 = message id
C/I = message status, C = corrupted, I = intact
msg# = message number
time = time tsunami detected
begin = first data point time stamp
height = first data point water column height in millimeters
dev1...dev15 = deviation from height in millimeters, 2-byte hexadecimal
tries = number of tries to deliver BPR data
* = checksum delimiter
checksum = exclusive OR of all characters preceding "*", 1-byte hexadecimal
 	
Example:
`D$2I 01 tt 22:53:15 ts 22:52:30 3259892`
`000000440000ffffffffffffffffffffffffffffffffffffefffefffefffe01* 29`
`D$2I 02 tt 22:53:15 ts 22:44:00 3259897`
`fffffffffffefffdfffcfffcfffb000cfffafffafff9fff9fff8fff8fff701* 2C`
`D$2I 03 tt 22:53:15 ts 22:52:00 3259909`
`ffeeffeeffedffedffecffecffebffeaffeaffeaffeaffe9ffe8ffe8ffe701* 22`

Figure 4-12. Examples of Event-Mode Reports

Extended Mode Hourly Reporting

Extended reporting mode consists of 120 1-minute average values, transmitted via Iridium each hour for additional data redundancy. Extended reporting mode transmits data from 1 hour prior to the next top of the hour until the Tsunami Detection

Algorithm is in non-triggered status. Figure 4-13 provides an example of an extended-mode hourly report.

120, 1-minute averages transmitted via Iridium each hour

D$3 C/I tt ts height dev1 dev2 dev3.........dev119 tries * checksum

D$3 = message id
C/I = message status, C = corrupted, I = intact
tt = time tsunami detected
ts = first data point time stamp
height = water column height in millimeters
dev1...dev119 = deviation from height in millimeters, 2-byte hexadecimal
tries = number of tries to deliver BPR data
* = checksum delimiter
checksum = exclusive OR of all characters preceding "*", 1-byte hexadecimal

Example:

```
D$3Itt 22:53:15 ts 23:00:00 3259888
ffffffffffffffffffefffdfffdfffcfffcfffcfffbfffbfffafff9
fff9fff8fff8fff7
fff7fff6fff6fff5fff4fff4fff3fff2fff2fff1fff1fff0ffefffef
ffeeffeeffedffec
```

Figure 4-13. Extended-Mode Hourly Report Example

High-Resolution On-Demand Data Format

The DART High-Resolution On-Demand Data Format consists of 1-hour of high-resolution 15-second data, sent via Iridium on demand by the warning centers. This data is in ASCII-Hexadecimal Data Format. An example is shown in Figure 4-14.

(1 hour's worth transmitted via Iridium)

D$5C/Icafedata…
D$6C/Idata…
D$7C/Idata…
D$8C/Idata…

D$5-8 = message id
I = 2-byte hexadecimal representing the beginning of the data
C/I = message status, C = corrupted, I = intact
To decipher:

1) Remove the message IDs and status (i.e. D$5I, D$6I, D$7I, and D$8I)
2) Remaining data block is decoded as Flash Card data (above)

Example:

```
D$5Icafe4843040a1406110000a707000180b6073fde847<snip…>
D$6I01c388ab014f903a01aa88ab0103903a019388ab00b<snip…>
D$7I003f88ab016d903a006388ab012a903a008888ab00e<snip…>
D$8I011f88ab02bb903a017188ab027b903a01c388ab023<snip…>
```

Figure 4-14. Example of DART High-Resolution On-Demand Data Format

DART Real-time Data Formats - Reformatting Iridium Messages

NDBC reformats the received Iridium messages into SXXX46 messages for distribution via the National Weather Service Telecommunications Gateway.

Raw Standard Mode Message from the Buoy:

D$1I 08/22/2006 18:15:00 1474142 4709825 4709819 4709819 4709824 1* 35
D$1I 08/22/2006 19:15:00 1474142 4709831 4709842 4709862 4709883 1* 07
D$1I 08/22/2006 20:15:00 1474142 4709906 4709933 4709962 4709995 1* 3B
D$1I 08/22/2006 21:15:00 1474142 4710033 4710072 4710115 4710155 1* 7F
D$1I 08/22/2006 22:15:00 1474142 4710198 4710244 4710282 4710322 1* 30
D$1I 08/22/2006 23:15:00 1474142 4710363 4710398 4710431 4710457 1* 01

NDBC applies bulletin header (SXXX46 KWBC) and Date-Time Group (230012 – 23rd day of the month at 0012 UTC). NDBC then applies GOES1 header line (DDDDDDD0 235001256) and *end-message line* (00-0NN 00E) to keep the DART II data message compatible with DART I, so that decoders can process the messages.

```
SXXX46 KWBC 230012
DDDDDDD0 235001256
D$1I 08/22/2006 18:15:00 1474142 4709825 4709819 4709819 4709824 1* 35
D$1I 08/22/2006 19:15:00 1474142 4709831 4709842 4709862 4709883 1* 07
D$1I 08/22/2006 20:15:00 1474142 4709906 4709933 4709962 4709995 1* 3B
D$1I 08/22/2006 21:15:00 1474142 4710033 4710072 4710115 4710155 1* 7F
D$1I 08/22/2006 22:15:00 1474142 4710198 4710244 4710282 4710322 1* 30
D$1I 08/22/2006 23:15:00 1474142 4710363 4710398 4710431 4710457 1* 01
00-0NN 00E
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Important Points to Remember about Data Formats

- Tide gage data for tsunami monitoring should be transmitted at 1-minute (or better) intervals, with averaged data values transmitted at least every 15 minutes.
- Data are transmitted over a number of different satellites to regional telecommunications hubs of the WMO.
- Two primary WMO data formats are: Binary Universal Form for the Representation of meteorological data (BUFR), and Character form for the Representation and EXchange of data (CREX).
- DART provides internally stored high-frequency data for temperature and pressure averaged over 15-second intervals.

Chapter 5

Tsunami Detection

A tsunami warning center must be able to process and analyze seismic and sea level data to detect the occurrence of a tsunami and forecast its impact (Figure 5-1). National Tsunami Warning Centers (NTWC) and Regional Tsunami Watch Providers (RTWP) require a variety of hardware, software, computer applications and programs, and communication capabilities to support and maintain tsunami detection and prediction capacity. Maintenance programs and backup capacity are also needed for each center. This chapter should be read by persons who need to understand the types of hardware and software that are necessary for a warning center to function, and the importance of comprehensive maintenance programs and backup plans.

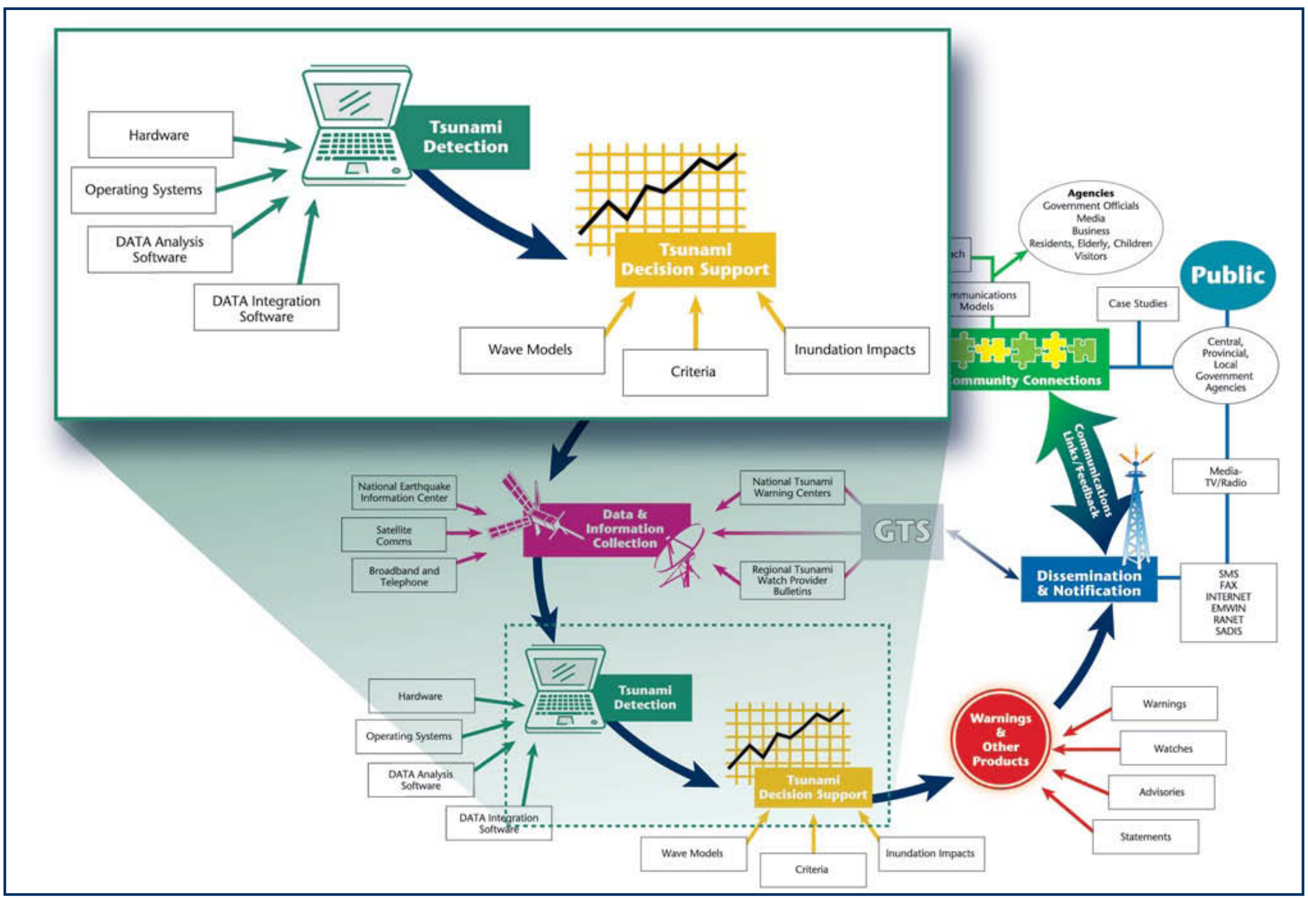

Figure 5-1. Components of a Tsunami Warning Center's Tsunami Detection and Prediction Requirements

How Does Tsunami Detection Fit into an End-to-End Tsunami Warning System?

A tsunami warning center functions on a day-to-day basis in a manner similar to a seismological observatory. The center should strive to do two things as fast as possible. First, the center must locate any moderate sized or larger earthquake in its area of responsibility (AOR) and assess its magnitude. Once that is accomplished, the center can begin to assess any potential tsunami threat to the regions in its AOR. If the earthquake poses a tsunami hazard, then the watch standers look for evidence of tsunami activity using an extensive network of tide gages, and ideally, tsunameters, at the center's disposal. The capacity to detect a tsunami signal and predict its impact requires both scientific expertise and on-the-job experience in order to make quick decisions and issue products in a short period of time, especially for local tsunamis (Figure 5-2). For this reason, a tsunami warning system cannot be fully automated.

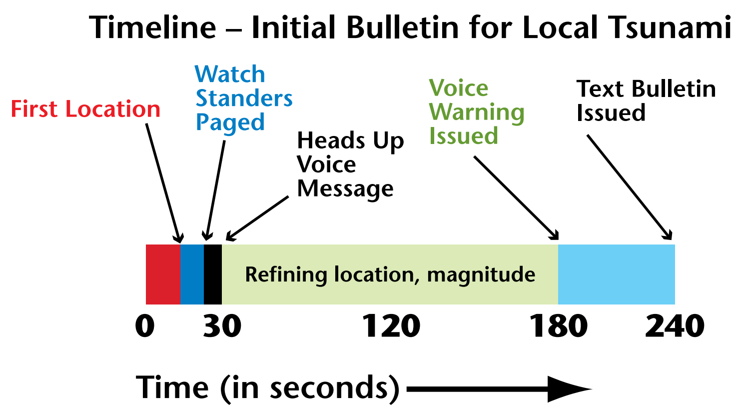

Figure 5-2. Timeline for Issuance of a Tsunami Bulletin for a Local Tsunami (in Seconds)
(Adapted from the Pacific Tsunami Warning Center Operating Plan)

Compared to local tsunami events, more time is available for issuing bulletins for teleseismic (originate more than 1000 kilometers away) events, as shown in Figure 5-3 (minutes instead of seconds). Both timelines illustrate, however, the critical need for the center to have reliable, redundant communications channels and effective computer applications for collecting, processing, and displaying data, and creating and disseminating voice and text bulletins. To meet these requirements a center needs hardware (networks, workstations) and computer programs (operating systems, applications).

Analyzing and displaying earth data for watch standers is the core of the hazard detection and forecast component of an end-to-end tsunami warning system. The rapid detection and characterization of tsunami-generating earthquakes by computer applications programs provides the first indication of a potential tsunami in an

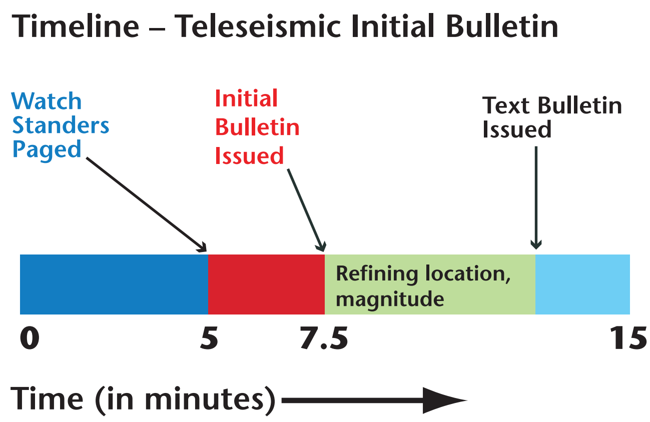

Figure 5-3. Timeline for Bulletin Issuance for a Teletsunami Event (in Minutes)

end-to-end tsunami warning system. Initial seismic-based warnings based on data from networks of seismic gages are subsequently refined by the detection of tsunami-generated changes in sea level, measured by tide gages and buoys and analyzed by applications programs. The refinement of initial seismic-based warnings with data on sea level changes can greatly increase the credibility of the warnings by decreasing false alarms.

Critical seismic and sea level data must be received and processed rapidly at tsunami warning centers to be of any use in the warning process. Thus, data collection communications systems are crucial to the success of the warning system.

What Is in this Chapter?

This chapter contains sections that discuss the following topics:

- **Information technology (IT) networks** required by centers. This includes Wide Area Networks (WAN) for center connection to far-flung data gathering networks, and Local Area Networks (LAN) for analyzing and integrating data into display systems and computer models.
- **Operating systems and hardware** (workstations) that are available for use at NTWCs and RTWPs.
- **Applications programs** needed to collect, analyze, integrate, and display data at centers.
- **Maintenance program requirements** for NTWCs and RTWPs
- **Redundancy programs** and their importance.

What Are the Most Important Points to Remember about Tsunami Detection Requirements for NTWCs and RTWPs?

- Tsunami warning centers require a variety of hardware, software, computer applications programs, and communications capabilities to process and analyze seismic and sea level data and detect the occurrence of a tsunami.
- Computer programs that analyze and display earth data for watch standers are the core of the hazard detection and forecast component of an end-to-end tsunami warning system.
- Critical seismic and sea level data must be received and processed rapidly at tsunami warning centers to be of any use in the warning process.
- The capacity to detect a tsunami signal and predict its impact requires both scientific expertise and on-the-job experience in order to make quick decisions and issue products in a short period of time.

Information Technology Requirements

An NTWC or RTWP requires computer power to effectively collect, process, monitor, and display seismic and sea level data and produce and disseminate products. This generally means that a tsunami warning center requires one or more connections to distant networks, notably the internet. This effectively makes the center part of one or more WANs. Much of the information on WANs and LANs comes from the *Wikipedia article* **http://en.wikipedia.org/wiki/Local_area_network** for LANs and **http://en.wikipedia.org/wiki/Wide_area_network** for WANs and is licensed under the *GNU Free Documentation License*.

Wide Area Networks (WAN)

A **WAN** is a computer network covering a broad geographical area, in contrast to a local area network (LAN), which is usually limited to a room, building, or campus. The largest and best-known example of a WAN is the internet.

WANs are used to connect LANs together so that users and computers in one location can communicate with users and computers in other locations. Many WANs are built for one particular organization and are private. Others, built by Internet service providers, provide connections from an organization's LAN to the internet. WANs are most often built using leased lines. At each end of the leased line, a router connects to the LAN on one side and a hub within the WAN on the other. Leased lines can be very expensive. Instead of using leased lines, WANs can also be built using less costly circuit switching or packet switching methods. Network protocols including Transmission Control Protocol/Internet Protocol (TCP/IP) deliver transport and addressing functions. Protocols including Packet over SONET/SDH, MPLS, ATM and Frame relay are often used by service providers to deliver the links that are used in WANs.

A WAN generally requires the crossing of public right-of-ways, and relies at least in part on circuits provided by a common carrier. Typically, a WAN consists of a number of interconnected switching nodes. A transmission from any one device is routed through these internal nodes to the specified destination device. These nodes (including the boundary nodes) are not concerned with the contents of data; rather, their purpose is to provide a switching facility that will move the data from node to node until they reach their destination. Several different options are available for WAN connectivity, as shown in Table 5-1.

Table 5-1. Various Wide-Area Network Connectivity Options

Options	Description	Advantages	Dis-advantages	Bandwidth Range	Sample Protocols Used
Leased line	Point-to-point connection between two computers	Most secure	Expensive		Point to Point Protocol, High Level Data Link Control, Synchronous Data Link Control
Circuit switching	A dedicated circuit path is created between end points. Best example is a dialup connection.		Call Setup	28 Kb/s–144 Kb/s	Point to Point Protocol, Integrated Services Digital Network
Packet switching	Devices transport packets via a shared single point-to-point or point-to-multipoint link across a carrier inter-network. Variable-length packets are transmitted over Permanent Virtual Circuits or Switched Virtual Circuits.				X.25 Frame-Relay
Cell relay	Similar to packet switching, but uses fixed-length cells instead of variable-length packets. Data is divided into fixed-length cells and then transported across virtual circuits.	Best for simultaneous use of voice and data	Overhead can be considerable		Asynchronous Transfer Mode

Transmission rate usually ranges from 1200 bits per second to 6 megabits per second. Typical communication links used in WANs are telephone lines, microwave links, and satellite channels. Figure 5-4 shows is an example of a tsunami warning center's WAN setup, depicting the West Coast/Alaska Tsunami Warning Center's (WC/ATWC) connections to several WANs.

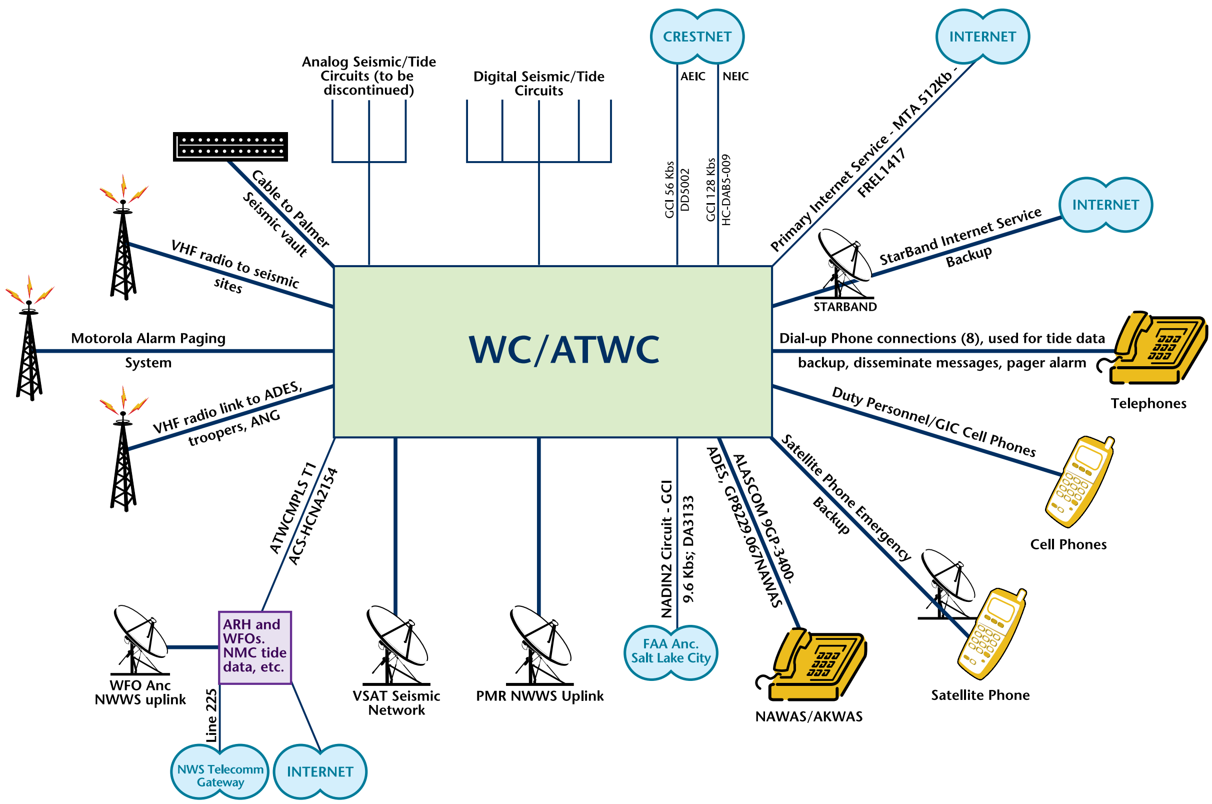

Figure 5-4. WC/ATWC Connections to WANs

Local Area Network (LAN)

NTWCs and RTWPs also require communication amongst several data monitoring, processing, and display computers via a **LAN**, a computer network covering a local area such as a home, office, or group of buildings. Current LANs are most likely to be based on switched IEEE 802.3 Ethernet running at 10, 100 or 1,000 megabits per second or on Wi-Fi technology.

The defining characteristics of a LAN in contrast to a WAN are their much higher data rates and smaller geographic range, and that they do not require leased telecommunication lines. Figure 5-5 shows an example of an idealized LAN. Note that the LAN can include devices other than just personal computers (PC) or workstations, and it should have a firewall if connected to a public WAN like the internet.

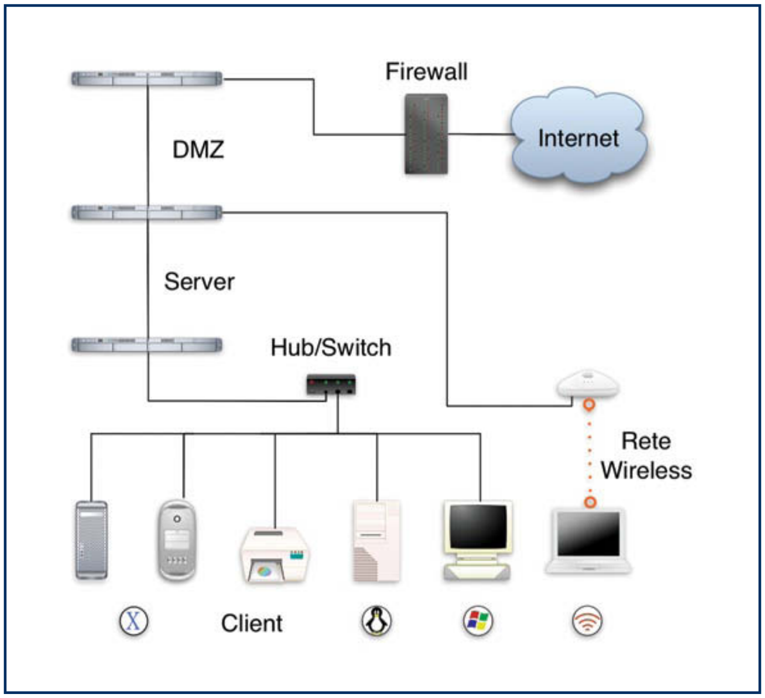

Figure 5-5. Idealized LAN

Physical Components of LANs

The physical properties of a LAN include network access interface units (or interfaces) that connect the personal computer to the network. These units are actually interface cards installed on computer motherboards. Their job is to provide a connection, monitor availability of access to the LAN, set or buffer the data transmission speed, ensure against transmission errors and collisions, and assemble data from the LAN into usable form for the computer.

The next part of a LAN is the wiring, which provides the physical connection from one computer to another, and to printers and file servers. The properties of the wiring determine transmission speeds. The first LANs were connected with coaxial cable, the same type used to deliver cable television. These facilities are relatively inexpensive and simple to attach. More importantly, they provided great bandwidth (the system's rate of data transfer), enabling transmission speeds initially up to 20 megabits per second.

Another type of wiring, developed in the 1980s, used ordinary twisted wire pair (commonly used for telephones). The primary advantages of twisted wire pair are that it is very cheap, simpler to splice than coaxial, and is already installed in many buildings; the downside is that its bandwidth is more limited.

A more recent development in LAN wiring is optical fiber cable. This type of wiring uses thin strands of glass to transmit pulses of light between terminals. It provides tremendous bandwidth, allowing very high transmission speeds, and because it is optical rather than electronic, it is impervious to electromagnetic interference. Still, splicing it can be difficult and requires a high degree of skill. The primary application of fiber is not between terminals, but between LAN buses (terminals) located on different floors. As a result, fiber-distributed data interface is used mainly in building risers. Within individual floors, LAN facilities remain coaxial or twisted wire pair.

When a physical connection cannot be made between two LANs, such as across a street or between buildings, microwave radio may be used. However, it is often difficult to secure frequencies for this medium. Another alternative in this application is light transceivers, which project a beam of light similar to fiber optic cable, but through the air rather than over cable. These systems do not have the frequency allocation or radiation problems associated with microwave, but they are susceptible to interference from fog and other natural obstructions.

LAN Topologies

LANs are designed in several different topologies, or physical patterns to depict connections between terminals. These connection patterns can range from straight lines to a ring. Each terminal on the LAN contends with other terminals for access to the system. When it has secured access to the system, a terminal broadcasts its message to all the terminals at once. The message is picked up by the one or group of terminal stations for which it is intended. The branching tree topology is an extension of the bus (shared communications line), providing a link between two or more buses.

A third topology, the star network, also works like a bus in terms of contention and broadcast. But in the star, stations are connected to a single, central node (individual computer) that administers access. Several of these nodes may be connected to one another. For example, a bus serving six stations may be connected to another bus serving 10 stations and a third bus connecting 12 stations. The star topology is most often used where the connecting facilities are coaxial or twisted wire pair.

The ring topology connects each station to its own node, and these nodes are connected in a circular fashion. Node 1 is connected to node 2, which is connected to node 3, and so on, and the final node is connected back to node 1. Messages sent over the LAN are regenerated by each node, but retained only by the addressees. Eventually, the message circulates back to the sending node, which removes it from the stream.

Transmission Methods Used by LANs

LANs function because their transmission capacity is greater than any single terminal on the system. As a result, each station terminal can be offered a certain amount of time on the LAN, like a timesharing arrangement. To economize on this small window of opportunity, stations organize their messages into compact packets that can be quickly distributed. When two messages are sent simultaneously, they could collide on the LAN, causing the system to be temporarily disrupted. Busier LANs usually utilize special software that virtually eliminates the problem of collisions by providing orderly, "no contention" access.

The transmission methods used on LANs are either baseband or broadband. The baseband medium uses a high-speed digital signal consisting of square wave DC voltage. While it is fast, it can accommodate only one message at a time. As a result, it is suitable for smaller networks where contention is low. It also is very simple to use, requiring no tuning or frequency discretion circuits. This transmission medium may be connected directly to the network access unit and is suitable for use over twisted wire pair facilities.

By contrast, the broadband medium tunes signals to special frequencies, much like cable television. Stations are instructed by signaling information to tune to a specific channel to receive information. The information within each channel on a broadband medium may also be digital, but they are separated from other messages by frequency. As a result, the medium generally requires higher capacity facilities, such as coaxial cable. Suited for busier LANs, broadband systems require the use of tuning devices in the network access unit that can filter out all but the single channel it needs.

The File Server

The administrative software of the LAN resides in a dedicated file server, or in a smaller, less busy LAN in a PC that acts as a file server. In addition to performing as a kind of traffic controller, the file server holds files for shared use in its hard drives, administers applications such as the operating system, and allocates functions.

When a single computer is used as both a workstation and a file server, response times may lag because its processors are forced to perform several duties at once. This system will store certain files on different computers on the LAN. As a result, if one machine is down, the entire system may be crippled. If the system were to crash due to lack of capacity, some data could be lost or corrupted.

The addition of a dedicated file server may be costly, but it provides several advantages over a distributed system. In addition to ensuring access even when some machines are down, its only duties are to hold files and provide access.

Other LAN Equipment

LANs are generally limited in size because of the physical properties of the network, including distance, impedance, and load. Some equipment, such as repeaters, can extend the range of a LAN. Repeaters have no processing ability, but simply regenerate signals that are weakened by impedance. Other types of LAN equipment with processing ability include gateways, which enable LANs operating dissimilar protocols to pass information by translating it into a simpler code, such as American Standard Code for Information Interchange (ASCII). A bridge works like a gateway, but instead of using an intermediate code, it translates one protocol directly into another. A router performs essentially the same function as a bridge, except that it administers communications over alternate paths. Gateways, bridges, and routers can act as repeaters, boosting signals over greater distances. They also enable separate LANs located in different buildings to communicate with each other.

The connection of two or more LANs over any distance is referred to as a WAN. WANs require the use of special software programs in the operating system to enable dial-up connections that may be performed by a telephone lines or radio waves. In some cases, separate LANs located in different cities—and even separate countries—may be linked over the public network.

LAN Difficulties

LANs are susceptible to many kinds of transmission errors. Electromagnetic interference from motors, power lines, and sources of static, as well as shorts from corrosion, can corrupt data. Software bugs and hardware failures can also introduce errors, as can irregularities in wiring and connections. LANs generally compensate for these errors by working off an uninterruptible power source, such as batteries, and using backup software to recall most recent activity and hold unsaved material. Some systems may be designed for redundancy, such as keeping two file servers and alternate wiring to route around failures.

Security problems can also be an issue with LANs. They can be difficult to manage and access because the data they use is often distributed between many different networked sources. In addition, many times this data is stored on several different workstations and servers. Most companies have specific LAN administrators who deal with these issues and are responsible for the use of LAN software. They also work to back up files and recover lost files.

Tip

Tsunami warning centers should make sure that firewalls and other security measures are in place to protect the integrity of their networks.

Important Points to Remember about IT Networks

- A WAN is a computer network covering a broad geographical area. They are used to connect local area networks (LANs) together, so that users and computers in one location can communicate with users and computers in other locations.
- A LAN is a computer network covering a local area, like a home, office, or group of buildings. LANs have much higher data rates, smaller geographic range, and do not require leased telecommunication lines like most WANs.
- A LAN should have a firewall if connected to a public WAN like the internet.

Operating System and Hardware Requirements for NTWCs and RTWPs

An NTWC or RTWP requires computers and computer operating systems to effectively collect, process, monitor, and display seismic and sea level data and produce and disseminate products. Currently there are two main choices for tsunami warning center hardware and operating systems, PCs with Windows or Mac OS X, and UNIX-based workstations. Each has its strengths and weaknesses. Each requires significant resources to maintain.

Operating Systems

Currently the most appropriate network operating systems for a NTWC or RTWP utilizing PCs come from Microsoft. Microsoft's PC operating system options include Windows NT Advanced Server and Windows for Workgroups, and more recently Windows XP.

UNIX computer workstation from vendors such as Sun Microsystems, Hewlett-Packard, Silicon Graphics, Intergraph, NeXT and Apollo have historically used TCP/IP based networking. Although this market segment is now much reduced, the technologies developed in this area continue to be influential on the internet and in both Linux and Apple/Macintosh operating system (Mac OS X) networking, and the TCP/IP protocol has now almost completely replaced Internetwork Packet Exchange (IPX), AppleTalk, NetBIOS Extended User Interface (NETBEUI) and other protocols used by the early PC LANs.

There are advantages and drawbacks to utilizing a Windows-based LAN. Similarly, there are pros and cons to implementing a UNIX/Linux-based LAN in an NTWC or RTWP environment. But in both instances there needs to be redundancy and attention to security to ensure data availability and processing at all times.

Workstations

There are two basic types of "workstations" that can be used to perform necessary operations in a tsunami warning center, i.e., collect data, run applications, and disseminate products. True high end workstations are usually coupled with some variant of the UNIX operating system. PCs, on the other hand, usually run a version of Windows or Apple/Macintosh operating system (Mac OS X), although higher end PCs can now use Linux as the operating system.

Following the performance trends of computers in general, today's average PC is more powerful than the top-of-the-line workstations of one generation before. As a result, the workstation market is becoming increasingly more specialized, since many complex operations that formerly required high-end systems can now be handled by general-purpose PCs. However, workstation hardware is optimized for high data throughput, large amounts of memory, multitasking, and multithreaded computing. In situations requiring considerable computing power, workstations remain usable while traditional PCs quickly become unresponsive.

PCs use components that are often at or near the cutting edge of technology. These days, workstations have changed greatly. Since many of the components are now the same as those used in the consumer market, the price differential between workstations and consumer PCs is correspondingly much narrower than it once was. For example, some low-end workstations use CISC (complex instruction set computer) based processors like the Intel Pentium 4 or AMD's Athlon 64 as their central processing units (CPU). Higher-end workstations still use more sophisticated CPUs such as Intel Itanium 2, AMD Opteron, IBM POWER, or Sun's UltraSPARC, and run a variant of UNIX, delivering a truly reliable workhorse for computing-intensive tasks. This makes deciding whether or not to purchase a true workstation very difficult for many organizations. Sometimes these workstation systems are still required, but many organizations opt for the less-expensive, if more fault-prone, PC-level hardware. Either route has advantages and disadvantages, but will, in general, still do the jobs an NTWC or RTWP requires.

Under optimal conditions, all NTWCs and RTWPs would use the same hardware, operating systems, and applications programs. That way development, maintenance, trouble shooting, and operations could be standardized and economies realized. The reality is the operating system and hardware chosen by a center is often dictated by institutional norms, staff skills and capabilities, and/or budget constraints.

Tip

NTWCs and RTWPs should all strive to use the same hardware, operating systems, and applications programs.

The number of workstations needed for center operations depends on the hardware and operating system, the number of applications, the extent of communications, and the approach taken to ensure the redundancy of critical functions.

The Pacific Tsunami Warning Center (PTWC) utilizes UNIX Reduced Instruction Set Computer (RISC) workstations, and the core of operations consists of 6 Sun Microsystems (SUN) computers. Two computers serve as loading docks. All seismic waveform data and most of the parametric seismic data pass through the loading docks. Four workstations are used to process the seismic and sea-level data, and run other software such as travel-time computations and messaging software. The PTWC operations are split into primary and redundant sides so as to avoid a single point of failure. PTWC's hardware configuration is shown in Figure 5-6.

WC/ATWC currently uses PCs running the latest Windows operating system. The center has two basic interconnected networks with redundant servers: "EarlyBird" for processing seismic events, and "tide" for sea level data. Figure 5-7 illustrates the basic topology for the WC/ATWC seismic network of ten Windows XP-based PCs that comprise the EarlyBird seismic processing system. Five PCs import and export data using standard Earthworm modules. Two of the remaining PCs are the main and backup

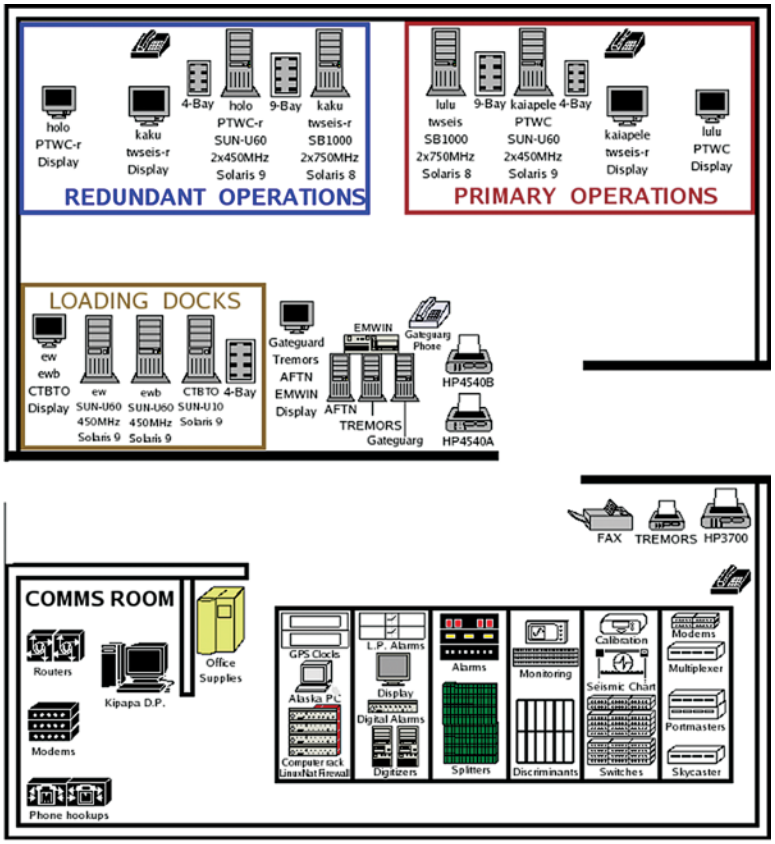

Figure 5-6. PTWC Hardware Configuration as of July 2006

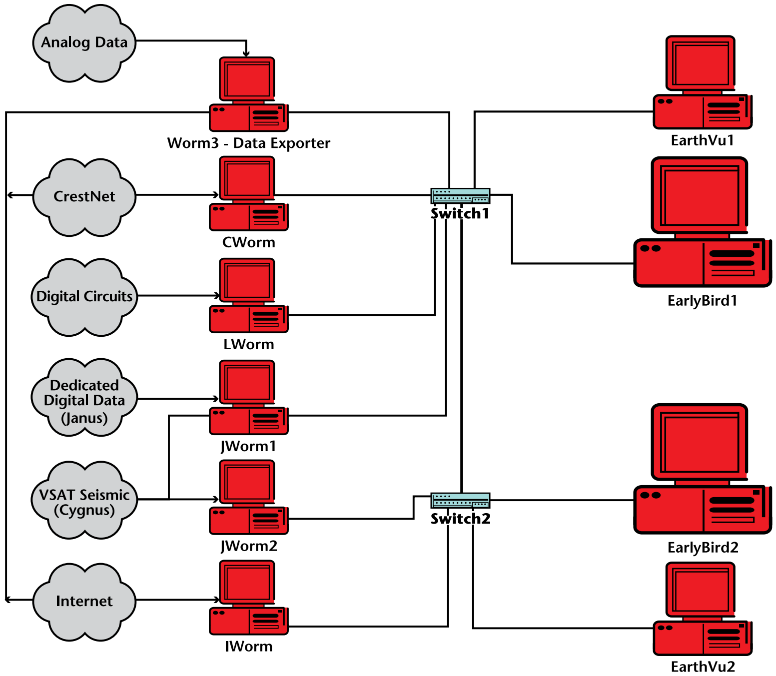

Figure 5-7. WC/ATWC Network for Processing Seismic Information (Note redundant servers)

seismic data processors. Both constantly monitor earthquake activity on approximately 200 seismic channels. Each seismic processor has an associated PC that runs the EarthVu Geographic Information System (GIS). The GIS PCs display earthquake locations processed on EarlyBird 1 and 2 and provide a graphical interface for database access. Many overlays of interest to the watch stander can be shown on the maps.

Important Points to Remember about Operating Systems and Hardware

- Windows NT Advanced Server, Windows for Workgroups, and Windows XP are currently the most appropriate network operating systems for a NTWC or RTWP utilizing personal computers.
- There are advantages and drawbacks to using a Windows-based LAN. Similarly, there are pros and cons to implementing a UNIX/Linux-based LAN in an NTWC or RTWP environment.
- For both Windows and UNIX operating systems, redundancy and attention to security are needed to ensure data availability and processing at all times.
- It would be optimal if all NTWCs and RTWPs used the same hardware, operating systems, and applications programs. That way development, maintenance, trouble shooting, and operations could be standardized and economies realized.

Computer Applications and Processing Requirements for NTWCs and RTWPs

Computer programs (applications) are critical to watch stander success at maintaining situational awareness. Applications can also provide processed information from earth data observations for input to decisions on what products the tsunami warning center needs to issue following an earthquake. The requirements for rapid characterization of earthquakes and determination of tsunami threat include processing speed, sufficient observation (both seismic and sea level) network density, and sufficiently short interrogation intervals.

Applications

Applications are groups of computer code that provide a tsunami warning center's watch stander with the tools needed to maintain situational awareness, collaborate, make decisions, prepare products, and disseminate these products in a timely fashion. In other words, applications help the watch stander do the required job, and most of these applications are critical to getting the job done. The center's operating system usually dictates what form the applications take, for example, Tool Command Language/Tool Kit (Tcl/Tk) for UNIX-based systems, and C++ for Windows-based systems. Experience at established NTWCs suggests that applications can be divided into several categories:

- Collect seismic and sea-level data in real time
- Process and database data in real time

- Automatically monitor data for exceeding criteria thresholds
- Compute parameters that must be derived from observed data
- Display data and information for the watch stander to maintain situational awareness
- Disseminate text and graphic products to customers and other tsunami watch centers

While each center may utilize applications developed elsewhere, or develop their own on site, following are some applications that have been found to be needed. Some of the programs are elaborated upon in greater detail in the PTWC and WC/ATWC operations manuals.

Collect Seismic and Sea-level Data in Real Time

Sea-level data are normally collected from international networks via the World Meteorological Organization's (WMO) Global Telecommunications System (GTS), the internet, or a country's WAN. Seismic data applications generally utilize internet communications and standard modules from the U.S. Geological Survey's (USGS) Earthworm program. These applications are:

- Digitize analog data (although now done mostly in the field)
- Receive data from the Incorporated Research Institutions for Seismology' International Deployment of Accelerometers (IRIS/IDA) network into Earthworm
- Gather hypocenter and trace data from other centers
- Start and restart all modules when necessary

Tip

USGS's Earthworm is a good program for processing seismic data.

Process and database data in real time

- Log hypocenters to disk and EarthVu
- Process surface wave data for moment magnitude (Mw) and mantle magnitude (Mm)
- Process data for moment tensor

Auto-monitor data for exceeding criteria thresholds

- Read, display, and analyze seismic data
- Archive data
- Call earthquake and tsunami databases
- Read, display, and analyze tide gage and Deep Ocean Assessment and Reporting of Tsunami (DART) buoy readings
- Read, display, and analyze run-up detection data

Compute parameters that are derived from observed data

- P-picking and magnitude determination algorithm
- Interactively locate earthquake hypocenter
- Trigger processing and compute Richter magnitude, surface magnitude (Ms), mantle magnitude (Mm), moment magnitude (Mw), p-wave moment magnitude (Mwp), etc.
- Compute and display tsunami travel times

Display data and information for situational awareness

- Display real-time, short period seismic data
- Display computed hypocenter parameters and adjust P data
- Display real-time, long period seismic data and process data for MS
- Display location and P data to screen
- Display earthquake summary to monitor
- Display epicenters on large, small, and regional-scale maps
- Overlay pertinent information such as historic tsunamis and earthquakes, volcanoes, elevation contours, roads, pipelines, and tsunami watch/warning areas
- Display large-scale maps
- Display small-scale maps
- Display regional maps and show last 7 days' epicenters
- Create and display tsunami travel time maps triggered by tsunami message generation

Disseminate text and graphic products to customers and other centers

- Send hypocenter and trace data to other centers
- Send alarm messages out from a serial port (for paging system)
- Create tsunami warning and other messages based on earthquake hypocenter parameters
- Create information maps in the background to post on website with tsunami messages
- Create maps in background and write to disk for transfer to website
- Automatically send emails to list of subscribers

Sea Level Data Processing Requirements

Several decades of experience at a number of national and regional centers have led to the determination of requirements for processing capabilities of sea level gage networks to adequately support a tsunami warning program. Guidelines were developed by the Global Sea Level Observing System (GLOSS) program based on science principles, and due to the compelling requirement to issue time-critical products to protect life and property. The following discussions are based on the very different needs of teletsunami and local tsunami warning programs. Each nation or jurisdiction will have to assess its needs in terms of early warning requirements.

The current specifications for the basin-wide (regional) in situ sea level component of tsunami warning systems requires data collection and transmission standards that include "sampling of 1 minute averages and a continuous 15 minute transmission cycle via WMO's GTS to the JMA (Japan Meteorological Agency), PTWC, and other appropriate warning centers/watch providers." These guidelines were developed in consultation with existing tsunami warning center scientists and technicians from PTWC and JMA, and with JMA and European Meteorological Satellite (EUMETSAT) geostationary satellite operators.

The Intergovernmental Oceanographic Commission (IOC) and GLOSS have been following these guidelines in establishing and/or enabling sea level stations as part of the core network of sea level stations for the Indian Ocean Tsunami Warning System (IOTWS). However, subsequent Intergovernmental Coordination Group (ICG) meetings in Europe and the Caribbean and Concept of Operations (CONOPS) Team meetings identified the need for subregional and national data collection and transmission standards. The ICGs' proposed standards include the following requirements:

Subregional sites (i.e., sites within 1 hour travel time of the tsunamigenic zones):

- A sampling of 15-second averages, and a continuous transmission cycle of 5 minutes.
- Immediate transmission via WMO's GTS to JMA, PTWC, and other appropriate warning centers. (However, it is noted that the European and Japan geostationary meteorological satellites cannot be used since they are limited to a 15-minute transmission cycle.)

National sites (i.e., sites within 100 km of tsunamigenic areas):

- A sampling of 15-second averages, and a continuous or 1-minute transmission cycle for sites within 100 km of the tsunamigenic zones.
- Immediate transmission via WMO's GTS to JMA, PTWC, and other appropriate warning centers and regional watch providers.

Standards should include data reports that cover a greater time period than the transmission frequency (to provide redundant data transmission).

Sea Level Data Processing Software

The software package TideTool provides end users with the ability to decode, display, and manipulate sea-level data broadcast over WMO's GTS. The software utilizes the Tcl/Tk software package, specifically the BLT extension. Tcl/Tk is an open source,

Tip

The **TideTool** program is a good application to use for processing sea level data.

platform-independent software package offering a powerful shell programming language and graphical toolkit.

The software application was developed by the PTWC to provide an operational tool for real-time, continuous tsunami monitoring in the Indian Ocean. Its primary users would be national meteorological and hydrological services, or other agencies with a downlink from the GTS or to a data file containing those data formatted in a similar manner. It has been tested under Linux, Windows 2000, and Windows XP environments in Indonesia and Malaysia. A manual is available providing information on its installation and use. Additional documentation on the program is available at: **http://ioc3.unesco.org/ptws/documents/TWCOpsSeminar/InformationTools/SLdecode_display_summary2.doc.pdf**

Seismic Data Network and Processing Requirements for Centers with a 5-Minute Response Need

To produce accurate moment magnitudes, NTWCs and RTWPs require reliable, broad-frequency, low-noise, high-dynamic-range, digital seismic data in real time. The timeliness of the data is crucial to issuing an initial bulletin within 5 minutes of an earthquake. This is especially important for centers with local tsunami sources.

Seismic Network Data Density and Timing Requirements

- Twelve evenly distributed seismometers within 900 km (2-minute P-wave travel time) of all coastal source areas.
- Assume 80 percent data availability (9 to 10 sites operating at a time)
- Up to 30 seconds of data latency
- Above conditions will provide 9 to 10 P-wave observations within 2.5 minutes after the earthquake occurrence (or O-time). With an adequate processing system, a correct hypocenter location can be produced at this time.
- 60 seconds further to record the P-wave will provide data with which to compute a moment magnitude.
- Moment magnitude and hypocenter available at 3.5 minutes after O-time.
- 30 seconds for experienced professional analyst review.
- 60 seconds to compose and send bulletin = 5 minutes total since O-time.

Seismic Data Processing Capabilities

- Process seismic data to produce P-wave arrival times and appropriate magnitude parameters.
- Trigger alarms based on strong ground shaking at a single station or pair of stations.

- Produce immediate hypocenter locations given sufficient number of P arrivals (5 to 7 arrivals).
- Support a graphical user interface which allows an analyst to review and alter data in real time and support relocation of events interactively.
- Compute moment magnitude within 60 seconds of P-arrival for a given station.
- Interact directly with product generation software to produce bulletins with minimal analyst effort.

Seismic Data Processing Software

The USGS Earthworm seismic data processing system should be used as the base processing architecture for interoperability with other centers, availability of source code, and easy sharing of modules and processes. The Earthworm Version 7.1 User's Guide can be found at: **http://folkworm.ceri.memphis.edu/ew-doc/**

Important Points to Remember about Applications and Processing Requirements

- Experience at established tsunami warning centers suggests that required applications can be divided into several categories:
  - Collect, process, and database seismic and sea level data in real-time
  - Automatically monitor data for exceeding criteria thresholds
  - Compute parameters that must be derived from observed data
  - Display data and information for the watch stander to maintain situational awareness
  - Disseminate text and graphic products to customers and other centers
- ICG and the CONOPS team identified the need for subregional and national data collection and transmission standards.
- The software package TideTool provides end users with the ability to decode, display, and manipulate sea level data broadcast over the WMO's GTS.
- The timeliness of seismic data is crucial to issuing an initial bulletin within 5 minutes of an earthquake. This is especially important for centers with local tsunami sources.
- The USGS Earthworm seismic data processing system should be used as the base processing architecture for interoperability with other centers.

Redundancy and Backup Capabilities

As discussed in the section on backup communications in Chapter 4, several types of backup systems should be used by tsunami warning centers. Alternate communication paths for data collection and also for product dissemination are needed by each

NTWC and RTWP. In the event of the failure of one of a center's primary communication links, information can be re-routed through a secondary connection. Similarly, centers should not rely on a single network or single gages, but utilize redundant networks. Then if their primary earth data network is unavailable, either through equipment failure or communications problems, the center can still function using alternate networks.

Center functionality backup by another center means that procedures are in place for an RTWP to assume the functions of one of its NTWCs if that national center has lost all communications links. Similarly, each RTWP must have agreements in place for another RTWP to take over in the event of a catastrophic event at the disabled regional center. Typically, a tsunami warning center should have connections to at least two other centers, and each RTWP should have agreements with at least one other regional provider to provide backup communications.

Full backup capability by another center theoretically provides complete redundancy of the original center's functions. There is, however, a high price for such a capability. The backup center must be trained in the other office's procedures and responsibilities, and additional communications channels are usually needed if the backup center is to collect all pertinent data and reach all of the original center's customers. And of course, the backup site staff must test backup procedures frequently.

Because of the high cost in both funds and resources, and the high probability of encountering problems due to the infrequency of use, full backup should be used only as a last resort. A center should strive to establish on-site redundancies in communications, hardware, and software so that it can continue to function in the event of a minor system outage.

Tip

Avoid invoking full backup by creating redundant

- communications,
- hardware, and
- software systems.

As illustrated in Figures 5-6 and 5-7, hardware redundancy is an important requirement for a center. This hardware redundancy goes hand in hand with the need for a center to redundantly obtain seismic and sea level data from several different networks, and via several different communications channels. Redundancy helps to ensure that the data for applications programs will be available when most needed—during an event. As an added bonus, the backup system can also be configured as a training tool.

Important Points to Remember about Redundancy and Backup Operations

- Full backup capability by another center theoretically provides complete redundancy of the original center's functions and should be established.

- Because of the high cost and high probability of encountering problems due to the infrequency of use, full backup should be avoided whenever possible, and each center should strive to establish on-site redundancies in communications, hardware, and software.

Maintenance Requirements

A well coordinated and supported maintenance program is critical to the success of a tsunami warning center. The breadth and depth of the maintenance program requirements will depend on the types of equipment deployed by that center, and the extent to which the center maintains the equipment in-house. For example, if an NTWC needs to deploy its own seismic or sea level gages, then the training and knowledge set of the center's electronics technicians will be different than those for a center that relies solely on international seismic or sea-level gage networks, or one whose national networks are maintained by another government agency or contractor. Similar conditions exist for computer and communications hardware and software.

There are strong arguments favoring use of an in-house maintenance program versus relying on other groups to maintain critical equipment. The converse is also true; there are good arguments, especially with regard to budgets and redundancy of effort, for relying on "experts" to maintain the center's critical equipment. One thing is clear, however: Tsunami warning centers require a good computer-based program for specifying, logging, and tracking critical equipment maintenance.

Whether a center operates with an in-house maintenance program, contracts out all maintenance, or has a program that is a mixture of the two approaches, it must track all maintenance activities in order to effectively manage the program. A center should establish an Engineering and Maintenance Reporting System (EMRS) similar to those used by many national meteorological agencies. The data collected by EMRS are vital to achieving maximum responsiveness to the center's mission. EMRS should be the primary field-level-maintenance data collection, analysis, and maintenance-workflow management tool used by the center. EMRS data allow the center to:

- Determine systems reliability and maintainability (R&M)
- Anticipate systems and facilities maintenance requirements
- Measure the effectiveness of systems and facilities upgrades and modifications
- Provide configuration data for specific systems and facilities
- Provide evidence of a system's operational status for use in legal matters
- Monitor engineering resources expended on designated systems and facilities
- Provide program performance data
- Manage maintenance workflow at the center

- Assess systems and facilities maintenance requirements, and assist in planning for future staffing levels

A center should establish what constitutes reportable maintenance events. These are events that should be tracked in order to maintain the center's programs. In general, there are five types of reportable maintenance events:

- **Corrective Maintenance.** The remedial action to correct failures and restore system/equipment or facility operation to prescribed capabilities and tolerances. This includes unplanned and nonperiodic repairs, as well as systems administration performed as a result of evidence indicating a failure has occurred or is imminent.
- **Equipment Management.** The accomplishment of system, equipment, or facilities activation, deactivation, relocation, and other similar activity.
- **Modification.** The authorized hardware and/or software configuration changes required to improve or extend system, equipment, or facility operations or life, or to satisfy new requirements.
- **Special Activity.** The authorized short-term or limited collection of data (special sampling), system or equipment installation, equipment relocation, equipment modification system test, and other similar activity for a specific purpose.
- **Preventive/Routine Maintenance.** Maintenance actions performed on system, equipment, or facilities to ensure continued operation within the prescribed capabilities or to minimize failure probability. Routine maintenance includes scheduled, planned, or periodic preventive maintenance actions.

An EMRS program is essential to maintaining critical equipment, setting staffing levels, and formulating budgets.

Software Maintenance

Most software maintenance will fall into a few general categories:

- Loading commercial software, including operating systems and applications.
- Keeping current commercial software (operating systems and applications) up to date. This includes loading interim patches.
- Assisting local programmers in developing, debugging, and maintaining staff authored computer programs, and distributing such programs to other centers.
- Adapting software applications from other NTWCs and RTWPs to fit center needs, and possibly improving the application for distribution to other centers.

Hardware Maintenance

Hardware maintenance can involve work on any of the following systems, depending on the center's maintenance program philosophy and goals (for example, whether maintenance is in-house or contracted). While this list is not exhaustive, it illustrates the wide range of skills needed by the electronics staff at a center:

- Seismometers
- Tide gages
- DART buoys
- PCs (operational and administrative)
- RISC workstations
- Servers
- Routers
- Cabling
- Firewalls
- Telephone systems, including answering machines
- Satellite uplinks and downlinks
- UHF and VHF links
- HAM radio transmitters

Electronics Technician Training

Electronics technicians must be proficient in at least three very distinct areas:

- Mechanical devices (e.g., tide gages)
- Electronic devices, including microelectronics
- Software

International training is available for both tide gage and seismometer installation and maintenance (see below). Training in software applications, including operating systems and programming, is also readily available and should be utilized whenever possible.

Training on other electronic devices like routers, satellite downlinks, and HAM radio transmitters is more difficult to obtain but should be budgeted for, as these types of systems are crucial to center operations.

Seismometers

In July 2003 the USA National Science Foundation released a report titled, "Review of the Global Seismographic Network." In this review it was stated that "the Review Committee is obliged and pleased to note that this community enterprise, the GSN, has been an extraordinary success. The establishment of a high-quality global digital network has been achieved, and it now serves as the primary source of data for seismologists worldwide."

The sensor of choice has been the STS-1, with the KS-54000I an acceptable alternate. Both sensors have yielded high quality data, but the STS-1 has a significantly broader band of response. The future availability of the STS-1, however, is in question for two reasons:

(a) The high quality and uniformity of the sensor depends on the personal skill of the designer/assembler, who has intimated that he no longer wishes to build the instrument.

(b) The original supply of fabrication material is nearly exhausted, and the uniformity depends in part on use of this common material.

As the GSN begins a decade of O&M, sensor failure will become more common. The question arises as to where replacement STS-1 instruments can be obtained, and ultimately whether a suitable replacement for the STS-1 can be developed. One possibility is to close poorly performing stations and recycle their instruments; another is to purchase spare instruments from other networks with surplus equipment. But in the long run, a replacement broadband sensor needs to be developed.

With the above caveats it becomes evident that the decision for a NTWC to field some of their own seismometers is not clear cut. In the short term the existing networks will likely meet TWS needs, except in oceanic regions where the network is currently sparse or non-existent, and underwater landslides are a significant threat. An example of this situation is the Hawaiian Islands, where the State of Hawaii and PTWC have installed additional seismometers. Longer term needs will depend largely on the future actions of those operating the international networks.

If a NTWC opts to augment existing networks with their own deployed and maintained seismometers there are numerous references to assist the Center in the endeavor. One such document is a USA USGS publication "Methods of Installing United States National Seismographic Network (USNSN) Stations—A Construction Manual, Open-File Report 02-144 2002." The USGS has learned that after many years of network operation some of the important design features of the US National Seismograph Network include:

- Use of off-the-shelf electronic equipment when possible;
- The ability to install a seismic station in diverse environments;
- A physically protective, dry, and thermally stable environment for the broadband sensors;
- An overall station design that is easy to maintain;
- Manageable installation costs.

Further guidance for NTWCs to deploy seismic stations is given by the IRIS GSN Design Goals Subcommittee Report—Global Seismic Network Design Goals Update August 26, 2002.

In addition to training material for seismic installations from the USA USGS and other governments, sensor manufactures offer model specific training. For example, Guralp Corporation offers maintenance training at **http://www.guralp.com/services/training/bsctrouble.htm**, where they break down maintenance into electronics and mechanics.

The Public Seismology Network website (**http://psn.quake.net**) has posted manuals for several popular types of seismograph equipment. These are:

- Teledyne/Geotech BB-13 Long Period Sensor Operator and Maintenance Manual
- Sprengnether MEQ800 Portable Seismic System Technical Manual
- Instructions for Construction of a Lehman Seismometer by Kelly Knight

Tide Gages

International tide gage networks are coordinated by UNESCO-IOC. Data and training are administered by several sources, notably the Permanent Service for Mean Sea Level (PSMSL) of the Proudman Oceanographic Laboratory (POL), UK, which is accessible at **http://www.pol.ac.uk/psmsl/**. The applicable tide gage materials are IOC Manuals and Guides No. 14: Volumes I–IV.

Volumes I–IV comprise the IOC Manual on Sea Level Measurement and Interpretation. Volume I (Basic Principles) was published in 1985 and is based on training courses held at the Proudman Oceanographic Laboratory (POL) on behalf of the PSMSL and IOC. It contains information on the scientific aspects of sea level change and on practical aspects of sea level measurement and data reduction. Volume II (Emerging Technologies) was published in 1994 and is complementary to the earlier volume, extending and updating the material on measurements.

In the late 1990s, it was realized that the contents of Volumes I–II were beginning to show their age and so Volume III was constructed and finally published in 2000. A much larger Volume IV followed in 2006. However, note that Volumes I–III are still useful, and still provide the basic sets of information for people intending to install and operate tide gauges.

Manuals I–IV are available in both paper and electronic forms. For paper versions, email **psmsl@pol.ac.uk**. Electronic versions are provided at **http://www.pol.ac.uk/psmsl/** as PDF files.

- *Volume I: Basic Procedures*
- *Volume II: Emerging Technologies*

- *Volume III: Reappraisals and Recommendations as of the year 2000*
- *Volume IV: An update to 2006*

Several updates to sections of the older manuals are also available e.g.:

- *List of tide gage manufacturers (updated from Vols. 1 and 2).*
- *Glossary of terms used in tidal measurements and analysis (updated from Vol. 1).*
- *Frequently used abbreviations and acronyms (updated from Vol. 1).*

GLOSS (or GLOSS-related) training courses have been held a rate of approximately one per year since 1983. These have been held in all continents and in all languages, with the majority of the first courses held at the Proudman Oceanographic Laboratory. For people unable to attend courses, most of the training materials employed in a typical course are available on the web at the PSMSL training page (**http://www.pol.ac.uk/psmsl/training/training.html**).

Another source of documentation on tide gage installation, maintenance, and use is from the website: **http://www.icsm.gov.au/tides/SP9/index.html** which provides access to the Australian Tides Manual Special Publication No. 9.

Important Points to Remember about Maintenance Programs for Tsunami Warning Systems

- The need for a well coordinated and supported maintenance program is critical to the success of NTWCs and RTWPs.
- Whether a center operates with an in-house maintenance program, contracts out all maintenance, or has a program that is a mixture of the two approaches, it must **track** all maintenance activities in order to effectively manage the program.
- A center should establish what constitutes reportable maintenance events. These are events that should be tracked in order to maintain the center's programs.
- There is international training available for both tide gage and seismometer installation and maintenance.
- Training on other electronic devices like routers, satellite downlinks, and HAM radio transmitters are more difficult to obtain, but should be budgeted for as these types of systems are crucial to center operations.

Chapter 6

Tsunami Warning Decision Support

Once an earthquake has been detected and its magnitude and location analyzed, tsunami warning centers use criteria and, where available, models to determine if an initial tsunami warning should be issued. Tsunami warning centers require additional capabilities to refine the forecast beyond the initial warning. This chapter focuses on the tsunami warning system decision support programs that are used in watch-stander decision making:

- **Criteria** for issuing warnings based upon science and historical events.
- **Situational awareness** software that helps watch-standers detect events in real time.
- **Computer models** of tsunami wave height based upon science, historical events, and earth observations.

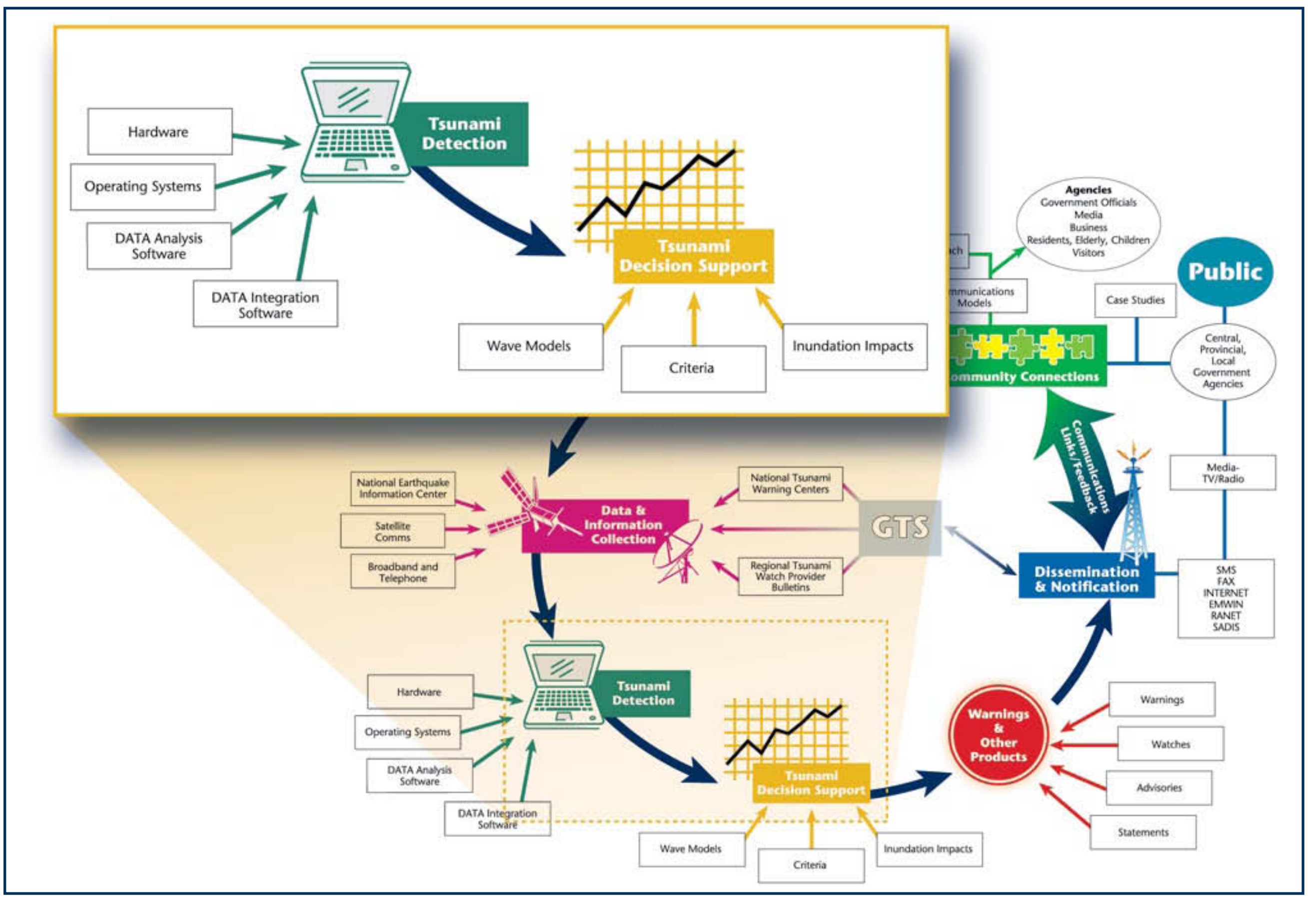

Figure 6-1. Where Decision Support Fits into the End-to-End Tsunami Warning System Chain

- **Assessment of impacts** of events based upon inundation models, preparedness, land use and mitigation programs, etc.
- **Training** for operational watch standers.
- **Research and development** to improve center operations and products.

The infrastructure required for decision support programs, including the hardware, operating systems, communications, and maintenance programs, are discussed in Chapter 5, Tsunami Detection. This chapter should be read by persons who need to understand the types of programs that support operational decision making, and how these programs are evolving.

How Does Tsunami Decision Support Fit into an End-to-End Tsunami Warning System?

As discussed in Chapter 5, National Tsunami Warning Centers (NTWC) and Regional Tsunami Watch Providers (RTWP) function on a day-to-day basis much as a seismological observatory does. A tsunami warning center should do two things as fast as possible: locate any moderate or larger sized earthquake, and assess its magnitude. Once that is accomplished, the center can begin to assess any potential tsunami threat to the regions in its area of responsibility (AOR).

The rapid detection and characterization of tsunami-generating earthquakes by computer applications programs provide the first indication of a potential tsunami in an end-to-end tsunami warning system. Initial seismic-based warnings are subsequently refined by the detection of tsunami-generated changes in sea level, measured by tide gages and buoys. Computer applications programs are used to analyze sea level data to generate forecasts of tsunami wave height and inundation for specific coastal areas. The refinement of initial seismic-based warnings by good computer models can greatly increase the credibility of the warnings by decreasing false alarms.

What Is in this Chapter?

This chapter contains sections that discuss the following topics:

- **Bulletin threshold criteria** used by some NTWCs and RTWPs
- Description of **watch stander situational awareness software** used at West Coast/Alaska Tsunami Warning Center (WC/ATWC)
- **Tsunami wave height models**
- **Computer inundation** models for assessing local impacts
- **Watch stander training requirements**
- **Research and development** to support operations and product improvement

What Are the Most Important Points to Remember about Tsunami Decision Support Requirements for NTWCs and RTWPs?

- The rapid detection of tsunami-generating earthquakes by computer applications programs provides the first indication of a potential tsunami.
- Situational awareness software is crucial to watch-stander efforts to respond as quickly as possible to seismic events.
- Computer applications programs are used to analyze sea level data to generate forecasts of tsunami wave height and inundation for specific coastal areas.
- Training programs and applied research help centers improve their performance.

Bulletin Threshold Criteria

Tsunami bulletins are initially issued solely on the basis of seismic data. Three key earthquake parameters that can be determined quickly from seismic waveform data for the evaluation of an earthquake's tsunamigenic potential are:

- **Location** - whether the earthquake is located under or very near the sea
- **Depth** - whether the earthquake is located close enough to the earth's surface to have caused a significant displacement of that surface
- **Magnitude** - the size of the earthquake

Bulletins are issued as soon as the earthquake's tsunami potential has been analyzed. The first messages are based on earthquake magnitude and location. The type of message issued generally depends on predetermined criteria or thresholds.

After the initial bulletin has been issued, a tsunami warning center must monitor recorded tsunami effects through tide gages and tsunameters (such as the Deep Ocean Assessment and Reporting of Tsunami [DART™] system) to confirm the existence or nonexistence of a tsunami and its degree of severity. In coordination with other NTWCs and RTWPs, the NTWC should issue a cancellation, extension, or final bulletin as appropriate.

Tsunami history and pre-event modeling are taken into account along with observed tsunami amplitudes when determining the extent of danger for the AOR. A center may refrain from issuing a warning or may issue the warning for only selected areas if tsunami history (and modeling, if available) indicates there is no danger, or danger only to selected areas.

Bulletin Thresholds

Bulletin thresholds may vary somewhat due to local circumstances. Tsunami warning centers should strive, however, to adhere as closely as possible to the generally accepted values recommended by the Intergovernmental Oceanographic Commission's Indian Ocean Tsunami Warning System (IOC/IOTWS – II, January 2006) and used by most, if not all, NTWCs and RTWPs. These are given in Table 6-1. Definitions used in the table are:

- **Earthquake Magnitude**: The moment magnitude, Mw (Table 3-3), is more accurate for large earthquakes than the more common Richter magnitude. It is recommended that the moment magnitude to use for initial bulletins be Mwp, based on the first arriving seismic P waves. Subsequent estimates of Mw may be made by methods based on later-arriving seismic waves.
- **Local Tsunami**: A local tsunami is one with destructive or life threatening effects usually limited to within 100 kilometers (km) of the epicenter.
- **Regional Tsunami**: A regional tsunami is one with destructive or life threatening effects usually limited to within 1000 km of the epicenter.
- **Ocean-wide Tsunami**: An ocean-wide tsunami is one with destructive or life threatening effects that can extend across an entire ocean basin.

Table 6-1. Product Thresholds Based on Earthquake Strength

Earthquake Depth	Earthquake Location	Earthquake Magnitude Mw or Mwp	Description of Tsunami Potential	Bulletin Type
< 100 km	Under or very near the sea	≥ 7.9	Potential for a destructive ocean-wide tsunami	Tsunami Watch /Warning
		7.6 to 7.8	Potential for a destructive regional tsunami	Tsunami Watch /Warning
		7.0 to 7.5	Potential for a destructive local tsunami	Tsunami Watch /Warning
		6.5 to 7.0 or inland	Very small potential for a destructive local tsunami	Tsunami Information Bulletin
	Inland	≥ 6.5	No tsunami potential	Tsunami Information Bulletin
≥ 100 km		≥ 6.5	No tsunami potential	Tsunami Information Bulletin

For events that could trigger a tsunami that poses danger across an ocean basin, the area within 3 hours tsunami travel-time of the epicenter will be placed in a tsunami warning status, with the area within a 3- to 6-hour travel-time zone placed in a watch status. For smaller events only expected to be dangerous locally, warnings will be fixed to a certain distance from the source with no watch, as the tsunami is not expected to be dangerous elsewhere.

Japanese Meteorological Agency Approach

Figure 6-2, from the JMA website, graphically illustrates the basic decision process, including criteria based upon initial earthquake magnitude, that most NTWCs and RTWPs use when an earthquake occurs.

Interim Tsunami Advisory Information Service.

The upgrade of the regional sea level network for tsunami monitoring will enable the Centres to issue Tsunami Warning messages in the future.

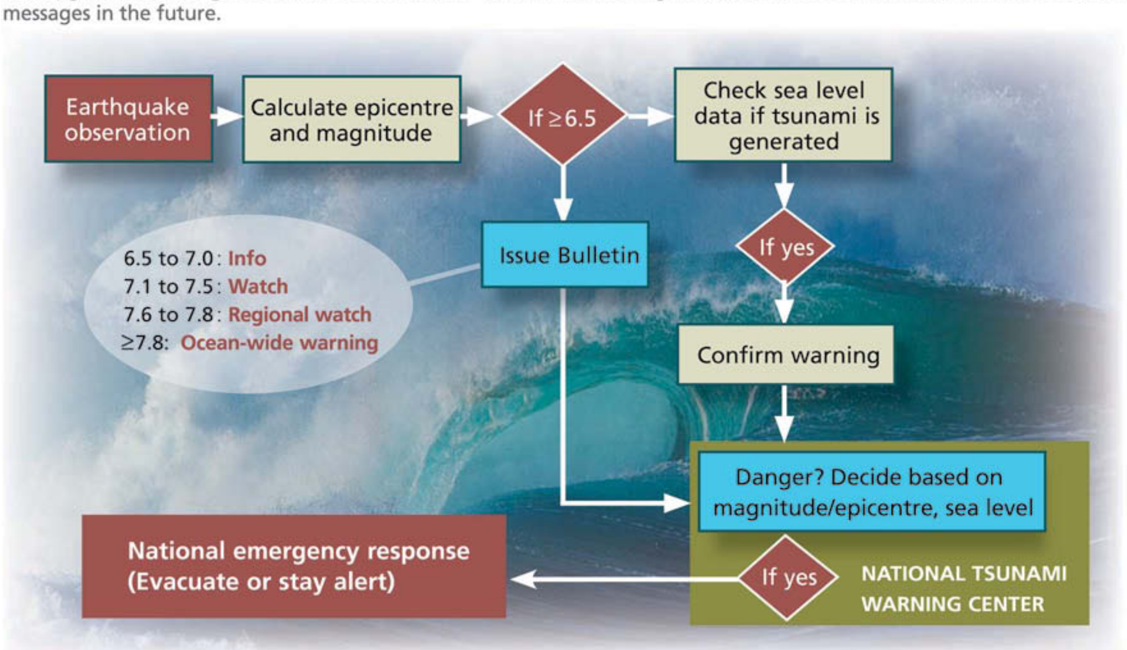

Figure 6-2. Basic Warning Center Response Procedures
(Source: JMA, http://www.jma.go.jp/en/tsunami/)

Thailand National Disaster Warning Center Approach

Based upon the Thailand NDWC's *Concept of Operations* (Draft Version 3.3, March 2006), prepared by the Pacific Disaster Center, Thailand has slightly different standard operating procedures for the tsunami warning decision. Once NDWC receives notification of seismic activity or of an earthquake of greater than Magnitude 7.0 Richter, from either domestic or international hazard information providers, the supervisor (duty officer) consults with the experts of the command center. The experts verify the information, use computer-based simulations to estimate the tsunami wave's arrival to coastal areas, and generate and analyze scenarios to assess the potential risk. Information from various geophysical sources is collected, compared, and analyzed to verify earthquake information, ensure redundancy, and understand the maximum level of risk (illustrated in Figure 6-3).

Magnitude (Richter)	Distance (Km) 0–24	25–48	49–112	113–200	201–400	401–720
3.0–3.9	Advisory	Advisory	Advisory	———	———	———
4.0–4.9	Warning Low Risk	Advisory	Advisory	Advisory	Advisory	———
5.0–5.9	Disaster	Warning High Risk	Advisory	Advisory	Advisory	Advisory
6.0–6.9	Disaster	Disaster	Warning High Risk	Warning Low Risk	Advisory	Advisory
7.0-7.9	Disaster	Disaster	Disaster	Disaster	Warning High Risk	Warning Low Risk
8.0–8.9	Disaster	Disaster	Disaster	Disaster	Disaster	Warning High Risk
> 8.9	Disaster	Disaster	Disaster	Disaster	Disaster	Disaster

Figure 6-3. Summary Table Showing "Levels of Risk" and the Distance of an Earthquake's Effective Radius from Coastal Areas of Thailand
(Source: NDWC)

Once an earthquake of Magnitude 7.0 or greater is confirmed, the NDWC immediately informs all relevant agencies. Command Output Officers are also informed to "stand by" and prepare to activate the warning towers. The NDWC immediately communicates with officers at the Similan Island to closely monitor sea level changes, which will indicate the presence of an approaching tsunami. Within 20 minutes of receiving the notification, NDWC compiles, analyzes, and assesses the probable impact, based on the hazard warning criteria shown in Figure 6-3.

In addition, NDWC has developed criteria to assess the possibility of a tsunami being generated based on the depth of the earthquake or its hypocenter (which is used to further refine the risk level), as shown in Figure 6-4.

Approach Used at a Center with Multiple Criteria

The thresholds listed in Table 6-1 cannot always be followed due to local circumstances. Figure 6-5 shows the thresholds used by the WC/ATWC for the west and east coasts of the United States, and the Caribbean Sea. These differences are substantial but necessary to meet unique circumstances in each of the areas served by this RTWP. Such differences place a large burden on operational watch standers as they must keep track of several different criteria during a single event. If there are multiple events occurring simultaneously, or nearly simultaneously, this complicates the use of criteria thresholds to issue a tsunami bulletin.

Magnitude	Depth of Hypocenter: less than 100 km	Depth of Hypocenter: more than 100 km
5.0–6.4	**Low possibility to generate Tsunami Advisory**	Low possibility to generate Tsunami **Advisory**
6.5–6.9	Possibility to generate Tsunami **Alert/Watching**	Low possibility to generate Tsunami **Advisory**
7.0–7.7	Possibility to generate Tsunami **Alert/Watching**	Possibility to generate Tsunami **Alert/Watching**
> 7.8	Very high possibility to generate Tsunami **Warning**	Possibility to generate Tsunami **Alert/Watching**

Figure 6-4. Likelihood of Tsunami Generation Considering the Hypocenter's Location
(Source: NDWC)

WC/ATWC-Pacific

Area / Mag	AK, BC, WA, OR, CA	Bering Sea Deep	Arctic O., and Bering Shallow	Not in AOR
4 – 5 – 6 – 6.4	TIS*** SEAK71 or SEUS71	TIS*** SEAK71	TIS*** SEAK71	
6.5 – 7	TIS WEPA43 and WEAK53	TIS WEPA43 and WEAK53	TIS WEPA43 and WEAK53 with appropriate Evaluation	TIS WEPA43 and WEAK53
7.1 – 7.5	Warning * 350Km WEPA41 and WEAK51	Warning * Pribilof/ Aleutian Is. WEPA41 and WEAK51		
7.6 – 7.8	Warning* 1000Km WEPA41/51			Advisory/ Watch/ Warning WEPA41 and WEAK51
7.9 – 10	**Warning 3W/3W WEPA41/ WEAK51**			

WC/ATWC-Atlantic

Mag	East Coast US & Canada	East Coast Inland <400 Mile	Gulf Mex Gulf St. L	Puerto Rico/ US VI	Not AOR Western Caribbean	Not AOR Eastern Caribbean	Not AOR Atlantic
4	TIS*** SEXX60	4	TIS SEXX60	TIS SEXX60			
5					TIS SEXX60	TIS SEXX60	
6	TIS WEXX22 and WEXX32	TIS WEXX22 and WEXX32	TIS WEXX22 and WEXX32	TIS WEXX22 and WEXX32	TIS WEXX22 and WEXX32	TIS WEXX22 and WEXX32 Warning * Puerto Rico/ US VI WEXX20/30	
6.7				Warning * Puerto Rico/ US VI WEXX20 and WEXX30			TIS WEXX22 and WEXX32
6.8 – 7.5	Warning * 350Km WEXX20 and WEXX30		Warning * Gulf only WEXX20 and WEXX30				
7.6 – 7.8	Warning* 1000Km WEXX20/30						
7.9 – 10	**Warning 3W/3W WEXX20/ WEXX30**				Warning * Puerto Rico/ US VI WEXX20/30		TIS/Warn-ing Spec. area WEXX22/32 and WEXX20/30

Notes: *TIS* *Tsunami Information Statement*
TIB *Tsunami Information Bulletin*

Figure 6-5. Bulletin Thresholds Used by the WC/ATWC

Important Points to Remember about Bulletin Thresholds Based Solely on Earthquake Information

- Bulletins are issued as soon as the earthquake's tsunami potential has been analyzed.
- Tsunami history and pre-event modeling are taken into account along with observed tsunami amplitudes in determining the extent of danger for the AOR.
- All tsunami warning centers should use the internationally agreed-upon suite of message products to avoid confusion, especially amongst the tourist population.
- Centers should strive to adhere as closely as possible to the generally accepted bulletin threshold values recommended by IOC/IOTWS.
- An RTWP may require different criteria for different portions of its AOR.

Watch Stander Situational Awareness Support

EarlyBird and EarthVu, two software packages developed at WC/ATWC, are excellent examples of an operational suite of tools that assist watch standers in maintaining situational awareness. Situational awareness is the capacity of the watch stander to detect seismic events in real time.

EarlyBird

WC/ATWC's EarlyBird seismic data processing system is used for both real-time and post-processing of seismic data. EarlyBird is a combination of standard USGS Earthworm modules, WC/ATWC-developed Earthworm modules, and stand-alone seismic processing software.

EarlyBird automatically locates and sizes, using Mb, Ml, Ms, Mw, and Mwp, (Table 3-3) worldwide, regional, and local earthquakes. Graphical interfaces for the Earthworm modules have been created to allow interactive additions and changes to automatically computed parameters during initial earthquake processing, or after the fact. Real-time data can be monitored and interacted with directly through Earthworm modules. Data logged to disk by the system can be analyzed immediately after logging through stand-alone analysis programs. The automatically computed seismic parameters are interfaced with the tsunami message generation software and the EarthVu GIS.

Seismic data arrives at the WC/ATWC by four basic paths: digital broadband data via leased circuits, digital broadband data transmitted via the CrestNet, digital broadband data transmitted over the internet, and digital data transmitted via a Very Small Aperture Terminal (VSAT) satellite ground station system. Data are exported to other centers using the CrestNet or internet.

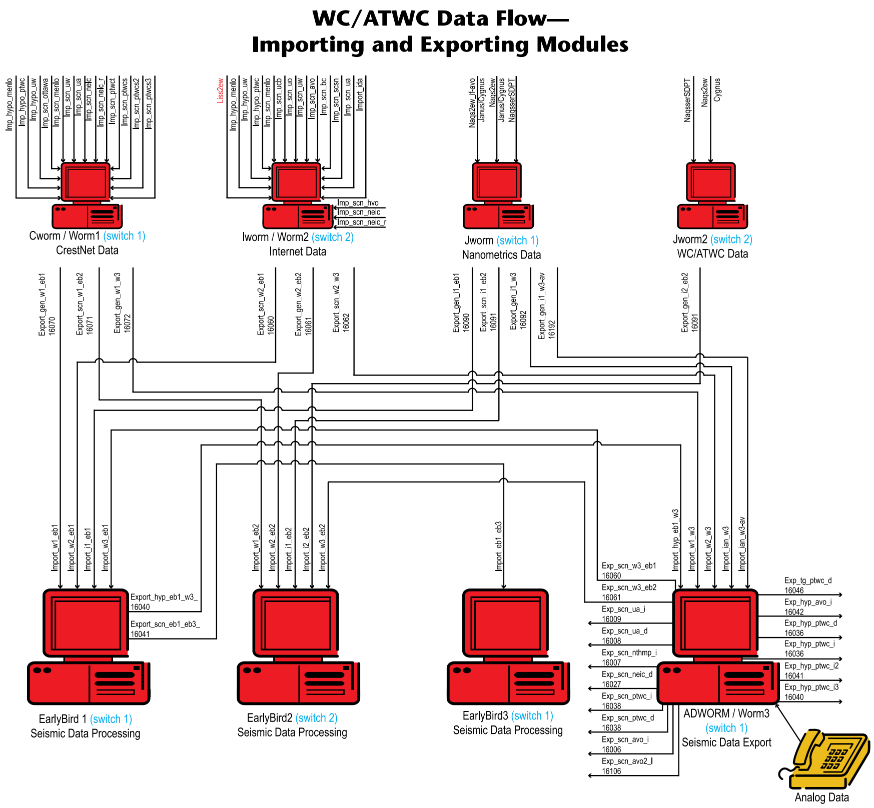

Figure 6-6. Connections Between Import/Export and Processing Systems at WC/ATWC

A separate PC is used to acquire data from each path and to export data and hypocenters to other centers. Connections between import/export and processing systems are shown in Figure 6-6. Switches, routers, PCs, and data paths are configured to eliminate any single points of failure.

A network consisting of eight Windows XP-based PCs comprises the EarlyBird seismic processing system. Five PCs, as described above, import and export data using standard Earthworm modules. Two of the remaining PCs are the main and backup seismic data processors. Both constantly monitor earthquake activity on approximately 250 seismic channels. The last PC is a training/development PC that mirrors the main EarlyBird system.

The data processing flow within EarlyBird 1 is shown in Figure 6-7. Earthworm rings are shared memory locations. The windows icons indicate modules that accommodate user interaction and review. Module Pick_wcatwc analyzes the signal to determine the onset of an earthquake. Once a pick has been made, the signal is further analyzed to determine Mb, Ml, and Mwp magnitude parameters. Alarms are triggered when parameters have been exceeded (location and size). When a large earthquake occurs (M>5), long period and broadband data are processed to refine the magnitude estimate. Each of the modules is described in greater detail below.

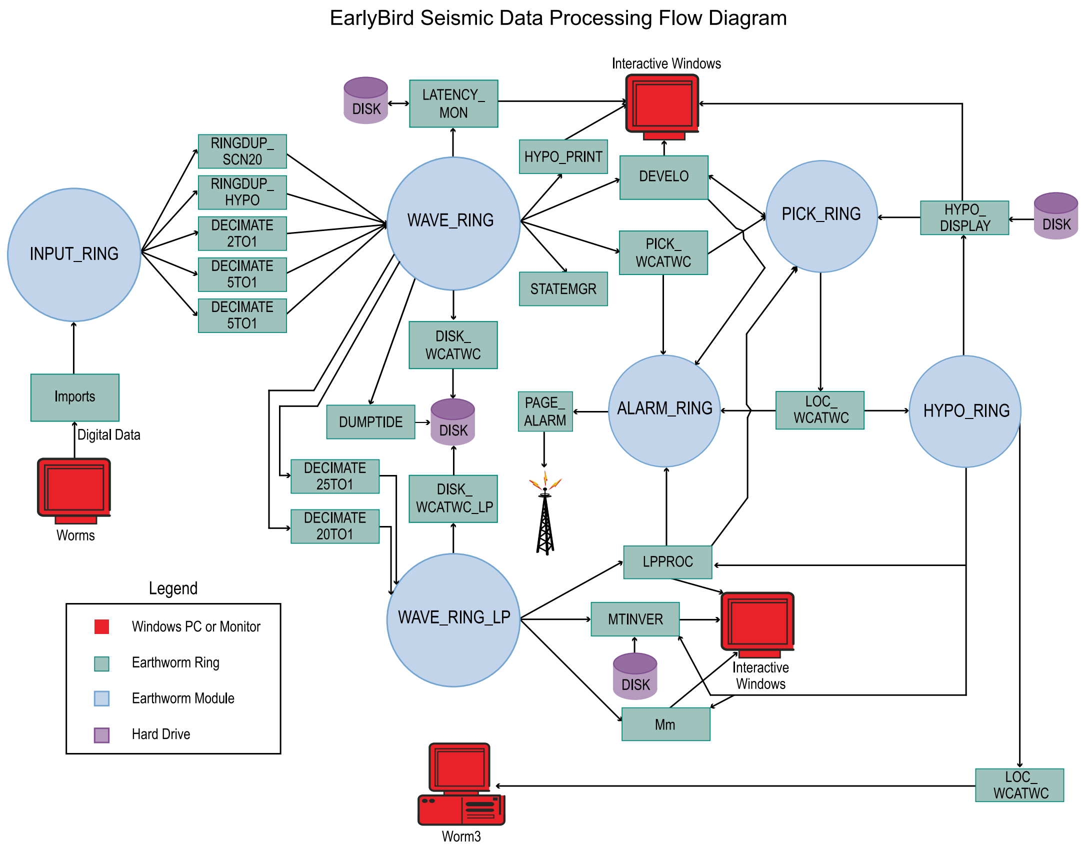

Figure 6-7. Data Processing Flow Within the WC/ATWC Earlybird Software

Earlybird uses the following standard Earthworm modules:

- adsend - digitize analog data
- copystatus - copy errors/heartbeats from one ring to another decimate - filter and reduce the sample rate of data for export and processing
- export_generic/scn - send hypocenter and trace data to other centers
- import_generic - gather hypocenter and trace data from other centers
- import_ida - receive data from the Incorporated Research Institutions for Seismology (IRIS) International Deployment of Accelerometers (IDA) network into Earthworm
- liss2ew - receive data from the IRIS Albuquerque Seismic Laboratory (ASL) network into Earthworm
- ringdup_scn/generic - copy messages from one ring to another
- statmgr - monitor modules attached to a ring
- startstop - start and restart all modules when necessary

Several locally developed Earthworm modules are:

- atplayer - imulate real-time events with older data
- develo - display real-time, short period seismic data in develocorder type view
- disk_wcatwc - log trace data to disk
- dumptide - log certain channels to disk (tide gage data)
- hypo_display - display computed hypocenter parameters and adjust P data
- hypo_print - log hypocenters to disk and EarthVu
- latency_mon - track data outages and latencies for all channels
- loc_wcatwc - associator/locator module
- lpproc - display real-time, long period seismic data and process data for Ms
- mm - process surface wave data for Mm (Mw)
- mtinver - process data for moment tensor
- page_alarm - send alarm messages through various interfaces
- pick_wcatwc - P-picking/magnitude determination algorithm

Four stand-alone, non-Earthworm-based programs are also part of the EarlyBird system:

- ANALYZE - program reads, analyzes and displays seismic data previously logged to disk, and archive data to CD-ROM
- LOCATE - watch stander can interactively locate detected earthquakes, trigger Long Period processing in lpproc, or the watch stander can run the ANALYZE program to determine Ms and Mw, and display location and P data to a PC screen
- MESSAGE2 - program creates tsunami warning and other messages
- SUMMARY - program displays earthquake summary and procedures to monitor

The stand-alone programs are designed to operate completely independently; that is, one does not have to be running for the others to operate. Data are shared between the programs through disk files, and sometimes semaphores. The Earthworm system is modular. If one module breaks, the others should not be affected. The Earthworm module statmgr monitors the modules and will restart them if necessary. The Earthworm startstop module starts and stops the Earthworm modules, and gives the status of each.

All of the programs, including the Earthworm-based components of EarlyBird, run on a PC with a graphics adapter that splits the screen into twelve monitors. The programs ANALYZE, LOCATE, and SUMMARY each display a window covering one monitor. Earthworm modules lpproc, develo, hypo_display, mm, mtinver, and latency_mon also have graphical displays that utilize a monitor. MESSAGE2 brings up a dialog box when activated in LOCATE. The EarthVu system uses the other four monitors. The EarlyBird system can be run on a single-monitor PC, but data will not be as clear as on a twelve-monitor system.

EarthVu

EarthVu is geographic display software developed at the WC/ATWC. Its main functions are to:

- Display epicenters on various scale maps
- Overlay pertinent information such as historic tsunamis and earthquakes, volcanoes, elevation contours, roads, pipelines, tsunami watch/warning areas, etc.
- Provide a graphical platform for computing tsunami models
- Display results of previously computed models for calibration during tsunami warnings
- Compute and display tsunami travel times
- Interface with earthquake and tsunami databases
- Create maps to link to tsunami messages issued by the center

Tip

EarthVu has four modes and runs in parallel with EarlyBird.

EarthVu runs in parallel with the Early Bird seismic processing system and normally uses four computer monitors. EarthVu is sent **automatic** and **interactively computed** earthquake locations. As these locations are acquired, appropriate maps are shown on the monitors.

EarthVu can be run in one of four modes:

1) Display large-scale maps and overlays

2) Interface for tsunami travel time maps

3) Display small scale maps

4) Display regional maps showing the last 7 days' events

Overlays

Several overlays are available in EarthVu:

- Major Cities
- Tsunamis - all known Pacific basin tsunamis, from NOAA National Geographic Data Center (NGDC)
- Earthquakes - all known quakes with magnitude >5, 1900-present, from USGS National Earthquake Information Center (NEIC)
- Volcanoes - from Global Volcanism Program
- Seismometers - seismometer data processed at WC/ATWC
- Tide Gages - tide gage sites recorded at WC/ATWC
- Watch/Warning Areas - present tsunami watch/warning status

- Lat/Lon Grids - meridians and parallels at specifiable intervals
- Cities - from U.S. Department of Defense (DOD) Digital Chart of the World
- Contours - from DOD Digital Chart of the World
- Geographic Names - from DOD Digital Chart of the World
- Airports, roads, pipelines, power lines, trails, railroads - from DOD Digital Chart of the World

Other interactive options available in EarthVu are: display detailed data on a tsunami, volcano, tide gage, or seismometer with a mouse click; re-draw a map with color coded elevations/bathymetries; turn on/off voice option (says location as displayed); call historic databases; and specify an area of the map to expand in the small-scale map program.

Historic tsunami and earthquake data are queried with program HISTORY, which is called from EarthVu. HISTORY retrieves information from the databases by date, location, and magnitude. The output can be in summary form or in great detail, and is written to the screen and/or printer. The earthquake database is from the USGS/NEIC. It contains all earthquakes between 1900 and the present over magnitude 5 (more than 70,000 quakes). The tsunami database is taken mostly from NOAA/NGDC studies (such as Lander et al., 1993; Lander, 1996). It contains more than 1,000 Pacific basin tsunamis dating back to 47 BC. The same information accessed by program HISTORY is also used by EarthVu and the other programs when displaying tsunamis and earthquake data on maps.

Tsunami Travel Times and Models

Tsunami travel time and tsunami model computations can also be performed and displayed through the EarthVu interface. Tsunami travel time results are displayed on an EarthVu map. EarthVu acts as a graphic interface where model areas are specified and results are displayed. EarthVu also displays pre-computed model results and provides a method to scale the results based on recorded tsunamis during a warning. Far-field tsunami amplitude forecasts can be made using the Model/Results option in the EarthVu program. These forecasts are based on pre-computed tsunami models scaled by observed sea level data. Over 300 pre-computed models are available. For WC/ATWC, maximum amplitudes (zero-to-peak in meters) are saved at 99 places along the coasts of Alaska, British Columbia, Washington, Oregon, California, Hawaii, and at all DART buoys. Models are run with grid increments of 5 feet over the deep ocean, 1 foot over the shelf, and, where necessary to describe local shoreline configuration. Nonlinear, shallow-water equations are used with friction effects over the finer grids included. Inundation is not taken into account. The basic technique is described by Kowalik and Whitmore (1991, *Science of Tsunami Hazards*). The methodology of utilizing pre-computed models during tsunami warnings is described by Whitmore and Sokolowski (1996, *Science of Tsunami Hazards*).

Important Points to Remember about Using WC/ATWC's EarthVu and EarlyBird Software to Maintain Situational Awareness

- EarthVu runs in parallel with the EarlyBird seismic processing system and normally uses four computer monitors.
- EarlyBird automatically locates and sizes (using Mb, Ml, Ms, Mw, and Mwp) worldwide, regional, and local earthquakes.
- EarthVu can be run in one of four modes and several GIS overlays are available for the watch stander to use.
- Tsunami travel time and tsunami model computations can be performed and displayed through the EarthVu interface.
- EarthVu also displays precomputed model results and provides a method to scale the results based on recorded (by tide gages and DART buoys) tsunamis during a warning.

Tsunami Wave Height and Inundation Computer Models

The current focus at established tsunami warning centers is to develop a fast, accurate operational tsunami forecast system that provides an optimal interpretation of the available earthquake and sea-level data, and quantifies the potential tsunami impact on coastal communities. Such a system is critical to decision-makers at tsunami warning centers, who must rapidly assess the hazard to coastal communities. The stakes are high: A missed warning could result in devastating fatalities, while needless evacuations are dangerous, expensive, and erode confidence in the warning system. Tsunami forecasting technology under development at NOAA and JMA is based on the well-tested approach used in most hazard forecast systems—i.e., the integration of real-time measurement and modeling technologies.

Model-based interpretation of the tsunami, such as those by the Method of Splitting Tsunamis (MOST) model developed at NOAA's Pacific Marine Environmental Laboratory (PMEL), occurs in two stages. First, a pre-computed database of deep-ocean model simulations is exploited to formally invert the real-time tsunameter (DART buoy) data stream and produce a linear best-fit solution in deep water; this step is completed within a few minutes of data acquisition. Second, the deep-water values just offshore are used to initiate real-time execution of nonlinear inundation models to provide community-specific forecasts of tsunami inundation; this step is completed in less than 10 minutes.

The MOST Model

The evolution of earthquake-generated tsunami waves has three distinctive stages: generation, propagation, and runup. The MOST numerical model (NOAA Technical

Memorandum ERL PMEL-112, 1997) computes all three stages, providing a complete tsunami simulation capability.

Tip

The MOST model uses a precomputed database of deep-ocean tsunami simulations.

Generation

The generation stage of tsunami evolution includes the formation of the initial disturbance of the ocean surface due to the earthquake-triggered deformation of the seafloor. This initial water surface disturbance evolves into a long gravity wave radiating from the earthquake source. Modeling of the initial stage of tsunami generation is therefore closely linked to studies of earthquake source mechanisms.

The tsunami generation process is based on a fault plane model of the earthquake source (Gusiakov, 1978; Okada, 1985), which assumes an incompressible liquid layer on an underlying elastic half-space to characterize the ocean and the Earth's crust. The implementation of this elastic fault plane model (Titov, 1997) utilizes a formula for static sea-floor deformation to calculate the initial conditions required for subsequent computations of tsunami propagation and inundation.

Propagation

A tsunami can propagate long distances before it strikes a shoreline hundreds or thousands of kilometers from the earthquake source. To accurately model tsunami propagation over such large distances, the Earth's curvature should be taken into account. Other factors, such as Coriolis forces and dispersion, may also be important.

Dispersion changes the wave shape due to slightly different propagation speeds of waves with different frequencies. This effect can be taken into account even without the explicit use of dispersive terms in the governing equations; Shuto (1991) suggested that this process could be simulated by exploiting the numerical dispersion inherent in finite-difference algorithms. This method accounts for dispersive effects, but allows the use of non-dispersive linear or nonlinear equations for wave propagation modeling. The MOST propagation model uses a numerical dispersion scheme and the nonlinear shallow-water wave equations in spherical coordinates, with Coriolis terms (Murty, 1984):

$$h_t + \frac{(uh)_\lambda + (vh\cos\phi)_\phi}{R\cos\phi} = 0$$

$$u_t + \frac{uu_\lambda}{R\cos\phi} + \frac{vu_\phi}{R} + \frac{gh_\lambda}{R\cos\phi} = \frac{gd_\lambda}{R\cos\phi} + fv$$

$$v_t + \frac{uv_\lambda}{R\cos\phi} + \frac{vv_\phi}{R} + \frac{gh_\phi}{R} = \frac{gd_\phi}{R} - fu$$

where λ is longitude, ϕ is latitude, $h = h(\lambda,\phi,t) + d(\lambda,\phi,t)$ is the amplitude, $d(\lambda,\phi,t)$ is the undisturbed water depth, $u(\lambda,\phi,t)$, $v(\lambda,\phi,t)$ are the depth-averaged velocities in the longitude and latitude directions, respectively, g is the gravity accelration, f is the Coriolis parameter ($f = 2\omega\sin\phi$), and R is the Earth radius. In the MOST model, these equations are solved numerically using a splitting method similar to that described by Titov (1997).

Inundation

Runup of a tsunami onto dry land is probably the most underdeveloped part of any tsunami simulation model, primarily because of a serious lack of two major types of data: high-quality field measurements for testing of the models, and fine-resolution bathymetry/topography data. The first major obstacle to improving simulations of the inundation process, i.e., the lack of high-quality experimental and field measurements of runup, has been especially severe. Recently, this problem has been somewhat alleviated by a series of large-scale runup experiments conducted at the Coastal Engineering Research Center (CERC) of the U.S. Army Corps of Engineers (Briggs *et al.* 1995) and by several post-tsunami surveys that provided high-quality field data (Yeh *et al.*, 1993; Synolakis *et al.*, 1995; Imamura *et al.*, 1995; Yeh *et al.*, 1995; Borrero *et al.*, 1997).

The second serious obstacle to accurate inundation model simulations is the requirement for high-resolution bathymetry and topography data in critical near-shore areas; in most cases, 10- to 50-meter horizontal resolution of gridded bathymetry and topography data are essential. Such high-resolution data are not easily obtained. Where adequate bathymetric and topographic data are available, the MOST model inundation computations are sufficiently accurate to develop useful hazard mitigation tools and guidance products such as inundation maps.

Asteroid-Generated Tsunami Model

A model of an asteroid-generated tsunami was developed by Robert Weiss, Kai Wünnemann, and Heinrich Bahlburg (2006) in Geophysical Journal International. This numerical model estimates the generation, propagation, and runup of tsunamis caused by oceanic impacts.

Hypervelocity impacts of asteroids in marine environments produce tsunami waves independent of the water depth and the diameter of the projectile, although the characteristics of induced waves are affected by these parameters. The authors present a model, consisting of the well-known impact model and a nonlinear wave propagation model, to study the generation and subsequent spread-out of the initial wave pattern caused by the strike of an asteroid or comet in the ocean. The numerical simulation of oceanic impacts requires some changes and extensions to the original impact model code. The handling of different materials (water and solid rocks) is particularly crucial due to the cratering process.

For the simulation of the propagation of tsunami waves generated by the impact process, they use a newly developed wave propagation model, which is based on the nonlinear shallow water theory with boundary conditions derived from the impact model. The runup of the tsunami wave on the coastline is handled as a special case of reflection and is realized by the well-established MOST code. Besides the model description, the authors illustrate the capability of the modeling scheme by the simulation of the strike of an asteroid 800 meters in diameter on a 5000-meter-deep ocean at 10.2 kilometers per second, the subsequent propagation of the induced tsunami waves over an artificial bathymetry, and the runup of the wave on the coast.

Other Inundation Models

Several other inundation models are being developed in addition to the inundation component of the MOST model. For example, The FLO-2D® model by FLO-2D Software, Inc., can be used to create detailed overland inundation mapping for ocean storm surge or tsunami hazards and is particularly effective in urban areas where buildings, obstructions, streets and channels can affect the flood wave progression. The modeling detail provided by FLO-2D® exceeds that of other hydrodynamic models, and the results include predicted flow depths, velocities, discharge hydrographs, dynamic and static pressure, specific energy, and area of inundation. The specific input data required for a FLO-2D® ocean storm surge model is wave height or water surface elevation as a function of time (time-stage data pairs) for the coastal grid elements.

Important Points to Remember about Tsunami Modeling

- NTWCs and RTWPs should strive to implement a fast, accurate, operational tsunami forecast system that provides an optimal interpretation of the available earthquake and sea-level data, and quantifies the potential tsunami impact on coastal communities.
- The evolution of earthquake-generated tsunami waves has three distinctive stages: generation, propagation, and runup. The NOAA MOST numerical model computes all three stages, providing a complete tsunami simulation capability.
- Runup of a tsunami onto dry land is probably the most underdeveloped part of current tsunami simulation models, primarily because of a lack of two major types of data: high-quality field measurements for testing of the models, and fine-resolution bathymetry/topography data.
- Models for asteroid-generated tsunamis are also available in addition to models for earthquake-generated tsunamis
- Other inundation models exist in addition to the MOST inundation model

Watch Stander Training

A scientist in the position of watch stander must possess the professional judgment necessary to gather and evaluate appropriate information for accuracy and completeness, and to implement the correct response in a timely manner for the protection of lives and property. He/she must be able to make observations, calculations, and interpretations, using all available geophysical, oceanographic, and geographic data, obtained by diverse methods of communications, to locate an earthquake, determine its magnitude, evaluate its potential for tsunami generation, evaluate appropriate tsunami data for degree of potential threat, and issue, with follow-up, a tsunami watch, a tsunami warning, or other information messages as necessary.

Tip

A tsunami warning center should have both geophysicists and oceanographers on staff.

The ability to take appropriate actions is based on an expert knowledge of theoretical and applied geophysics, volcanology, sedimentology, regional tectonics, geography, and oceanography of both the source region as well as potential impact areas. These skills and this knowledge are not all acquired during study in a single academic discipline; **a long period of on-the-job training is required for geophysicists and oceanographers to perform at an optimum level**.

A center should have a mix of geophysicists and oceanographers on staff. Further, the center should have a rigorous on-station training program that provides periodic training on the end-to-end procedures for obtaining and processing data and issuing test bulletins. One effective way to do this is to utilize historic data from past events. Some NTWCs and RTWPs have developed computer simulation programs (notably the WC/ATWC's EarlyBird system) to facilitate this type of training. These simulators can provide watch standers with many years of experience in a short period of time.

In addition to providing experience for watch standers, periodic operational end-to-end training also exercises the communications paths that a center uses to collect data and disseminate bulletins. This is very important as these communications channels are crucial to proper performance in actual events, which are relatively infrequent.

Important Points to Remember about Watch Stander Training

- A scientist in the position of watch stander must possess excellent professional judgment.
- A long period of on-the-job training is required for geophysicists and oceanographers to perform at an optimum level.
- Periodic operational end-to-end training provides experience for watch standers and also exercises the communications paths that a center uses to collect data and disseminate bulletins.

Research and Development

Applied research and program development activities at RTWPs and NTWCs generally fall into three broad categories:

- Science: Applied oceanographic and seismic research that leads to better models of parameters like hypocenter location, earthquake tsunami generation characteristics, tsunami wave speed and amplitude, inundation maps, etc. The emerging "what if" technology falls in this category.
- Processing: Development of computer methods for speeding the processing of seismic and sea level data, disseminating products to new technologies, and programs that assist watch standers in maintaining situational awareness.
- Social science: Developing education programs, warning messages, and other communications that produce the desired reactions by constituents.

Each RTWP and NTWC can function acceptably without a rigorous research and development program. A center can rely on improvements and new techniques developed at other NTWCs, RTWPs, and academic and government research institutions. However, a center can often better address its own unique local problems. Additionally, a local research and development program creates an atmosphere of progress within a tsunami warning center. A mix of oceanographers, seismologists, computer programmers, and networking/communications experts is optimal as it gives the center the skills needed to address research and development in all three of the above categories.

Tip

A tsunami warning center's local research and development program can often best address local problems.

In additional to building a multi-disciplinary staff, tsunami warning centers are urged to establish and exercise strong links with academic institutions and other professional research groups such as the Asian Disaster Preparedness Center (ADPC) and the Pacific Disaster Center (PDC). These links often lead to advances in procedures and help the center remain on the cutting edge of new technology and techniques. Collaborative ties can be established at nearby or co-located institutions, or by staff who are alumni, or through contacts made at meetings and workshops.

Experimental Products

The four basic international products (warning, watch, advisory, and statement) may not meet all the needs of an RTWP or a NTWC. For example, an RTWP may need to develop or modify a specialized product to meet the needs of one or more of the NTWCs it serves. A NTWC may need to develop or modify a specialized product to meet unique conditions or requirements of one or more of its customers. Similarly, RTWPs and NTWCs may contemplate providing a new, or changing an existing service. In all these cases the warning center should establish and follow an *a priori* process that has been thought through and discussed with the center's customer base well before the change process begins. Such an approach will help the center avoid many of the pitfalls associated with making changes.

A new or changed product or service begins as a concept, which is developed into a proposal. Once the proposal has been articulated but before development begins, the tsunami warning center should ensure that implementing the new or changed product or service would be acting in a fair and evenhanded manner with respect to all stakeholders, and accomplished in a manner that maximizes fairness and openness. Figure 6-8 describes the process to follow in developing and implementing a new or enhanced product or service. Products and services in this process can be national or local in scope. The six guiding principles outlined below should be followed when considering whether a new product or service or change to an existing product or service can be made.

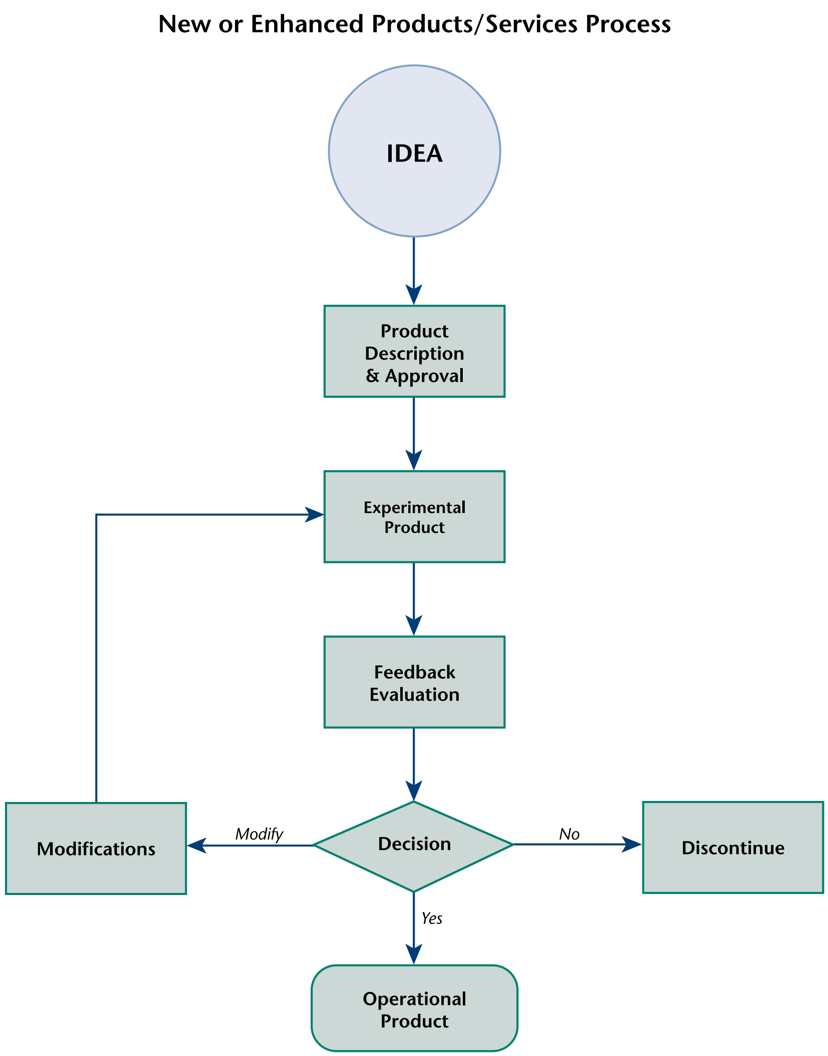

Figure 6-8. Steps to Implementing an Experimental Product (from National Weather Service Instruction 10-102 May 18, 2006)

Six guiding principles when considering beginning or changing an existing product or service:

1. **Mission connection** - The product or service must be connected to the center's mission.
2. **Life and property first** - Protection of life and property must be placed first in the allocation of resources and the development and dissemination of products and services.
3. **No surprises** - All users, including those in the private sector, must be provided adequate notice and opportunity for input into decisions regarding the development and dissemination of products and services.
4. **The stakeholders own the data** - Open and unrestricted dissemination of publicly funded information is good policy and may be the law.
5. **Equity** - All dealings with various constituents must be equitable and not show favoritism to particular partners, particularly those in the academic and commercial sectors. A service to a segment of the user community should not be provided that cannot be provided to all similar types of users.
6. **Maintain and explain the routine** - When faced with requests for specifically tailored services, make sure the user fully understands the products which the center "routinely" provides.

Product Improvement Program

The objective of tsunami modeling research is to develop numerical models for faster and more reliable forecasts of tsunamis propagating through the ocean and striking coastal communities. Forecast modeling software products specifically designed to support the tsunami warning center's forecasting operations are invaluable. In addition to this, inundation modeling designed to assist coastal communities in their efforts to assess the risk and mitigate the potential of tsunami hazard are also invaluable.

Tsunami Wave Forecast Modeling

The main objective of a forecast model is to provide an estimate of wave arrival time, wave height, and inundation area immediately after a tsunami event. Tsunami forecast models are run in real time while a tsunami is propagating in the open ocean. Consequently they are designed to perform under very stringent time limitations.

Given the time constraints of this type of study, the process of computing the three stages of tsunami modeling, namely, wave generation, propagation, and inundation, is usually expedited by generating a database of pre-computed scenarios. The pre-computed database contains information about tsunami propagation in the open ocean from a multitude of potential sources. When a tsunami event occurs, an initial source is selected from the pre-computed database. In the initial stages of the tsunami, this selection is based only on the available seismic information for the earthquake event.

As the wave propagates across the ocean and successively reaches the sea level gages and DART systems, these report the recorded sea level information back to the tsunami warning centers, which, in turn, process the information and produce a new and more refined estimate of the tsunami source. The result is an increasingly accurate forecast of the tsunami that can be used to issue watches, warnings, or recommend evacuations.

When an event similar to one of the pre-computed scenarios occurs, the available propagation information is used to compute the last stage of the study, wave inundation.

Inundation Modeling

An inundation modeling study attempts to recreate the tsunami generation in deep or coastal waters, wave propagation to the impact zone, and inundation along the study area. High-resolution bathymetric and topographic grids are used in this type of study to reproduce the correct wave dynamics during the inundation computations. The high-quality bathymetric and topographic data sets needed for development of inundation maps require maintenance and upgrades as better data become available and coastal changes occur.

Inundation studies can be conducted taking a probabilistic approach in which multiple tsunami scenarios are considered, and an assessment of the vulnerability of the coast to tsunami hazard is evaluated, or they may focus on the effect of a particular "worst-case scenario" and assess the impact of such a particularly high-impact event on the areas under investigation.

The results of a tsunami inundation study should include information about the maximum wave height and maximum current speed as a function of location; maximum inundation line; and time series of wave height at different locations, indicating wave arrival time. This information can be used by emergency managers and urban planners primarily to establish evacuation routes and the locations of vital infrastructure. Additionally, emergency managers and other officials are in urgent need of operational tools that will provide accurate tsunami forecasts as guidance for rapid, critical decisions in which lives and property are at stake. The more timely and precise the warnings are, the more effective the actions that local emergency managers can take and the more lives and property can be saved.

Combined, measurement and modeling techniques can provide reliable tsunami forecasts. To forecast inundation from early tsunami waves, seismic parameter estimates and tsunami measurements are used to sift through a pre-computed generation/propagation forecast database and select an appropriate (linear) combination of scenarios that most closely matches the observational data. This produces estimates of tsunami characteristics in deep water, which can then be used as initial conditions for a site-specific (nonlinear) inundation algorithm. A statistical methodology has been developed to forecast the maximum height of later tsunami waves that can threaten rescue and recovery operations. The results are made available through a user-friendly interface to aid hazard assessment and decision making by emergency managers.

The MOST model performed computations of generation/propagation scenarios for the forecast database. The nonlinear high-resolution model will provide the inundation forecasts. This methodology is the foundation of the next-generation forecast tools for tsunami warning and mitigation that are being developed in close collaboration with tsunami warning centers and academia. These new tools will provide site- and event-specific forecast of tsunami amplitudes to assist emergency managers during tsunami warning and mitigation procedures.

Important Points to Remember about Research and Development Programs at NTWCs and RTWPs

- Applied research and program development activities at RTWPs and NTWCs generally fall into three broad categories: geophysical science, processing, and social science.
- A tsunami warning center's research and development program creates an atmosphere of progress.
- Collaboration with other institutions helps a center remain on the cutting edge of new technology and techniques.
- A new product should pass a rigorous testing program before becoming operational.

Chapter 7

Warnings and Other Products

National Tsunami Warning Centers (NTWC) and Regional Tsunami Watch Providers (RTWP) should strive to adhere to internationally agreed-upon public products. If these public products are similar in name and content from one center to the next, confusion among users will be minimized. This is especially relevant for tourists and other visitors to coastal areas. As noted in Chapter 6, the basic public product suite consists of:

- **WARNING:** A tsunami was or may have been generated, which could cause damage; people in the warned area are strongly advised to evacuate.
- **WATCH:** A tsunami was or may have been generated, but is at least 2 hours travel time to the area in watch status. Local officials should prepare for possible evacuation if their area is upgraded to a warning.
- **ADVISORY:** An earthquake has occurred in the area of responsibility (AOR) basin, which might generate a tsunami. The tsunami watch center should issue hourly bulletins updating the situation.
- **INFORMATION STATEMENT:** An earthquake that is not expected to generate a tsunami has been recorded; a bulletin with information regarding the event is issued. Usually only one bulletin is issued.

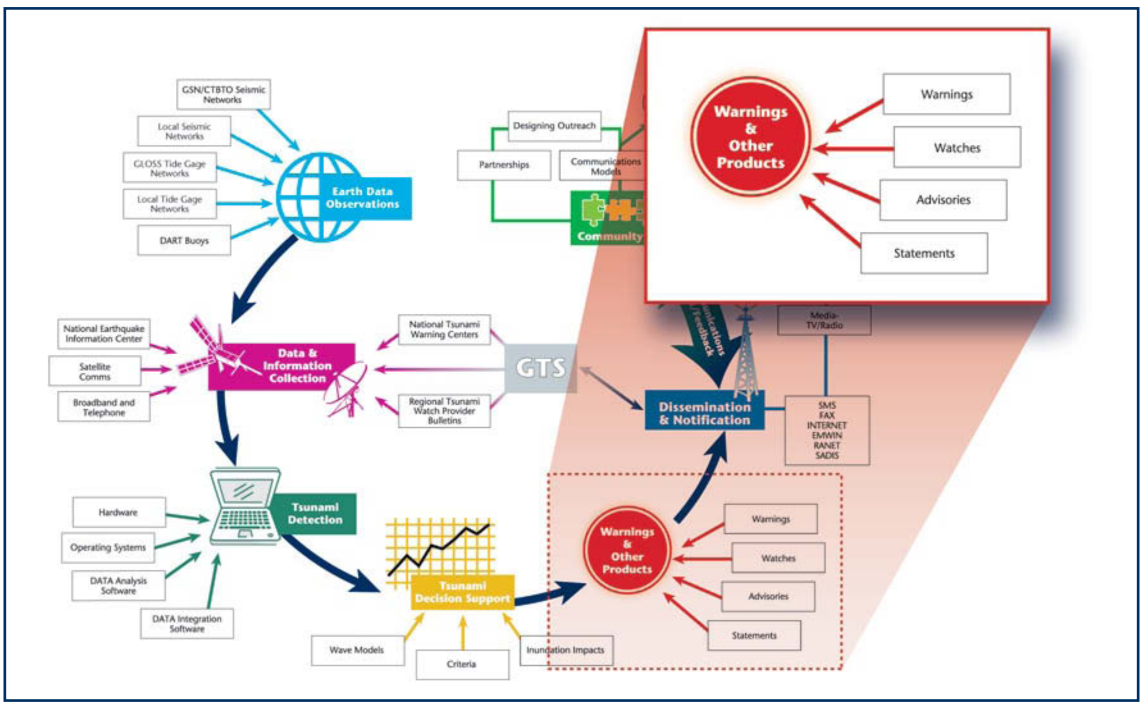

Figure 7-1. Warnings and Other Products in the End-to-End Chain

Tsunami bulletins should be issued by NTWCs and RTWPs when an earthquake with a magnitude of 6.5 or greater occurs. To prevent unnecessary local evacuations, information statements should also be issued for lower magnitude events that may have been felt near the coast.

The Intergovernmental Oceanographic Commission's Intergovernmental Coordination Group (IOC/ICG) has agreed that warning, watch, advisory, and information statement products should contain at least the following information:

- **World Meteorological Organization (WMO) Headers**
  This is crucial for transmission on WMO's Global Telecommunications System (GTS) because:
  - The heading provides a means by which communication data managers recognize a bulletin for telecommunication "switching" purposes.
  - The heading permits a uniqueness for a bulletin, which is sufficient enough to control the data for selective transmission required to meet the needs of the receiving end.
  - The heading is for accountability in the transmission delivery process by the switching system for data management purposes.
  - The heading is **not** intended for the data **processing systems**, as the first few lines of the text (bulletin content) further defines it for processing. (ref. *WMO Codes* Manual 306)

- **Earthquake information**
  a) Origin time (in Coordinated Universal Time [UTC])
  b) Coordinates (latitude and longitude) of the epicenter
  c) Location (name of geographical area)
  d) Magnitude (M)
  e) Depth (only for an earthquake occurring at a depth of 100 kilometers [km] or more) below the ocean floor

- **Tsunami information**
  a) Evaluation of tsunamigenic potential based on the empirical relationship between magnitude (M) of earthquake and generation/nongeneration of tsunami in the tsunami warning center's AOR basin(s)
  b) Estimated tsunami travel times to reach the respective coasts in the center's AOR (only for earthquakes of M greater than 7.0). This is best handled by specifying forecast points that are well known to emergency managers and the populace.

It is also suggested that definitions, call-to-action statements, and other pertinent information be included in bulletins if time allows.

How Do Warnings and Other Products Fit into an End-to-End Tsunami Warning System?

Once an earthquake has occurred and been analyzed, and a decision has been made on its potential impact on a center's AOR, information must be provided to government agencies, the media, the public, and other persons and groups that will be affected by the event. Information, especially that contained in life-saving warning messages, will have a much better chance of being understood if it is conveyed in concise, easy-to-understand language, in a predictable (and hence, familiar) format. Based upon many years of experience, the established NTWCs and RTWPs have settled on several standardized products, all with somewhat standardized structure and content.

These products issued by a tsunami warning center are crucial to the success of that center's end-to-end system. If the information presented is not understood, it is less likely that the proper actions will be taken by recipients.

Thus, both incoming data collection communications systems and outgoing communication of critical information are crucial to the success of the warning system for those affected by an event.

What Is in this Chapter?

This chapter contains sections that discuss the following topics:

- Definition and example of a **warning** product.
- Definition and example of a **watch** product.
- Definition and example of an **advisory** product.
- Definition and example of an **information statement**.

What Are the Most Important Points to Remember about Tsunami Product Requirements for NTWCs and RTWPs?

- NTWCs and RTWPs should strive to adhere to internationally agreed-upon names and contents for public products.
- If the information that a product contains is not understood then it is less likely that the proper actions will be taken by recipients.
- The core NTWC product suite should consist of:
  - Warning products
  - Watch products
  - Advisory products
  - Information statements

Warnings: The Highest Level of Tsunami Alert

A tsunami warning is issued by tsunami warning centers when a potential tsunami with significant widespread inundation is imminent or expected to occur in the center's AOR. Warnings alert the public that widespread, dangerous coastal flooding accompanied by powerful currents is possible and may continue for several hours after arrival of the initial wave. Warnings also alert emergency management officials to take action for the entire tsunami hazard zone. Appropriate actions to be taken by local officials may include the evacuation of low-lying coastal areas, and the repositioning of ships to deep waters when there is time to do so safely. Warnings may be updated, adjusted geographically, downgraded, or canceled. To provide the earliest possible alert, initial warnings are normally based only on seismic information. The following is an example of a tsunami warning product:

WEAK51 PAAQ 030202
TSUNAMI BULLETIN NUMBER 004
PACIFIC TSUNAMI WARNING CENTER
0902 PM HST 03 SEP 2005

TO - CIVIL DEFENSE IN THE STATE OF HAWAII

SUBJECT - TSUNAMI WARNING BULLETIN

A TSUNAMI WARNING IS ISSUED FOR THE STATE OF HAWAII EFFECTIVE AT 0902 PM HST.

AN EARTHQUAKE HAS OCCURRED WITH THESE PRELIMINARY PARAMETERS

ORIGIN TIME - 0112 PM HST 03 SEP 2005

COORDINATES - 16.0 SOUTH 73.3 WEST

LOCATION - NEAR COAST OF PERU

MAGNITUDE - 8.2 MOMENT

MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY

GAUGE LOCATION	LAT	LON	TIME	AMPL	PER
Arica, Chile	18.1S	178.4W	0050Z	0.88M	12MIN
Antofagasta, Chile	17.8S	168.3E	0220Z	0.91M	10MIN

TIME - TIME OF THE MEASUREMENT

AMPL - AMPLITUDE IN METERS FROM MIDDLE TO CREST OR MIDDLE TO TROUGH OR HALF OF THE CREST TO TROUGH

PER - PERIOD OF TIME FROM ONE WAVE CREST TO THE NEXT

EVALUATION

A TSUNAMI HAS BEEN GENERATED THAT COULD CAUSE DAMAGE ALONG COASTLINES OF ALL ISLANDS IN THE STATE OF HAWAII. URGENT ACTION SHOULD BE TAKEN TO PROTECT LIVES AND PROPERTY.

A TSUNAMI IS A SERIES OF LONG OCEAN WAVES. EACH INDIVIDUAL WAVE CREST CAN LAST 5 TO 15 MINUTES OR MORE AND EXTENSIVELY FLOOD COASTAL AREAS. THE DANGER CAN CONTINUE FOR MANY HOURS AFTER THE INITIAL WAVE AS SUBSEQUENT WAVES ARRIVE. TSUNAMI WAVE HEIGHTS CANNOT BE PREDICTED AND THE FIRST WAVE MAY NOT BE THE LARGEST. TSUNAMI WAVES EFFICIENTLY WRAP AROUND ISLANDS. ALL SHORES ARE AT RISK NO MATTER WHICH DIRECTION THEY FACE. THE TROUGH OF A TSUNAMI WAVE MAY TEMPORARILY EXPOSE THE SEAFLOOR BUT THE AREA WILL QUICKLY FLOOD AGAIN. EXTREMELY STRONG AND UNUSUAL NEARSHORE CURRENTS CAN ACCOMPANY A TSUNAMI. DEBRIS PICKED UP AND CARRIED BY A TSUNAMI AMPLIFIES ITS DESTRUCTIVE POWER. SIMULTANEOUS HIGH TIDES OR HIGH SURF CAN SIGNIFICANTLY INCREASE THE TSUNAMI HAZARD.

THE ESTIMATED ARRIVAL TIME IN HAWAII OF THE FIRST TSUNAMI WAVE IS

0221 AM HST 04 SEP 2005

BULLETINS WILL BE ISSUED HOURLY OR SOONER AS CONDITIONS WARRANT.

$$

Note in the example that all of the following recommended pieces of information are readily apparent in the product:

Earthquake information

a) Origin time (UTC)

b) Coordinates (latitude and longitude) of the epicenter

c) Location (name of geographical area)

d) Magnitude (M)

Tsunami information

a) Evaluation of tsunamigenic potential based on the empirical relationship between magnitude (M) of earthquake and generation/nongeneration of tsunami in the tsunami warning center's AOR basin(s).

b) Estimated tsunami travel times to reach the respective coasts in the center's AOR (only for earthquakes of M greater than 7.0).

Watches: The Second Level of Tsunami Alert

A Tsunami Watch is issued by RTWPs and NTWCs to alert other centers, emergency management officials, and the public of an event that may later impact the watch area. The watch may be upgraded to a warning or advisory (or canceled) based on updated information and analysis. Therefore, emergency management officials and the public should prepare to take action. Watches are normally issued based on seismic information without confirmation that a destructive tsunami is under way. The following is an example of a tsunami watch product:

WEAK51 PAAQ 030159
TSUNAMI BULLETIN NUMBER 001
PACIFIC TSUNAMI WARNING CENTER
0859 PM HST 03 SEP 2005

TO - CIVIL DEFENSE IN THE STATE OF HAWAII

SUBJECT - TSUNAMI WATCH BULLETIN

A TSUNAMI WATCH IS ISSUED FOR THE STATE OF HAWAII EFFECTIVE AT 0859 PM HST.

AN EARTHQUAKE HAS OCCURRED WITH THESE PRELIMINARY PARAMETERS

ORIGIN TIME - 0112 PM HST 03 SEP 2005

COORDINATES - 16.0 SOUTH 73.3 WEST

LOCATION - NEAR COAST OF PERU

MAGNITUDE - 8.2 MOMENT

MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY

GAUGE LOCATION	LAT	LON	TIME	AMPL	PER
Arica, Chile	18.1S	178.4W	0250Z	0.88M	12MIN
Antofagasta, Chile	17.8S	168.3E	0420Z	0.91M	10MIN

TIME - TIME OF THE MEASUREMENT

AMPL - AMPLITUDE IN METERS FROM MIDDLE TO CREST OR MIDDLE TO TROUGH OR HALF OF THE CREST TO TROUGH

PER - PERIOD OF TIME FROM ONE WAVE CREST TO THE NEXT

EVALUATION

BASED ON ALL AVAILABLE DATA A TSUNAMI MAY HAVE BEEN GENERATED BY THIS EARTHQUAKE THAT COULD BE DESTRUCTIVE ON COASTAL AREAS EVEN FAR FROM THE EPICENTER. AN INVESTIGATION IS UNDER WAY TO DETERMINE IF THERE IS A TSUNAMI THREAT TO HAWAII.

IF TSUNAMI WAVES IMPACT HAWAII THE ESTIMATED EARLIEST ARRIVAL OF THE FIRST TSUNAMI WAVE IS

0221 AM HST 04 SEP 2005

BULLETINS WILL BE ISSUED HOURLY OR SOONER AS CONDITIONS WARRANT.

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The following is an example of a product containing a watch for one area and a warning for another area:

WEAK51 PAAQ 011310
BULLETIN
PUBLIC TSUNAMI MESSAGE NUMBER 1
NWS WEST COAST/ALASKA TSUNAMI WARNING CENTER PALMER AK
510 AM AKDT SAT JUL 1 2006

...A TSUNAMI WARNING IS IN EFFECT WHICH INCLUDES THE ALASKA

COASTAL AREAS FROM CORDOVA ALASKA TO ATTU ALASKA...

...A TSUNAMI WATCH IS IN EFFECT FOR THE CALIFORNIA -– OREGON

- WASHINGTON - BRITISH COLUMBIA AND ALASKA COASTAL AREAS FROM THE CALIFORNIA-MEXICO BORDER TO CORDOVA ALASKA...

A TSUNAMI WARNING MEANS... ALL COASTAL RESIDENTS IN THE WARNING AREA WHO ARE NEAR THE BEACH OR IN LOW-LYING REGIONS SHOULD MOVE IMMEDIATELY INLAND TO HIGHER GROUND AND AWAY FROM ALL HARBORS AND INLETS INCLUDING THOSE SHELTERED DIRECTLY FROM THE SEA. THOSE FEELING THE EARTH SHAKE... SEEING UNUSUAL WAVE ACTION... OR THE WATER LEVEL RISING OR RECEDING MAY HAVE ONLY A FEW MINUTES BEFORE THE TSUNAMI ARRIVAL AND SHOULD EVACUATE IMMEDIATELY. HOMES AND SMALL BUILDINGS ARE NOT DESIGNED TO WITHSTAND TSUNAMI IMPACTS. DO NOT STAY IN THESE STRUCTURES.

ALL RESIDENTS WITHIN THE WARNED AREA SHOULD BE ALERT FOR INSTRUCTIONS BROADCAST FROM THEIR LOCAL CIVIL AUTHORITIES. THIS TSUNAMI WARNING IS BASED SOLELY ON EARTHQUAKE INFORMATION—THE TSUNAMI HAS NOT YET BEEN CONFIRMED.

A TSUNAMI WATCH MEANS...ALL COASTAL RESIDENTS IN THE WATCH AREA SHOULD PREPARE FOR POSSIBLE EVACUATION. A TSUNAMI WATCH IS ISSUED TO AREAS WHICH WILL NOT BE IMPACTED BY THE TSUNAMI FOR AT LEAST THREE HOURS. WATCH AREAS WILL EITHER BE UPGRADED TO WARNING STATUS OR CANCELED.

AT 500 AM ALASKAN DAYLIGHT TIME ON JULY 1 AN EARTHQUAKE WITH PRELIMINARY MAGNITUDE 7.9 OCCURRED 70 MILES SOUTHEAST OF NIKOLSKI ALASKA.

THIS EARTHQUAKE MAY HAVE GENERATED A TSUNAMI. IF A TSUNAMI HAS BEEN GENERATED THE WAVES WILL FIRST REACH NIKOLSKI ALASKA AT 540 AM ADT ON JULY 1.

ESTIMATED TSUNAMI ARRIVAL TIMES AND MAPS ALONG WITH SAFETY RULES AND OTHER INFORMATION CAN BE FOUND ON THE WEB SITE

WCATWC.ARH.NOAA.GOV

TSUNAMIS CAN BE DANGEROUS WAVES THAT ARE NOT SURVIVABLE. WAVE HEIGHTS ARE AMPLIFIED BY IRREGULAR SHORELINE AND ARE DIFFICULT TO PREDICT. TSUNAMIS OFTEN APPEAR AS A STRONG SURGE AND MAY BE PRECEDED

BY A RECEDING WATER LEVEL. MARINERS IN WATER DEEPER THAN 600 FEET SHOULD NOT BE AFFECTED BY A TSUNAMI. WAVE HEIGHTS WILL INCREASE RAPIDLY AS WATER SHALLOWS. TSUNAMIS ARE A SERIES OF OCEAN WAVES WHICH CAN BE DANGEROUS FOR SEVERAL HOURS AFTER THE INITIAL WAVE ARRIVAL. DO NOT RETURN TO EVACUATED AREAS UNTIL AN ALL CLEAR IS GIVEN BY LOCAL CIVIL AUTHORITIES.

THE PACIFIC TSUNAMI WARNING CENTER WILL ISSUE MESSAGES FOR HAWAII AND OTHER AREAS OF THE PACIFIC OUTSIDE CALIFORNIA/ OREGON/ WASHINGTON/ BRITISH COLUMBIA AND ALASKA.

ADDITIONAL MESSAGES WILL BE ISSUED HALF-HOURLY OR SOONER IF CONDITIONS WARRANT. THE TSUNAMI WARNING AND WATCH WILL REMAIN IN EFFECT UNTIL FURTHER NOTICE. FOR FURTHER INFORMATION STAY TUNED TO NOAA WEATHER RADIO... YOUR LOCAL TV OR RADIO STATIONS... OR SEE THE WEB SITE WCATWC.ARH.NOAA.GOV.

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Advisories: The Third Level of Tsunami Alert

A tsunami advisory is issued by tsunami warning centers for the threat of a potential tsunami that may produce strong currents or waves dangerous to those in or near the water. Coastal regions historically prone to damage due to strong currents induced by tsunamis are at the greatest risk. The threat may continue for several hours after the arrival of the initial wave, **but significant widespread inundation is not expected for areas under an advisory**. Appropriate actions to be taken by local officials may include closing beaches, evacuating harbors and marinas, and the repositioning of ships to deep waters when there is enough time to do so safely. Advisories are normally updated to continue the advisory, expand or contract affected areas, upgrade to a warning, or cancel the advisory. The following is an example of an advisory product:

WEAK51 PAAQ 231516
TSUNAMI BULLETIN NUMBER 001
PACIFIC TSUNAMI WARNING CENTER
11:16 AM HST 23 JUN 2001

TO: CIVIL DEFENSE IN THE STATE OF HAWAII

SUBJECT: TSUNAMI ADVISORY BULLETIN

A WATCH OR WARNING IS NOT IN EFFECT FOR THE STATE OF HAWAII AT THIS TIME. HOWEVER, THE PACIFIC TSUNAMI WARNING CENTER HAS ISSUED A TSUNAMI WATCH AND WARNING FOR OTHER PARTS OF THE PACIFIC, AND THERE IS THE POSSIBILITY THAT A WATCH OR WARNING MAY BE ISSUED FOR HAWAII IN THE NEAR FUTURE.

AN EARTHQUAKE HAS OCCURRED WITH THE FOLLOWING PRELIMINARY PARAMETERS:

ORIGIN TIME - 10:33 AM HST, 23 JUN 2001

COORDINATES - 16.0 SOUTH, 73.3 WEST

LOCATION - NEAR COAST OF PERU

MAGNITUDE - 8.0 (RICHTER)

MAGNITUDE - 8.2 (MOMENT)

EVALUATION: THIS ADVISORY IS BASED MAINLY ON EARTHQUAKE DATA. IT IS NOT KNOWN AT THIS TIME WHETHER A PACIFIC-WIDE DESTRUCTIVE TSUNAMI HAS BEEN GENERATED. AN INVESTIGATION IS UNDER WAY TO DETERMINE THE TSUNAMI THREAT.

IF A TSUNAMI HAS BEEN GENERATED, THE ESTIMATED EARLIEST TIME OF ARRIVAL IN HAWAII OF THE FIRST TSUNAMI WAVE IS:

11:52 PM HST, 23 JUN 2001

BULLETINS WILL BE ISSUED HOURLY OR SOONER AS CONDITIONS WARRANT.

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Information Statements

An information statement is issued to inform emergency management officials and the public that an earthquake has occurred. In most cases, information statements are issued to indicate there is no threat of a destructive tsunami affecting the issuing tsunami warning center's AOR and to prevent unnecessary evacuations as the earthquake may have been felt in coastal areas. An information statement may, in appropriate situations, caution about the possibility of destructive local tsunamis. Information statements may be reissued with additional information, though normally these messages are not updated. However, a watch, advisory or warning may be issued for the area, if necessary, after analysis and/or updated information becomes available. The following is an example of an information statement:

WEAK53 PAAQ 011308
PUBLIC TSUNAMI INFORMATION STATEMENT NUMBER 1
NWS WEST COAST/ALASKA TSUNAMI WARNING CENTER PALMER AK
608 AM PDT SAT JUL 1 2006

...A STRONG EARTHQUAKE HAS OCCURRED BUT A TSUNAMI IS NOT EXPECTED ALONG THE CALIFORNIA/ OREGON/ WASHINGTON/ BRITISH COLUMBIA OR ALASKA COASTS...

NO - REPEAT NO - TSUNAMI WARNING OR WATCH IS IN EFFECT FOR THESE AREAS.

BASED ON THE EARTHQUAKE MAGNITUDE AND HISTORIC TSUNAMI INFORMATION A DAMAGING TSUNAMI IS NOT EXPECTED ALONG THE CALIFORNIA/ OREGON/ WASHINGTON/ BRITISH COLUMBIA AND ALASKA COASTS. AT COASTAL LOCATIONS WHICH HAVE EXPERIENCED

STRONG GROUND SHAKING LOCAL TSUNAMIS ARE POSSIBLE DUE TO UNDERWATER LANDSLIDES.

AT 600 AM PACIFIC DAYLIGHT TIME ON JULY 1 AN EARTHQUAKE WITH PRELIMINARY MAGNITUDE 7.2 OCCURRED 300 MILES SOUTHWEST OF BERING I. KOMANDORSKI.

THE PACIFIC TSUNAMI WARNING CENTER WILL ISSUE MESSAGES
FOR HAWAII AND OTHER AREAS OF THE PACIFIC OUTSIDE CALIFORNIA/OREGON/
WASHINGTON/ BRITISH COLUMBIA AND ALASKA.

THIS WILL BE THE ONLY STATEMENT ISSUED FOR THIS EVENT BY THE WEST COAST AND ALASKA TSUNAMI WARNING CENTER UNLESS ADDITIONAL INFORMATION BECOMES AVAILABLE.

SEE THE WEB SITE WCATWC.ARH.NOAA.GOV FOR BASIC TSUNAMI INFORMATION - SAFETY RULES AND TSUNAMI TRAVEL TIMES.

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Cancellation of Tsunami Alert

Example of a cancellation of a Tsunami Watch bulletin that was issued for the Indian Ocean region on September 12th for the Southern Sumatra region earthquake:

WEIO21 PHEB 121505
TSUNAMI BULLETIN NUMBER 005
PACIFIC TSUNAMI WARNING CENTER/NOAA/NWS
ISSUED AT 1505Z 12 SEP 2007

THIS BULLETIN IS FOR ALL AREAS OF THE INDIAN OCEAN.

... FINAL INDIAN-OCEAN-WIDE TSUNAMI WATCH ...

THIS THE FINAL TSUNAMI WATCH FOR

INDONESIA / AUSTRALIA / INDIA / SRI LANKA / THAILAND /
UNITED KINGDOM / MALDIVES / MYANMAR / MALAYSIA / BANGLADESH /
MAURITIUS / REUNION / SEYCHELLES / MADAGASCAR / SOMALIA / OMAN /
PAKISTAN / IRAN / YEMEN / COMORES / CROZET ISLANDS /
MOZAMBIQUE / KENYA / TANZANIA / KERGUELEN ISLANDS /
SOUTH AFRICA / SINGAPORE

THIS BULLETIN IS ISSUED AS ADVICE TO GOVERNMENT AGENCIES. ONLY NATIONAL AND LOCAL GOVERNMENT AGENCIES HAVE THE AUTHORITY TO MAKE DECISIONS REGARDING THE OFFICIAL STATE OF ALERT IN THEIR AREA AND ANY ACTIONS TO BE TAKEN IN RESPONSE.

AN EARTHQUAKE HAS OCCURRED WITH THESE PRELIMINARY PARAMETERS

ORIGIN TIME - 1110Z 12 SEP 2007
COORDINATES - 4.5 SOUTH 101.3 EAST
LOCATION - SOUTHERN SUMATERA INDONESIA
MAGNITUDE - 8.2

MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY

GAUGE LOCATION	LAT	LON	TIME	AMPL	PER
SIBOLGA ID	1.7N	98.8E	1434Z	0.09M / 0.3FT	52MIN
PADANG ID	0.9S	100.4E	1348Z	0.98M / 3.2FT	34MIN
COCOS CC	12.1S	96.9E	1236Z	0.11M / 0.4FT	22MIN
DART 23401	8.9S	88.5E	1421Z	0.02M / 0.1FT	15MIN

LAT - LATITUDE (N-NORTH, S-SOUTH)
LON - LONGITUDE (E-EAST, W-WEST)
TIME - TIME OF THE MEASUREMENT (Z IS UTC IS GREENWICH TIME)
AMPL - TSUNAMI AMPLITUDE MEASURED RELATIVE TO NORMAL SEA LEVEL.
IT IS ...NOT... CREST-TO-TROUGH WAVE HEIGHT.
VALUES ARE GIVEN IN BOTH METERS(M) AND FEET(FT).
PER - PERIOD OF TIME IN MINUTES(MIN) FROM ONE WAVE TO THE NEXT.

EVALUATION

SEA LEVEL READINGS INDICATE A TSUNAMI WAS GENERATED. IT MAY HAVE BEEN DESTRUCTIVE ALONG COASTS NEAR THE EARTHQUAKE EPICENTER.

FOR THOSE AREAS - WHEN NO MAJOR WAVES HAVE OCCURRED FOR AT LEAST TWO HOURS AFTER THE ESTIMATED ARRIVAL TIME OR DAMAGING WAVES HAVE NOT OCCURRED FOR AT LEAST TWO HOURS THEN LOCAL AUTHORITIES CAN ASSUME THE THREAT IS PASSED. DANGER TO BOATS AND COASTAL STRUCTURES CAN CONTINUE FOR SEVERAL HOURS DUE TO RAPID CURRENTS. AS LOCAL CONDITIONS CAN CAUSE A WIDE VARIATION IN TSUNAMI WAVE ACTION THE ALL CLEAR DETERMINATION MUST BE MADE BY LOCAL AUTHORITIES.

BASED ON AVAILABLE DATA THIS CENTER DOES NOT EXPECT MORE WIDESPREAD DESTRUCTIVE EFFECT. HOWEVER ...
DUE TO ONLY LIMITED SEA LEVEL DATA FROM THE REGION IT MAY NOT BE POSSIBLE FOR THIS CENTER TO RAPIDLY NOR ACCURATELY EVALUATE THE STRENGTH OF A TSUNAMI IF ONE HAS BEEN GENERATED.

ESTIMATED INITIAL TSUNAMI WAVE ARRIVAL TIMES AT FORECAST POINTS WITHIN THE WARNING AND WATCH AREAS ARE GIVEN BELOW. ACTUAL ARRIVAL TIMES MAY DIFFER AND THE INITIAL WAVE MAY NOT BE THE LARGEST. A TSUNAMI IS A SERIES OF WAVES AND THE TIME BETWEEN SUCCESSIVE WAVES CAN BE FIVE MINUTES TO ONE HOUR.

LOCATION	FORECAST POINT	COORDINATES	ARRIVAL TIME
INDONESIA	BENGKULU	3.9S 102.0E	1123Z 12 SEP
	SIBERUT	1.5S 98.7E	1203Z 12 SEP
	PADANG	0.9S 100.1E	1214Z 12 SEP
	BANDAR LAMPUNG	5.7S 105.3E	1242Z 12 SEP
	SIMEULUE	2.5N 96.0E	1243Z 12 SEP
	CILACAP	7.8S 108.9E	1307Z 12 SEP
	BANDA ACEH	5.5N 95.1E	1329Z 12 SEP
	BALI	8.7S 115.3E	1345Z 12 SEP

LOCATION	FORECAST POINT	COORDINATES	ARRIVAL TIME
	KUPANG	10.0S 123.4E	1453Z 12 SEP
	BELAWAN	3.8N 99.0E	1703Z 12 SEP
AUSTRALIA	CHRISTMAS IS	10.4S 105.4E	1220Z 12 SEP
	COCOS ISLAND	12.1S 96.7E	1234Z 12 SEP
	NORTH WEST CAPE	21.5S 113.9E	1429Z 12 SEP
	CAPE INSPIRATIO	25.9S 113.0E	1526Z 12 SEP
	CAPE LEVEQUE	16.1S 122.6E	1542Z 12 SEP
	PERTH	32.0S 115.3E	1545Z 12 SEP
	AUGUSTA	34.3S 114.7E	1559Z 12 SEP
	GERALDTOWN	28.6S 114.3E	1603Z 12 SEP
	ESPERANCE	34.0S 121.8E	1726Z 12 SEP
	KINGSTON SOUTH	37.0S 139.4E	1906Z 12 SEP
	EUCLA MOTEL	31.8S 128.9E	1934Z 12 SEP
	DARWIN	12.1S 130.7E	1948Z 12 SEP
	HEARD ISLAND	54.0S 73.5E	1955Z 12 SEP
	HOBART	43.3S 147.6E	2015Z 12 SEP
INDIA	GREAT NICOBAR	7.1N 93.6E	1338Z 12 SEP
	LITTLE ANDAMAN	10.7N 92.3E	1421Z 12 SEP
	PORT BLAIR	12.0N 92.5E	1440Z 12 SEP
	NORTH ANDAMAN	13.3N 92.6E	1453Z 12 SEP
	CHENNAI	13.4N 80.4E	1540Z 12 SEP
	KAKINADA	17.2N 82.7E	1604Z 12 SEP
	TRIVANDRUM	8.3N 76.9E	1608Z 12 SEP
	BALESHWAR	21.6N 87.3E	1701Z 12 SEP
	MANGALORE	13.3N 74.4E	1732Z 12 SEP
	BOMBAY	18.8N 72.6E	2005Z 12 SEP
	GULF OF KUTCH	22.7N 68.9E	2019Z 12 SEP
SRI LANKA	DONDRA HEAD	5.8N 80.5E	1447Z 12 SEP
	TRINCOMALEE	8.7N 81.3E	1502Z 12 SEP
	COLOMBO	6.9N 79.8E	1515Z 12 SEP
	JAFFNA	9.9N 80.0E	1625Z 12 SEP
THAILAND	PHUKET	8.0N 98.2E	1508Z 12 SEP
	KO PHRA THONG	9.1N 98.2E	1554Z 12 SEP
	KO TARUTAO	6.6N 99.6E	1626Z 12 SEP
UNITED KINGDOM	DIEGO GARCIA	7.3S 72.4E	1526Z 12 SEP
MALDIVES	GAN	0.6S 73.2E	1528Z 12 SEP
	MALE	4.2N 73.6E	1544Z 12 SEP
	MINICOV	8.3N 73.0E	1614Z 12 SEP
MYANMAR	PYINKAYAING	15.8N 94.2E	1537Z 12 SEP
	CHEDUBA ISLAND	18.9N 93.4E	1554Z 12 SEP
	SITTWE	20.0N 92.9E	1629Z 12 SEP
	MERGUI	12.8N 98.4E	1647Z 12 SEP
	YANGON	16.2N 96.5E	1713Z 12 SEP
MALAYSIA	GEORGETOWN	5.4N 100.1E	1704Z 12 SEP
	PORT DICKSON	2.5N 101.7E	2048Z 12 SEP

LOCATION	FORECAST POINT	COORDINATES	ARRIVAL TIME
BANGLADESH	CHITTAGONG	22.5N 91.2E	1801Z 12 SEP
MAURITIUS	PORT LOUIS	20.0S 57.3E	1803Z 12 SEP
REUNION	ST DENIS	20.8S 55.2E	1820Z 12 SEP
SEYCHELLES	VICTORIA	4.5S 55.6E	1847Z 12 SEP
MADAGASCAR	TOAMASINA	17.8S 49.8E	1900Z 12 SEP
	ANTSIRANANA	12.1S 49.5E	1905Z 12 SEP
	MANAKARA	22.2S 48.2E	1919Z 12 SEP
	CAP STE MARIE	25.8S 45.2E	2009Z 12 SEP
	MAHAJANGA	15.4S 46.2E	2009Z 12 SEP
	TOLIARA	23.4S 43.6E	2034Z 12 SEP
SOMALIA	HILALAYA	6.5N 49.2E	1922Z 12 SEP
	CAPE GUARO	11.9N 51.4E	1933Z 12 SEP
	MOGADISHU	2.0N 45.5E	1938Z 12 SEP
	KAAMBOONI	1.5S 41.9E	2004Z 12 SEP
OMAN	SALALAH	17.0N 54.2E	1930Z 12 SEP
	DUQM	19.7N 57.8E	1939Z 12 SEP
	MUSCAT	23.9N 58.6E	1943Z 12 SEP
PAKISTAN	GWADAR	25.1N 62.4E	1937Z 12 SEP
	KARACHI	24.7N 66.9E	2031Z 12 SEP
IRAN	GAVATER	25.0N 61.3E	1943Z 12 SEP
YEMEN	AL MUKALLA	14.5N 49.2E	2003Z 12 SEP
	ADEN	13.0N 45.2E	2100Z 12 SEP
COMORES	MORONI	11.6S 43.3E	2006Z 12 SEP
CROZET ISLANDS	CROZET ISLANDS	46.4S 51.8E	2009Z 12 SEP
MOZAMBIQUE	CABO DELGADO	10.7S 40.7E	2034Z 12 SEP
	ANGOCHE	15.5S 40.8E	2044Z 12 SEP
	QUELIMANE	18.0S 37.1E	2213Z 12 SEP
	MAPUTO	25.9S 32.8E	2218Z 12 SEP
	BEIRA	19.9S 35.1E	2246Z 12 SEP
KENYA	MOMBASA	4.0S 39.7E	2039Z 12 SEP
TANZANIA	LINDI	9.8S 39.9E	2039Z 12 SEP
	DAR ES SALAAM	6.7S 39.4E	2047Z 12 SEP
KERGUELEN ISLAN	PORT AUX FRANCA	49.0S 69.2E	2049Z 12 SEP
SOUTH AFRICA	PRINCE EDWARD I	46.6S 37.6E	2146Z 12 SEP
	DURBAN	29.8S 31.2E	2205Z 12 SEP
	PORT ELIZABETH	33.9S 25.8E	2256Z 12 SEP
	CAPE TOWN	34.1S 18.0E	2359Z 12 SEP
SINGAPORE	SINGAPORE	1.2N 103.8E	0048Z 13 SEP

THE JAPAN METEOROLOGICAL AGENCY MAY ISSUE ADDITIONAL INFORMATION
FOR THIS EVENT. IN THE CASE OF CONFLICTING INFORMATION...THE
MORE CONSERVATIVE INFORMATION SHOULD BE USED FOR SAFETY.

Chapter 8

Dissemination and Notification

The tsunami warning system end-to-end chain of events, from collecting data to issuing an alert, will only protect the people within a center's area of responsibility (AOR) if individuals and groups receive the message in a timely fashion, understand its meaning, and take appropriate action. The initial link in the chain, earth data observations, requires partnerships between a tsunami warning center and the international community to access global seismic and sea level networks. Similarly, the dissemination and notification link requires partnerships between the center and the many national and local groups and individuals within its AOR. This chapter will discuss the distinctions between dissemination, (the process of physically getting the message to customers within a center's AOR) and notification (the understanding of the received message), along with the methods for each. Outreach and education focus on methods to increase the likelihood that customers will take appropriate actions. This chapter should be read by persons who need to understand this difference between dissemination and notification, and what a National Tsunami Warning Center (NTWC) or Regional Tsunami Watch Provider (RTWP) needs to do to be successful at these tasks.

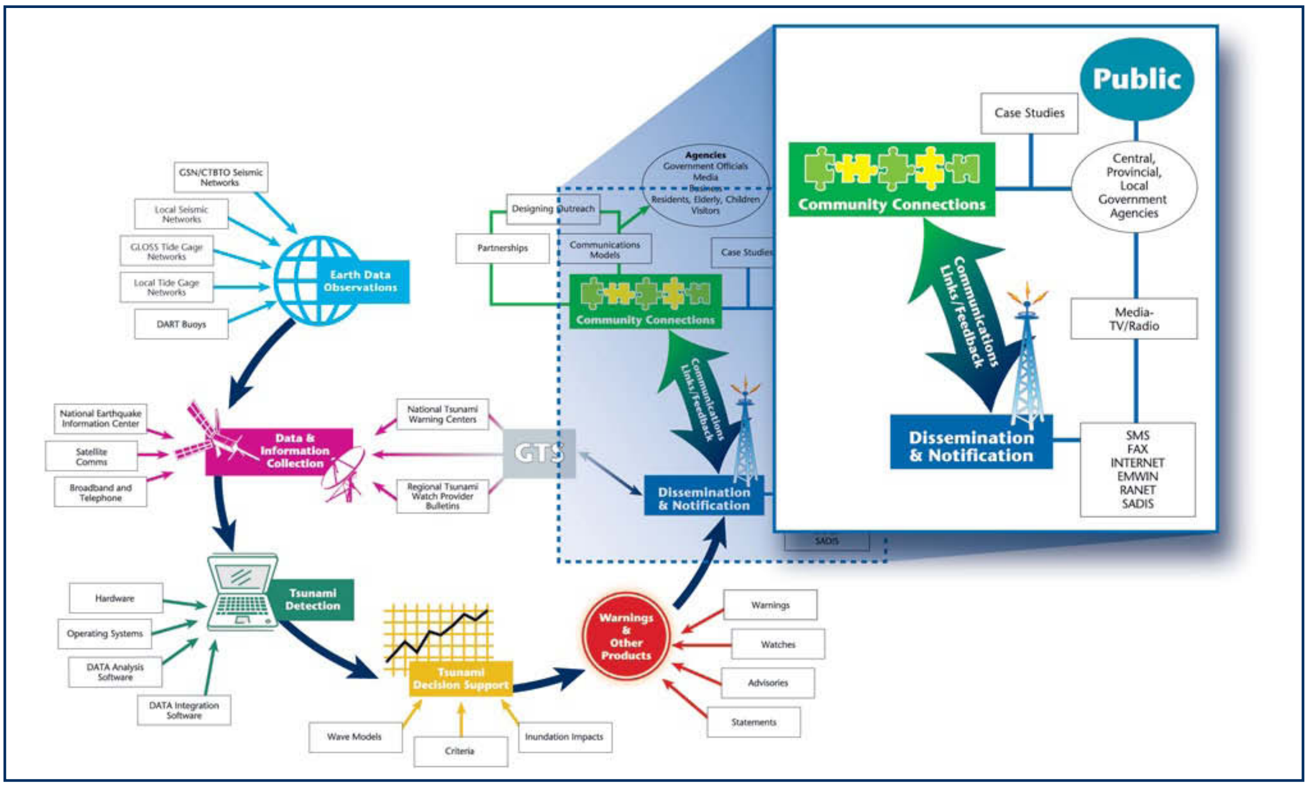


Figure 8-1. Notification and Dissemination Requirements for a Tsunami Warning Center

How Do Warnings and Other Products Fit into an End-to-End Tsunami Warning System?

As noted above, once a warning or other forecast/advisory product has been produced by a center, it must be conveyed to the many groups and individuals in the center's AOR. Once received, the product must be understood and acted upon appropriately. National and local emergency management officials and other government, academic, and private sector individuals usually play a major role in educating the populace, and helping local groups establish resilient communities, evacuation routes, and other procedures.

NTWCs and RTWPs play a significant and crucial role in this outreach and education effort too, especially with regard to receiving valuable feedback on product formats and dissemination methods. This feedback can assist the center in designing products that better meet customer needs. Feedback can also assist in identifying problems with dissemination channels.

What Is in this Chapter?

This chapter contains sections that discuss the following topics:

- **Regional dissemination methods**, including the Group on Earth Observations' (GEO) GEONETCast, Emergency Manager's Weather Information Network (EMWIN), and Radio and Internet for the Communication of Hydro-Meteorological and Climate-Related Information (RANET)
- **Notification procedures**, including warning system design, warning channels, and warning message content
- **Community preparedness**, including the TsunamiReady and Coastal Community Resilience programs
- **Training resources**

What Are the Most Important Points to Remember about Dissemination and Notification Requirements for NTWCs and RTWPs?

- Dissemination refers to the process of physically getting the message to partners and customers, while notification refers to the understanding of the received message by these same partners and customers.
- National and local emergency management officials and other government, academic, and private sector individuals usually play a major role in educating the populace.
- NTWCs and RTWPs also play a significant and crucial role in the outreach and education effort.

Dissemination

Dissemination refers to the process of physically getting the message to RTWP and NTWC customers. This is in contrast to notification, which is the understanding of the received message and, through outreach and education, customers taking appropriate actions. Warnings about events that are seconds, minutes, or hours away need to be disseminated rapidly through special warning systems using messages that have been designed during calmer times to encourage the desired behaviors. They may be for hazards that people can clearly perceive, such as a hurricane, or they may be for hazards that cannot be perceived without specialized equipment or access to intelligence information. In these latter cases, it is critical that the warning system and its operators have a high level of credibility so that people feel compelled to take action based solely on the warning message.

Some of the discussion in this section is based on the Partnership for Public Warning (PPW) publication, "Developing a Unified All-Hazard Public Warning System, a Report by the Workshop on Effective Hazard Warnings," Emmetsburg, Maryland, November 25, 2002 (PPW Report 2002-02).

Warnings are primarily a local government responsibility. Disasters are local, and local government has the primary responsibility to look after the welfare of its citizens. Thus local government has the primary responsibility to warn its citizens and help them to prepare for, respond to, and recover from disasters. However, it is beyond the capability or capacity of local governments to see that a unified, multi-channel, nationally standardized system is available to them for delivering warnings to their citizens.

Most warnings originate from government organizations. Some state and many Federal agencies develop warnings through extensive research and instrument or intelligence networks. In these cases, warnings are often issued by Federal agencies, but usually in close cooperation with state and local emergency managers. For example:

- National meteorological services issue warnings of severe weather and flooding focused on specific localities throughout their countries, and have done so for many years.
- National geological survey agencies issue warnings of earthquakes, volcanic eruptions, and landslides.

Most public disaster warnings are issued by government agencies because in the absence of clear standards of best practice, private organizations could incur significant liability. Many private organizations do issue warnings, for example for weather, but these are usually covered by contracts that limit liability. Media weathermen may refine local warnings for their community but must remain mindful of standards of best practice.

Warning systems require a national partnership between government and industry. Mass warning devices, such as sirens, are typically owned and operated by local government or managers of critical facilities. Warnings can be issued through telephones, pagers, computers, and many other personal communications devices, wired and unwired. The media play an important role in disseminating warnings. Thus, most warning delivery systems need government input, but are manufactured, owned, and operated by private industry and individuals. The government cannot afford to provide the devices that reach every person at risk. Industry can and will provide such devices, or include this capability in all types of devices sold primarily for other purposes, if there are clear national standards that create a national market. There must be an effective public-private partnership between government and industry to deliver warnings.

Tip

The **MEDIA** play a crucial role in disseminating warnings.

The private sector offers complementary resources and necessary infrastructure (e.g., telecommunications networks) that are needed for disseminating warnings. Civil society provides social infrastructure at the grass roots (from **http://www.lirneasia.net/2005/03/national-early-warning-system/**, National Early Warning System: Sri Lanka (NEWS:SL), A Participatory Concept Paper for the Design of an Effective All-Hazard Public Warning System (Version 2.1), Rohan Samarajiva, et al., LIRNE*asia*, Sri Lanka). The use of already existing capacities is not only cost-effective, but ensures the continuity and maintenance of the system during periods where there are no hazard events. The cost to the government of implementing a nationwide warning system is significantly less when all stakeholders shoulder the costs for maintenance, management, and service.

Successful partnerships can be fostered by identifying the key beneficiaries of a warning system, such as the hotel industry and the insurance industry, in addition to the general public. The government can work with such partners in developing and implementing a warning system. The government can provide authority for the system, while the private and civil society sectors provide the mechanisms to get the warning out as fast as possible to all the potentially affected people. There is an ongoing role that the private sector, especially the media, can play in raising education and awareness. The tasks of education and trust-building at the community level are often best done by civil society organizations like the International Red Cross, television channel and newspaper environmental reporters, etc.

Authority is something that has to come from the government. The government must take the ultimate responsibility for the issuance of a warning. People need assurance that a warning message is legitimate before making the sudden decision to abandon their possessions and evacuate the area. They cannot afford to waste precious minutes verifying warning messages to ensure that they are making the right decision. False alarms cost money, breed cynicism, and undermine the credibility of the warning organization.

Warning Message Timing

Centers should be prepared to disseminate specific warnings even if there is a high level of uncertainty about the threat, because the information needed to reduce that uncertainty might arrive only shortly before the incident occurs. In such cases, casualties could occur because an official warning could not be received and acted upon in time by all of those at risk.

Authorities must not withhold information because of concerns for public panic (which is commonly anticipated by authorities but almost never occurs). If authorities do not provide information, people will seek it from other—usually less reliable—sources.

Repeated warning messages at regular intervals ensure that those who missed an earlier warning will have another chance to receive it, and those who ignored an earlier warning will have another opportunity to respond. Repetition also provides those who did not understand an earlier warning another opportunity to comprehend it and those who did not believe an earlier warning another opportunity to reconsider.

Information must be updated quickly when conditions change significantly so that people can adapt their responses to the new situation.

Bulletin Dissemination

Each center needs to inventory all international, national, and local government agencies, and media that require timely receipt of its tsunami bulletin messages. Recipients and communication methods should be identified, established, and tested on a routine basis. Dissemination processes should not be manual; they should be automated as much as possible in order to improve efficiencies that decrease the time required to issue warnings. Automation also decreases elements of human error. Whenever possible, centers should use redundant communications paths to ensure the receipt of critical data and dissemination of important bulletins.

The center should establish protocols between domestic organizations for acquiring information in a timely manner. Improved protocols must be established for seamless transfer of information and data between agencies to ensure the warning system is efficient and effective.

Interagency coordination, operations, and policy issues must be addressed by the NTWC or RTWP. This includes, but is not limited to:

- Developing a “Matrix of Roles and Responsibilities for Key Agencies” supporting the center for tsunami forecasting
- Solidifying political commitment regarding interagency coordination to improve data sharing and agency support to the center
- Allocating sufficient personnel to develop and sustain the national early warning system

- Avoiding duplication by delineating clear lines of agency support. A Memorandum of Understanding between pertinent organizations is useful in delineating roles and responsibilities.

To meet international standards, the following national and local dissemination channels should be used to disseminate bulletins:

- Global Telecommunications System of the World Meteorological Organization (WMO GTS)
- Internet (Frame Relay)
- Internet email
- Telefax
- Internet websites
- RANET
- GEONETCast

The WMO Global Telecommunications Service is the backbone of the international hydrometeorological data dissemination system, but telefax and email are also widely utilized. Two levels of product are distinguished and given separate WMO identifiers:

> The International Civil Aviation Organization (ICAO) maintains an international network of global aeronautical telecommunications circuits for the relay of aeronautical and meteorological data, forecasts, and warnings, for the benefit of the aeronautical users. The Aeronautical Fixed Telecommunications Network (AFTN), used for collection and dissemination of aeronautical and meteorological information for aviation users, is being replaced by higher-speed aeronautical circuits that can be utilized for dissemination of multi-hazard warning messages.
>
> GEONETCast, a planned global multi-hazard dissemination system within the Global Earth Observation System of Systems (GEOSS), shows promise as a reliable primary dissemination method for tsunami products and warning messages.

Warning centers have found that it is important to limit the number of primary dissemination channels and steer customers to those methods. It is recommended that NTWCs and RTWPs use the WMO GTS as the primary dissemination channel for tsunami watch, warning, and advisory products, with secondary and complementary communications systems, such as the satellite-based GEONETCast, EMWIN, and RANET broadcasts as backup. Figures 8-2a and 8-2b show dissemination channels used by the West Coast/Alaska Tsunami Warning Center (WC/ATWC) and Pacific Tsunami Warning Center (PTWC), respectively.

Tip

Tsunami warning centers should strive to limit dissemination channels to a manageable number.

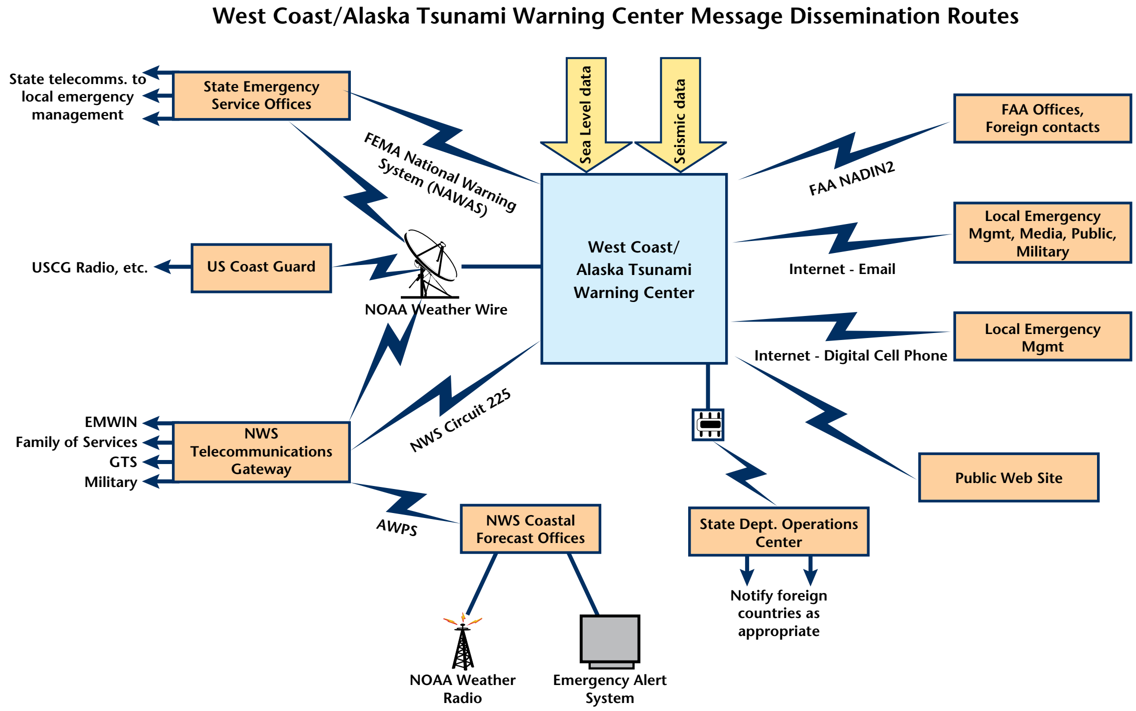


Figure 8-2a. WC/ATWC Dissemination Channels

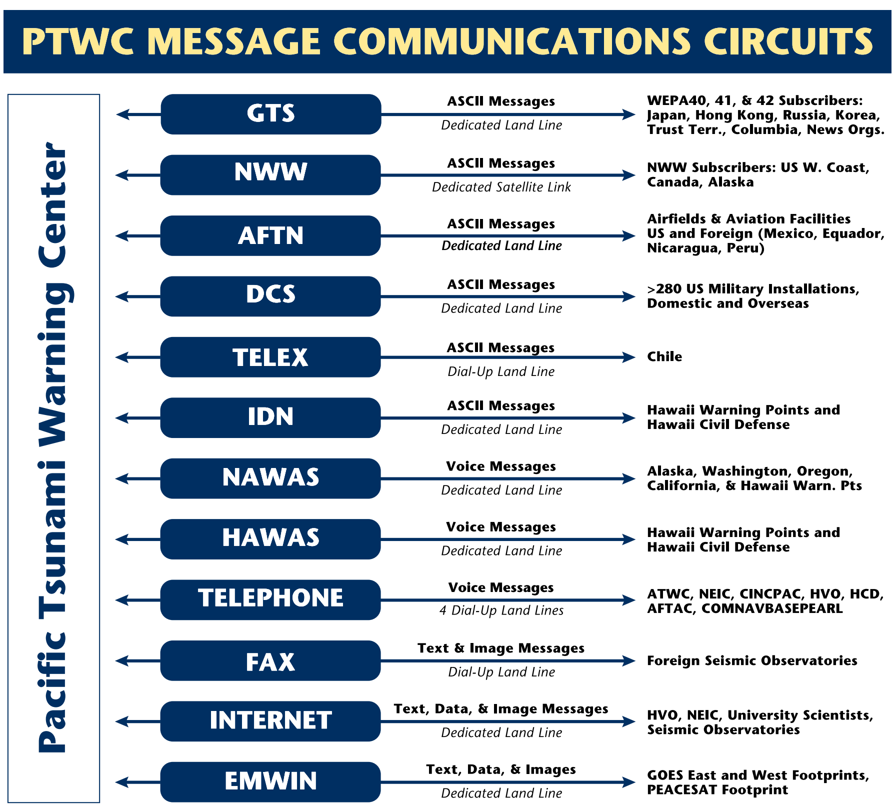


Figure 8-2b. PTWC Dissemination Channels

NTWCs should also strive to establish ways to confirm that both automatic and manual tsunami watch, warning, advisory, and test messages are received by responsible national, regional, and local government agencies. Dissemination techniques need to take advantage of new communications technologies, including cell phone text messaging via Short Messaging Service (SMS), syndicated news feeds via Really Simple Syndication (RSS), Extensive Markup Language (XML/CAP), and Enhanced Multilevel Precedence and Pre-emption Services (EMLPP).

Warning Receivers

Warning message electronic receivers should be used on a daily basis, or they will be put away and forgotten by the public. Ideally, warning capabilities will be found in commonly used appliances, such as radios, cell phones, and telephones, in the near future.

- Receivers must take into account the fact that many people are not adept in the use of advanced technology.
- Warning alerts must be distinct, attention grabbing, and not appear to be another common occurrence. Ideally the alert will provide an indication of the hazard threat level.
- Receivers should provide individuals with the opportunity to test the system themselves; for example, calling a toll free number which sends an alert message only to their receiver.

Warning System Reliability

Even the most carefully designed warning system requires continual maintenance to ensure that it will be effective. Critical phases of maintenance include training, evaluation, and development. Core elements must be used every day, with regular testing by the end user.

Important Points to Remember about Dissemination of Tsunami Warnings

- The WMO GTS is the backbone of the international dissemination of hydrometeorological data products and watch, warning, and advisory messages, and is both point-to-point, and point-to-multi-point. Telefax and email are also widely utilized. The International Civil Aviation Organization (ICAO) Aeronautical Fixed Telecommunications Network/Aeronautical Telecommunications Network (AFTN/ATN) is the backbone for dissemination of aeronautical and meteorological data, and because of its reliability for use by air traffic agencies, is suitable for dissemination of tsunami products to aeronautical users.
- Secondary and complementary communications systems, such as the satellite-based GEONETCast, EMWIN, and RANET broadcasts should be established as backup dissemination channels, although it is acknowledged that in some developing countries, they may be a primary means for receipt of tsunami messages.

- Centers have found that it is important to limit the number of primary dissemination channels and steer customers to those methods, if they are readily available.
- Dissemination techniques should take advantage of new communications technologies.
- The media play an important role in distributing warnings.
- Repeated warning messages at regular intervals ensure those who missed an earlier warning will have another chance to receive it, and those who ignored an earlier warning will have another opportunity to respond.
- The dissemination processes should be automated as much as possible to decrease the time required to issue warnings.

The Emergency Managers Weather Information Network (EMWIN)

Damage from powerful weather and tsunami events, and the threat of serious civil disasters, has illuminated the pressing need to keep the emergency management community up-to-date with the latest information. NOAA's National Weather Service, aided by the National Environmental Satellite Data Information Service (NESDIS) Geostationary Operational Environmental Satellite (GOES) satellites, is using EMWIN to supply vital information to computers throughout North and South America, the Caribbean, and much of the Pacific Ocean basin. The popularity of EMWIN has flourished from its inception, with support from public and private organizations.

What is EMWIN?

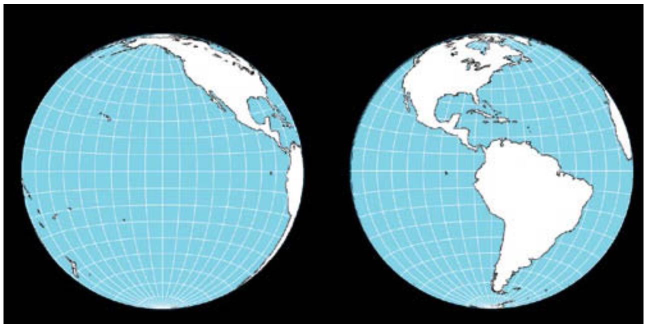


Figure 8-3. GOES West and East Satellites Coverage

EMWIN is a weather warning and data broadcast system that provides rapid dissemination of warnings, forecasts, graphics, and imagery to a desktop computer. The goal of EMWIN is to give emergency managers the capability to respond faster to tsunamis, severe weather, and other threats. That means greater lead times to warn and possibly evacuate communities. Faster response time improves the likelihood of sparing lives and property. The primary dissemination method is an L-band broadcast via the GOES East and West satellites. This allows the EMWIN signal to cover over half of the earth's surface. EMWIN is used both nationally and internationally, and the use of both satellites allows signal redundancy for many areas. The primary audience of EMWIN is the emergency management community; however, its low cost, no recurring fees, and ease of use has made it widely used by the general public.

How EMWIN Works

The National Weather Service (NWS) gathers live weather and emergency information from sources across the globe, and the EMWIN system broadcasts that data. As depicted in Figure 8-4, a satellite downlink enables users to access the EMWIN data stream of real-time weather information and other data. This provides a very reliable data receipt method that can function with little or no infrastructure, making it more reliable than wire and fiber optic systems in disaster situations. This fact has made EMWIN especially useful to island countries, prone to devastating hurricanes and tsunamis.

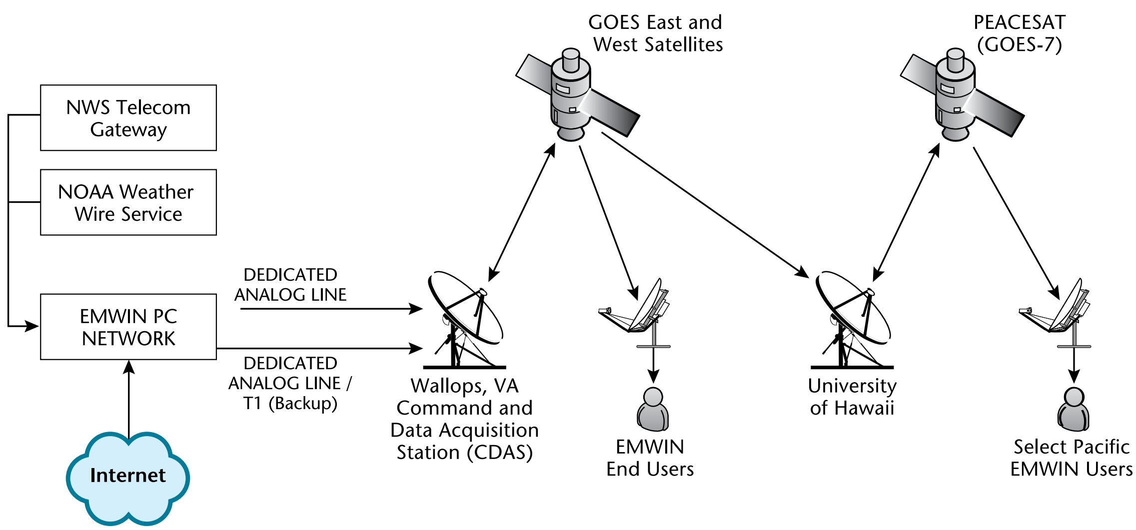


Figure 8-4. EMWIN Configuration

In addition to the GOES satellite broadcast, portions of the EMWIN data stream are also rebroadcast via very high frequency (VHF) radio by dedicated volunteers in certain areas. In the Pacific, the EMWIN signal is rebroadcast on the Pan-Pacific Education and Communication Experiments by Satellite (PEACESAT), operated by the University of Hawaii, thus extending the coverage to the eastern edge of Australia. The rebroadcast technologies allow local emergency management groups and municipal agencies to tailor the information to fit their specific area by filtering the products that do not apply and then allowing the insertion of additional products pertinent to the locality.

The broadcast is also available through the internet in its entirety via internet “push” technology. With this method, users with the appropriate software connect to one of the many EMWIN data servers and begin to receive the broadcast. They are then free to use the data and may also decide to allow connections to their personal computer (PC) if they wish to become part of the distributed network of EMWIN data servers.

Several vendors market EMWIN end user software with many outstanding features. The packages allow the users to display the text products, graphics, and imagery.

Some of the software packages allow users to configure their computer to trigger an alarm when a certain product arrives. Alarm features include automatic activation of lights, sirens, printers, pagers, electronic mail, and other forms of notification. The mail and paging options are extremely powerful. They allow users to receive email alerts and messages to telephones or handheld computers. One package even allows users to send mail to an internet paging service that will then convert the message to speech and call a list of phone numbers. Persons on the phone list will receive a call and a spoken alert.

International Use of EMWIN

A number of countries outside the United States have also begun to use EMWIN to assist with emergency management. This is particularly true in the Pacific Ocean, where EMWIN enjoys a robust partnership with many Pacific island nations through the dedication and coordination of the NWS Pacific Region. EMWIN is a major component of NOAA's contribution to assist the Caribbean region too. Part of the effort focuses on disaster preparedness and mitigation efforts to shield critical commercial and environmental infrastructure in the Caribbean from natural disasters, such as tsunamis and hurricanes.

Based on the feedback from countries initially utilizing the EMWIN capability, additional deployments throughout the Caribbean and South and Central America are planned. The Bahamas purchased a dozen EMWIN systems to ensure coverage for some of its 700 islands. Trinidad and Tobago also plans to deploy the EMWIN capability as part of its ongoing tsunami warning program. EMWIN can also be used as a template for other countries to develop a similar capability in order to tap into their own meteorological satellites.

Unfortunately, EMWIN satellite coverage on the NOAA GOES satellites does not reach into the Indian Ocean region. The orbital position of the GOES West satellite is 135° west longitude and the orbital position of PEACESAT is 175° west. As a result, the usable range of a global beam from GOES West extends to approximately 155° east, and a global beam from PEACESAT extends to approximately 110° east longitude for stations located near the equator. The longitude of Malé and Colombo are 73° 30' and 79° 52', respectively, so the EMWIN system does not provide coverage to these countries.

In addition on the current NOAA GOES satellites, there are brief satellite outages ranging from several minutes up to 60 minutes during each 3- to 4-day satellite eclipse period, each spring and fall. Since tsunami warning information is of a time-critical nature, such outages pose a threat to warning delivery of what is presumed to be the backup system for a terrestrial link. Any loss of terrestrial communications during the eclipse periods would potentially put a station at risk of not receiving a timely warning if EMWIN were to be used as the sole satellite backup to the terrestrial line. Of note is that EMWIN serves as the most reliable source of critical weather information for many Pacific Island countries.

The Future of EMWIN

EMWIN will undergo a transition to remain compatible with the next series of GOES satellites, the GOES-N through P constellation. A transponder dedicated for EMWIN use has been provided on this constellation. Sometime before 2011, the current GOES satellite will be replaced by the new series. All current EMWIN users will need to migrate to newer technologies due to frequency, power, and modulation changes. To meet these future needs, NWS has teamed with NESDIS to develop the EMWIN-N proof-of-concept receive system. Moving to the EMWIN-N broadcast will allow the NWS to make use of improved technologies and will double the current data rate, as well as allow for the use of additional product compression. The EMWIN team is also currently in discussions with NESDIS regarding specifications for the EMWIN broadcast in the GOES-R series of satellites. This collaboration will ensure EMWIN's continued availability well into the future.

Transmission Protocol

EMWIN is designed to be an open system. The format of the EMWIN data-stream transmissions is in the public domain and presented here. This format is intentionally simple to enable reception by a wide range of user hardware. This format, called the Quick Block Transfer protocol, is used across all of the EMWIN dissemination methods, whether radio, satellite, internet or direct cable.

The EMWIN data stream consists of NWS products and other data files. Each product or file, whether American Standard Code for Information Interchange (ASCII) text or binary data, is divided into 1-kilobyte (KB) packets and sent as a series of asynchronous (async) 8-bit bytes, N parity. For example, most current EMWIN radio broadcasts are receivable, when demodulated, as async 1200,8,N,1, while the satellite broadcasts are async 9600,8,N,1.

Each product or file is sent as one or more packets, which are numbered 1...N within the given product. Because the data is packetized, a particular product can be gracefully interrupted by a high-priority warning or alert product and then resume. Note that because the broadcast is receive-only, the receiver has no means of notifying the transmitter of any block errors or of requesting retransmission of individual blocks. Instead, each product is usually transmitted at least twice, to "fill in" any blocks received in error.

Each packet of data contains 1116 bytes, in the following fields:

1. 6 bytes of ASCII 0 (null) to clear the receiver buffer.
2. "/PF" followed by an 8-character file name, a period, and a 3-character file type.
3. "/PN" followed by the block number—the number of this block (1..N) within this file.
4. "/PT" followed by the total number of blocks (N) being sent for this file.

5. "/CS" followed by a checksum number—the sum of all bytes in the 1024-byte data portion of this packet, as a 16-bit unsigned decimal.
6. "/FD" followed by the date/time stamp of this file—in the format of: MM/DD/YY HH:MM:SS AM, without space padding.
7. ASCII 32 (SP) fill—to pad the total bytes in fields 2..8 to a full line of 80 bytes.
8. ASCII 13 (CR) and ASCII 10 (LF) to enhance readability.
9. The data, as a 1024-byte block; if the remaining data of the product is less than 1024 bytes, this block is null-filled so that each packet's data block is always 1024 bytes long.
10. 6 bytes of ASCII 0 (nullNUL) to clear the receiver buffer.

An example of a typical packet header is:

/PFZFPSFOCA.TXT/PN 3 /PT 5 /CS 63366 /FD2/10/95 5:24:26 PM

The content of the NWS products (in the 1024-byte blocks) may be plain ASCII text or graphics or imagery. The products are not encrypted, but will often be compressed. Interpretation of the content of the products is up to the receiver's software. Details of the particular text, graphics, imagery, and compression formats are given below.

Text. Text products are transmitted in English and are usually public forecasts. However, some products may contain a variety of abbreviations or weather-specific acronyms, or may simply be "readable" tables of computer-summarized data. The content is generally 7-bit printable ASCII text, but often also contains hex bytes C5, 80, 03, or 83.

The first line of text of a product is the "WMO" heading, which includes a 4- to 6-character product identifier, a 4-character source site code, and a 6-digit origination date/time in Coordinated Universal Time (UTC). The next line may contain an Advanced Weather Information Processing System (AWIPS) identifier, of 4 to 6 characters portion. In some products, the next line (or embedded lines) may be a Universal Generic Code (UGC) line, giving the specific states, zones, or counties to which the product applies, plus a product-purge date/time (UTC).

Graphics. Graphic products are transmitted in NWS Universal Transmission Format (UTF), a display-independent format. The UTF format includes vectors, characters, and gridded data, but not bitmaps or rasters. It was originally designed to be closely compatible with low end display monitors. The EMWIN UTF products are typically national or regional coarse radar images that can be zoomed by the display software.

Imagery. Satellite weather images (products from GOES) and other interesting pictures are transmitted in standard formats as indicated by the file type/extension. Currently, .GIF and .JPG are used.

Compression. Local data and watches/warnings/advisories are transmitted as clear text and not compressed. Other national data products, such as all surface observations (METARs) for a given hour, are first packed into one "file" and then compressed and transmitted. The EMWIN "UNPACKER" software task will decompress these files upon receipt, and then unpack the constituent data products as if received normally.

The compression/decompression software used is the standard PKUNZIP Data Compression format.

For more information. News updates and additional EMWIN background information can be found on the EMWIN website at: **http://www.nws.noaa.gov/emwin/index.htm**.

Important Points to Remember about EMWIN

- EMWIN is a warning and data broadcast system that provides rapid dissemination of warnings, forecasts, graphics, and imagery to a desktop computer.
- EMWIN can supply vital information to computers throughout North and South America, the Caribbean, and much of the Pacific Ocean basin.
- In addition to the GOES satellite broadcast, portions of the EMWIN data stream are also rebroadcast via VHF radio by dedicated volunteers in certain areas.
- The broadcast is also available through the internet in its entirety via internet "push" technology.

Radio and Internet Technologies for the Communication of Hydro-Meteorological and Climate-Related Information (RANET) to Rural and Remote Communities

RANET is a collaborative effort of many national hydro-meteorological services, non-governmental organizations (NGO), and communities. These varied partners come together to make weather and climate information available to rural and remote populations, which are often among the most in need of environmental forecasts, observations, and warnings. While significant advances have been made in our ability to predict and observe our environment, much of this valuable information remains inaccessible to those outside major cities.

RANET works with partners to identify new and existing technologies that can be utilized by rural communities in a sustainable way. RANET therefore engages in system development and network deployment, but also stresses training and community ownership to ensure that the networks it helps to create are long-lasting.

Tip

RANET has a simple mission: Help national and regional organizations get useful information that is locked in urban areas to rural and remote places in the hope of promoting sustainable development and reducing disaster impacts.

The RANET Approach

The concept and program of RANET was articulated by a number of national agencies and the African Center of Meteorological Applications for Development in the late 1990s. By 2001 the program had begun setting up networks and working with a number of communities. It began in Africa to address real infrastructure problems that face national meteorological and hydrologic services (NMHS) and the development community, but those working on RANET soon found that while the issue of rural communication may be pronounced in Africa, it is in fact a common challenge throughout the globe. As a result, RANET has been working in parts of Africa, Asia, and the Pacific for a number of years. New projects in the United States and elsewhere in Latin America and the Caribbean are likely to emerge in the future. While technology offers a number of solutions to the communication challenges in all these regions, RANET believes that its success is due to a community-based approached that stresses scalability, local ownership, and multi-purpose systems.

Many in the development community would refer to RANET as a "last mile" initiative from the hydro-meteorological community, meaning that the program attempts to deliver information directly to communities and bridge the access gap. There are many "last miles," so to be effective RANET has stressed scalability in its program. What does scalability mean? It means identifying solutions that are very inexpensive to initially deploy, that do not require much if any training, and that can be maintained and serviced with local resources. Whether it is a satellite ground station, a community FM radio station, an HF (High Frequency radio frequencies between 3 and 30 mega Hertz), email network, or other system, RANET works with partners to develop solutions that meet its scalability criteria.

Tip

SCALABILITY =

- inexpensive
- uncomplicated
- locally maintained

Local ownership is also key to sustainability. Simply put, equipment will not be maintained or utilized if ownership is not encouraged. To that end, RANET stresses community listening groups and encourages community associations be established that take on ownership and commitment to maintain equipment and networks. RANET may maintain the satellite platform as a public communications commons, but in the end the program is directed at the national level and equipment owned at the local level.

Finally, RANET encourages its networks to be utilized for other education and humanitarian purposes beyond that of earth science and services. Resources are too scarce to establish communication networks dedicated solely to weather, tsunami, and climate information. Moreover, often communities will not be interested in utilizing hydro-meteorological services and products until their other information needs in agriculture, health, and general education are met. RANET therefore seeks partnerships with organizations that provide useful information and that can share development of a joint network. While new technologies are helping to reduce barriers to knowledge, these technologies can only be of long-term use if community participation and dialogue are encouraged.

RANET Activity Areas and Programs

- **Training:** Communications technology has undergone significant change in just the last decade. Even in rural areas, new technologies allow for new ways of accessing knowledge. RANET provides training to the NMHS community on how to utilize these new systems and technologies.
- **Operations:** On behalf of the meteorological community, RANET maintains a number of operational systems that provide service to a number of countries and regions. These include satellite platforms and a mobile phone messaging infrastructure.
- **RANET Internet Presence Initiative (RIPI):** While the internet and World Wide Web does not reach rural communities, the technologies underpinning the internet are increasingly common across multiple platforms. Moreover, it is important for NMHSs to maintain a web presence that serves the regional and international communities. RANET therefore provides NMHSs with server capacity and training, such that they can maintain a web presence and build capacities utilizing such technologies.
- **RANET Satellite Broadcast Services (RSBS):** RANET works with national agencies to ensure that their information can be broadcast over various satellite platforms, which are appropriate for rural communities or intermediaries such as field extension workers. Traditionally, RANET has utilized capacity on the WorldSpace AfriStar and AsiaStar satellites through an agreement with First Voice International. Such capacity is used to send daily forecasts and agricultural bulletins, and even as part of a tsunami warning system.
- **RANET.mobi:** Mobile phones have become one of the most effective means to reach areas previously underserved by terrestrial communications. RANET is using mobile phone and has developed its own backbone infrastructure to support the collection of remote field data (under the Community Reporter Program), to send alerts to key decision makers, allow users to dynamically queue material on satellite broadcasts, and to allow NMHSs to provide forecasts and similar information through mobile messaging.
- **RANET Alert Watcher:** Utilizing mobile phone SMS (text messages) RANET is providing notification services to key emergency managers and other officials throughout Asia, the Pacific, and Caribbean regions. As a “heads up” system, RANET passes warnings, such as for tsunami, from regional centers to these key decision makers so that they know to seek additional information through official communications.

RANET Organization and Support

RANET is an international collaboration based upon the partnership and resources of many national weather services and related agencies, NGOs and private sector partners, as well as the communities in which RANET works. Base budgetary and technical support for RANET is provided by the U.S. Agency for International Development

(USAID) Office of U.S. Foreign Disaster Assistance (OFDA), the NWS, the Australian Bureau of Meteorology, the Australian Agency for International Development (AusAID), the New Zealand Meteorological Service Ltd., and New Zealand's international aid and development agency (NZAID). Many other donor nations and organizations have provided specific and significant project support. The communities in which RANET works, however, provide an invaluable resource of dedication and time, which in the end is what makes RANET work.

RANET is organized at the country level and most often through an NMHS. Each participant country appoints an individual or team to oversee the development and maintenance of communication infrastructure within the country. Additionally, the national points of contact work with communities to determine information needs and develop field sites. Eventual ownership of field equipment, however, is passed to the recipient community. Generally such ownership is through an existing local NGO or community association. RANET Global consists of a number of technicians and project managers who help to maintain common infrastructure, such as the satellite broadcasts, as well as coordinate resources to support national programs. Each region (Africa, Pacific, etc.) also organizes itself into leadership teams. Such teams consist of the national managers and other relevant individuals. The regional teams come together to mobilize resources, identify need, and articulate a shared vision forward.

News, updates, and further details on the RANET programs are available at **http://www.ranetproject.net**.

International Satellite Communications System (ISCS)

The ISCS is a satellite data distribution system operated by NOAA and the Federal Aviation Administration in support of the World Area Forecast System. The system is operated by MCI Corporation under a NOAA National Weather Service contract. The ISCS support of WAFS is on behalf of the ICAO program for distribution of data to support international civil aviation. ISCS/WAFS provides the worldwide aviation community with operational meteorological forecasts and information about meteorological phenomena required for flight planning and safe, economic, and efficient air navigation.

ISCS support for RMTN is part of a cooperative effort between U.S. NWS and WMO to improve the GTS in WMO Region IV (North and Central America). The RMTN allows for a two-way exchange of meteorological information between the United States and nations in the Caribbean and Central America. The GTS component of ISCS replaced the WMO Caribbean and Central America distribution and collection land line systems for Region IV and makes use of two-way (send/receive) Very Small Aperture Terminal (VSAT) satellite systems. Since the satellite protocols are proprietary, the receiving equipment (2.4-meter parabolic antenna and satellite receiver) must be purchased from MCI, and access to the satellite broadcast is controlled by the meteorological authority of each contracting state.

The system operates a Transmission Control Protocol/Internet Protocol (TCP/IP) multicast broadcast of data in BUFR (Binary Universal Form for the Representation of meteorological data)., GRIB (GRIdded Binary), and alphanumeric formats, with several daily scheduled pushes of large quantities of graphical WAFS data and model data. However, the system can be configured to interrupt the transfer of large, time-consuming files in order to insert high-priority messages such as a tsunami warning. The forward bandwidth of the IP multicast is 128 kilobytes per second (kbps) with capacity up to 512 kbps. The return VSAT links are a minimum of 4 kbps with capacity up to 128 kbps. The ISCS uses commercial C-band satellites operated by Intelsat to broadcast to the Atlantic Ocean Region and to the Pacific Ocean Region, including eastern Asia. The system originates meteorological information from the NWS Telecom Gateway (NWSTG) in Silver Spring, MD, which relays the data for uplink by MCI from Andover, ME, to Intelsat 903 over the Atlantic Ocean Region and from Yacolt, WA, to Intelsat 701. Figure 8-5 shows the ISCS configuration.

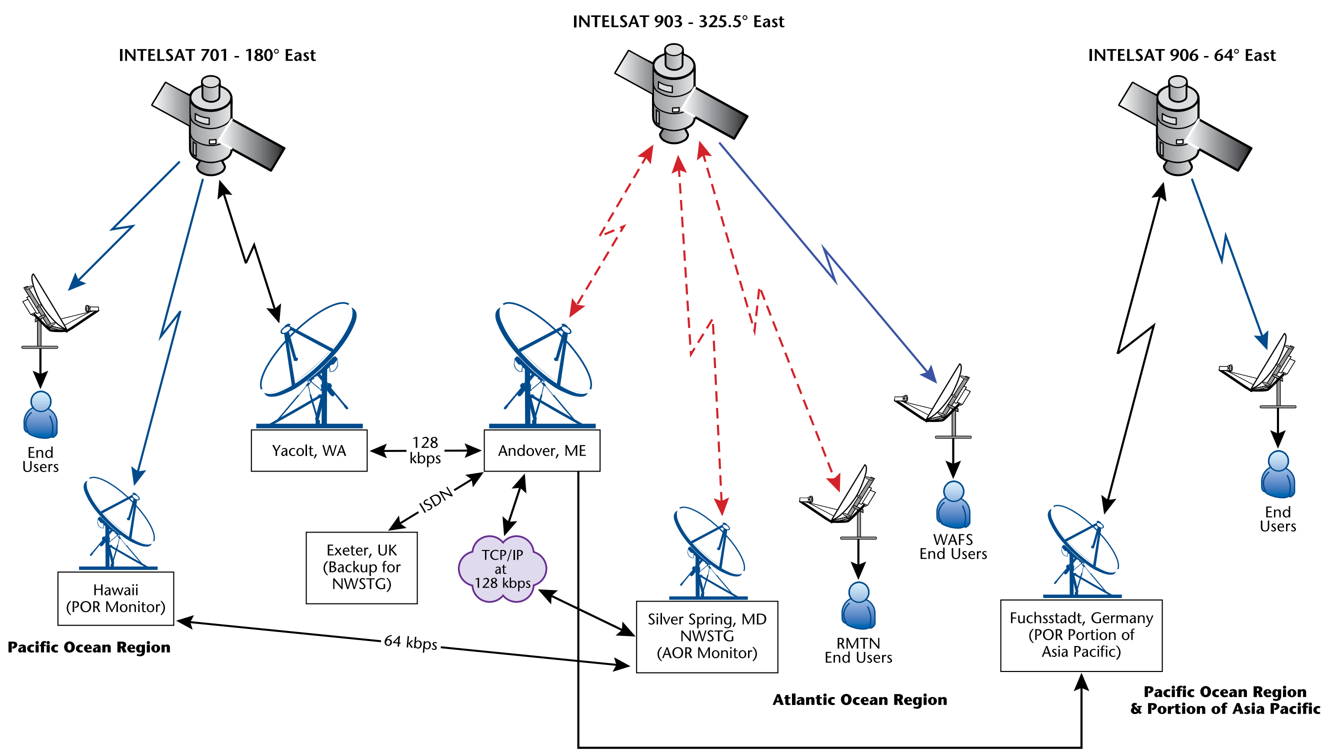


Figure 8-5. International Satellite Communications System (ISCS) Configuration

Important Points to Remember about the International Satellite Communications System

- ISCS is a satellite distribution system operated by NOAA to support WAFS and the WMO Region IV Meteorological Telecommunications Network.
- ISCS allows for a two-way exchange of meteorological information between the United States and nations in the Caribbean and Central America.
- The system can be configured to interrupt the transfer of large, time-consuming files in order to insert high-priority messages such as a tsunami warning.

UK Met SADIS and India Meteorological Department INSAT Satellite Distribution Systems

In addition to US satellite distribution systems like ISCS, EMWIN, and RANET, numerous other countries extend the footprint of areas served by supporting other satellite delivery programs. Two of those programs are the UK Meteorological Office's SADIS and India's INSAT system.

UK Met Office's Satellite Distribution (SADIS) System

The United Kingdom, on behalf of ICAO, operates the SADIS system to broadcast WAFS data to the European, African, Middle Eastern, and Indian Ocean regions not included in the coverage of the ISCS. The SADIS coverage area and the ISCS coverage area are intentionally overlapped to assure continuous worldwide coverage for WAFS. SADIS is uplinked from Whitehall, UK, to Intelsat 904 located at 60° east over the Indian Ocean, and is downlinked using the satellite's C-band global beam. Coverage is from the eastern Atlantic, Cape Verde (20° W) to central Australia (140° E), providing contiguous coverage of the Indian Ocean region.

The SADIS system is a fee-based system with the collected revenue going to offset costs incurred by the UK Met Office for personnel salaries, hardware and software maintenance and replacement, and satellite bandwidth. As with ISCS, the suite of data products may be excessive compared to what is necessary to fulfill the basic requirements for tsunami warning centers.

India's INSAT Distribution System

The Indian Space Research Organization operates several multipurpose satellites in its INSAT fleet. In addition to standard C-band and Ku-band data and video services, part of the INSAT fleet is equipped with S-band capabilities and meteorological observation payloads. In particular, in cooperation with the India Meteorological Department (IMD), INSAT 3A gathers observational data such as infrared and visual observations and distributes this data through the S-band downlink along with additional products uplinked by the IMD from New Delhi. This broadcast of meteorological information essentially constitutes an extension of the GTS throughout India via satellite.

The INSAT distribution system can carry tsunami warning information and may be a good option for satellite reception by national meteorological centers within its footprint. Available footprint plots indicate the satellite's power is concentrated on the country of India and falls off sharply outside the country.

The INSAT feed is also provided by the IMD to WorldSpace, which broadcasts it using the westernmost AsiaSat satellite. This offers a much wider potential distribution area, as this satellite was specifically designed to cover India, parts of Asia, and the Middle East. The general coverage footprint for the three operational AsiaSat satellites is shown in Figure 8-6. The WorldSpace system was designed to deliver multiplexed audio and data services to small, portable, inexpensive consumer receivers with small patch antennas. To receive the INSAT meteorological data feed via WorldSpace, the user needs a WorldSpace receiver, a small data interface unit that forwards data from the receiver to a PC, the associated PC software, and a WorldSpace subscription. In addition, the INSAT data feed is offered only to a closed user group, and authorization is required by the IMD.

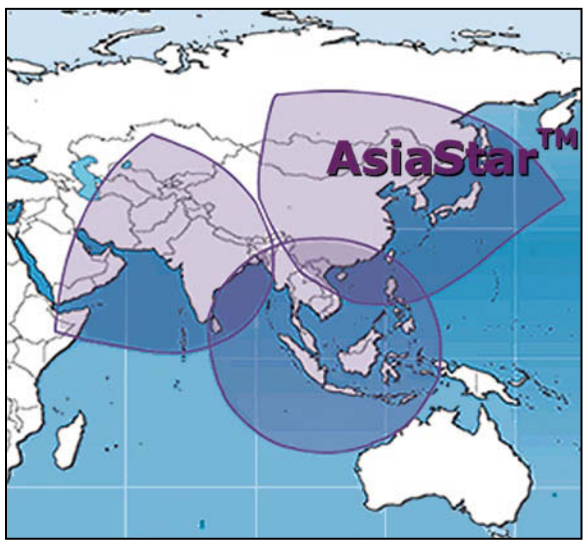


Figure 8-6. WorldSpace's AsiaSat Satellite Coverage Footprint

Important Points to Remember about SADIS and INSAT

- SADIS broadcasts WAFS data to the European, African, Middle Eastern, and Indian Ocean regions not included in the coverage of the U.S.-operated ISCS.
- The INSAT feed is provided by the IMD to WorldSpace, which broadcasts it using its AsiaSat satellite. This provides a wide distribution area, as this satellite was specifically designed to cover India, Asia, and the Middle East.

GEONETCast—the Dissemination Component of GEOSS

GEONETCast is an initiative within the United Nations' GEO framework. Led by NOAA, WMO, the Chinese Meteorological Agency (CMA), and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), GEONETCast addresses the global dissemination needs of the GEOSS environmental data in a coordinated way.

Based on discussions between EUMETSAT and the United States NOAA, U.S. Co-Chair retired Navy Vice Admiral Conrad C. Lautenbacher, Jr, Ph.D., undersecretary of commerce for oceans and atmosphere and NOAA administrator, presented the concept to the GEO Executive Committee on September 30, 2005. EUMETSAT and NOAA then presented it to the second GEO plenary meeting in December 2005, which adopted the concept in principle. GEO members and participating organizations recognized that GEO could add value to existing operational and prototype technological efforts that were already under way to enhance the delivery of data and information to users.

Tip

GEONETCast: a worldwide, operational, end-to-end Earth observation data collection and dissemination system.

Participation in GEONETCast as a data provider, end user, or dissemination infrastructure provider is voluntary. The intergovernmental GEO has defined the GEONETCast task as Capacity Building Task #CB-06-04, with oversight by the GEO Architecture and Data Committee. It is critical, however, that the task also work with the GEO User Interface and Capacity Building Committees and others to identify additional data, products, and services.

GEONETCast builds on the experience gained by EUMETSAT with the EUMETCast operational dissemination system, and on the WMO Integrated Global Data Dissemination Service (IGDDS) concept. GEONETCast is a truly global dissemination system by which environmental in situ, airborne, and space-based observations, products, and services posted to the GEOSS are transmitted to users through a global network of communications satellites, using a multicast, access-controlled, broadband capability.

Overview

GEONETCast uses the multicast capability of a global network of communications satellites to transmit environmental satellite and in situ data and products from providers to users within GEO (see Figure 8-7). Commercially available technology provides cost-efficient solutions with easy-to-implement terminals, which are widely used for direct-to-home digital television. The multicast capability allows different datasets to be handled in parallel, regardless of the source. The use of a key access capability enables the data policy of each data provider to be respected, and also allows for the distribution to individuals or groups of users, as appropriate, to be targeted within the footprint of each satellite (see Figures 8-8 and 8-9). This capability is especially useful in parts of the world where high speed land lines and/or internet are not available.

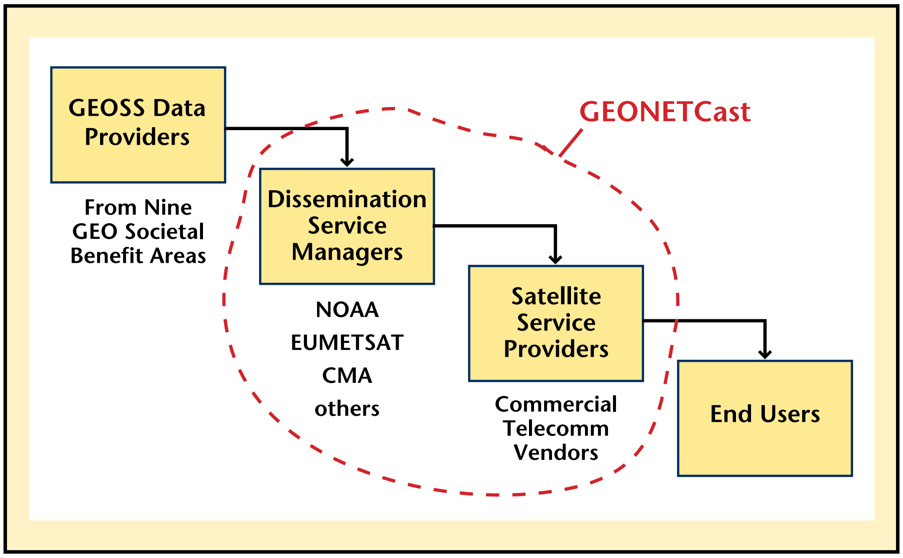


Figure 8-7. Structure of GEONETCast

GEONETCast consists of three major components:

- Existing dissemination infrastructure
- Data providers/sources
- The global environmental user community

Currently, EUMETCast, operated by EUMETSAT, provides the dissemination infrastructure that hosts GEONETCast. This provides geographic coverage of Europe, the Middle East, Africa, and South, Central and most of North America. The Chinese Meteorological Administration (CMA) is integrating FengYunCast into GEONETCast. This provides geographic coverage of the Asia/Pacific region. FengYunCast is planned as an evolution of an existing CMA-operated dissemination system that provides geographic coverage of China and a number of neighboring countries, including the Southwest Pacific. Additionally, NOAA is establishing a dissemination system that provides comprehensive coverage of the Americas, called GEONETCast Americas. The draft *GEONETCast in the Americas: A Vision and Concept Document* provides an overview of the GEONETCast Americas concept developed within NOAA. Users in the region will, with GEONETCast Americas, be provided with a long-term perspective for access to GEONETCast.

Together, these three regional systems (EUMETCast, FengYunCast, and GEONETCast Americas) form GEONETCast, and have the capability to provide near global geographic coverage as shown in Figures 8-8 and 8-9. The added value that GEONETCast brings is to facilitate and enhance access, particularly for developing countries, to key environmental data of GEO by applying standards across, and encouraging the development of, regional systems. These three regional systems are seen as the minimum required to establish global geographic coverage. Should additional regional systems

Figure 8-8. Initial and Final Coverage for GEONETCast Americas

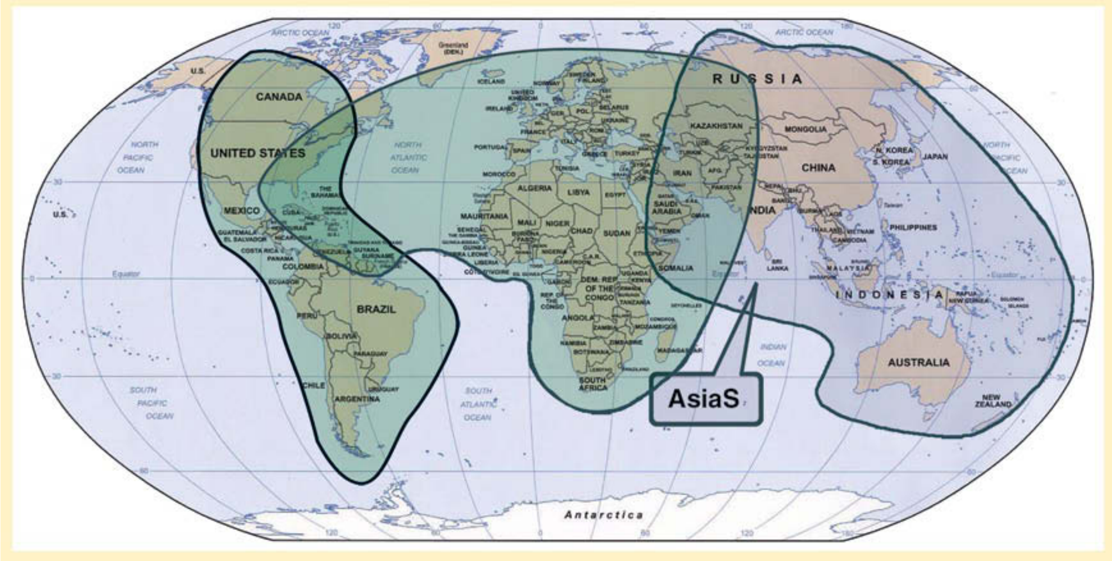


Figure 8-9. Coverage of EUMETCast and FengYunCast

be made available, the GEONETCast concept is flexible and scalable enough to easily accommodate them.

These systems will utilize uplink ground stations and available telecommunication technology from geostationary satellites so that costs can be kept affordable for users through the purchase of existing off-the-shelf equipment. Data from each region can be disseminated outside the originating region through the utilization of data-exchange links between the regions. This inter-region data exchange can take place using a number of possible methods such as dedicated data-exchange links, overlapping satellite footprints, or some existing network such as the GTS or the internet.

This satellite-based dissemination system is one component of a larger GEO data distribution network that may utilize the internet and/or high-speed fiber optic land lines; however, these methods are not specifically addressed by the current GEONETCast concept. The scope of GEONETCast may evolve over time to include these data distribution methods as a means to distribute data to users as required.

Service Standards

Each of the dissemination systems which together form GEONETCast (and any future regional systems) are recommended to comply with a number of service standards:

- Each regional system provides a single entry point, known as a network center.
- The network centers can be linked together to provide data exchange between them.
- Each network center should provide connectivity and system capacity to data providers from all GEO Societal Benefit Areas (SBA) within the region.
- Each network center should provide bandwidth to support data dissemination from outside the region.
- Network center operators are responsible for managing and interfacing with users in coordination with data providers located within the region.
- Network center operators are responsible for managing and interfacing with users in coordination with the other network center operators (who are representing the data providers of their respective regions).

Technical Standards

At the technical level, a number of standards have emerged as forming the baseline for dissemination systems that contribute to the GEONETCast infrastructure:

- Contributing dissemination systems should be generic, multi-service dissemination systems, based on standard Digital Video Broadcast (DVB) technology.
- Use of commercial broadcast channels on television, direct-to-home telecommunication satellites is encouraged.
- Use of commercial, off-the-shelf, commonly available reception equipment is encouraged.
- Use of IP is encouraged over DVB standard coding.
- Systems should support transparent transfer of files (files should be received exactly as sent).
- Use of standard, openly described file formats is encouraged; examples currently in use are L/HRIT, BUFR, GRIB, HDF, netCDF.

- Contributing systems should provide secure access control at individual file and user level.
- The systems should be open, flexible, and scalable at both the network center and user terminal levels.
- Quality of service should be ensured and regularly monitored.
- Catalogues of transmitted data should be maintained and made available for consultation by users in order to facilitate data discovery and subscription.
- Dissemination should be organized in multiple multicast channels corresponding to product categories, which are associated with Program Identifiers.

Important Points to Remember about GEONETCast

- GEONETCast is a truly global dissemination system by which environmental *in situ*, airborne, and space-based observations, products, and services from contributions to the GEOSS are transmitted to users through a global network of communications satellites, using a multicast, access-controlled, broadband capability.
- Commercially available technology provides cost-efficient solutions with easy-to-implement terminals, which are widely used for direct-to-home digital television.
- Three regional systems (EUMETCast, FengYunCast and GEONETCast Americas) form GEONETCast, and have the capability to provide near global geographic coverage.
- Inter-region data exchange can take place using a number of possible methods such as dedicated data-exchange links, overlapping satellite footprints, or some existing network such as the GTS or the internet.
- Dissemination systems are generic, multi-service dissemination systems, based on standard DVB technology.
- Countries being serviced by a GEONETCast distributor should initiate contact and establish communications paths for the uplink of their environmental data, including data and products used by NTWCs and RTWPs, as a reliable method to disseminate tsunami warnings, forecasts, and advisories.

Notification

Notification encompasses the understanding of the received message by the target audience, and additionally the implementation of appropriate actions by those at risk. In many ways notification is more difficult than dissemination, which involves simply physically getting the message to stakeholders.

Much of the discussion in this section is based on the Partnership for Public Warning publication, “Developing a Unified All-Hazard Public Warning System, a Report by the Workshop on Effective Hazard Warnings," Emmetsburg, Maryland, November 25, 2002 (PPW Report 2002-02).

Tip

The goal of warning is to prevent hazards from becoming disasters.

Warnings seek action. A warning system is an organized process for detecting a hazard and rapidly disseminating information about the threat and about appropriate protective actions. An effective warning system is one that causes the maximum appropriate protective actions to be taken for a given commitment of resources, because it has been designed to be compatible with the context in which it operates. Understanding this context requires knowledge of the other participants in the warning system for a given hazard, the other types of hazards faced by those participants, and the warning systems that are currently in use for those other hazards.

The warning process consists of people with information communicating with people at risk, and others such as emergency responders, in advance of or during a hazardous event, with the intent that those at risk will take appropriate action to reduce casualties and losses. The success of a warning is measured by what actions people take. A warning might recommend immediate action or it might simply encourage people to seek more information.

Many people are involved in the warning process. Warnings must be received and understood by a complex target audience including the general public, institutional decision makers (in business, state and local government, and NGOs), and emergency responders (firefighters, law enforcement officers, paramedics, public health workers, and emergency managers).

The news media and the emergency management community frequently act as intermediaries between those issuing warnings and households (or other information end-users). These intermediaries—together with independent experts in university research institutes, national laboratories, and other agencies—critically evaluate the information disseminated by the technical experts to determine if it is accurate, internally consistent, consistent with other sources' messages, complete, specific, timely, relevant, and important. If a warning is judged to be inadequate in any of these respects, it will be challenged, supplemented with additional information, or ignored.

Moreover, end users evaluate the warnings they receive from all sources in terms of their prior knowledge about the hazard and the recommended response actions. Finally, end users also evaluate the warnings they receive about any given hazard in terms of their knowledge about other safety and health hazards and recommended actions for those other hazards. It is also important to remember that "the general public" is really "publics" since it involves:

- Decision makers at all levels in the community
- People with many different levels of education

- People with many different levels of financial ability and responsibility
- People of different races and beliefs
- People with many different primary languages
- People with widely varying experience with the hazard
- People with varying levels of physical ability

It is critically important for centers to test their message dissemination communication channels frequently, and identify dissemination problems, so the tsunami messages reach the end users when a real tsunami event occurs.

Warning System Design

NTWCs and RTWPs should not assume that there will be immediate reception of a warning, unlimited attention to the warning message, perfect comprehension of message content based upon accurate prior knowledge about the threat, and perfect compliance with the recommended actions. None of these conditions will occur, even though reception, attention, comprehension, and personalization increase when there is an imminent threat. Consequently, warning systems and warning strategies must be carefully designed to make it more likely that warnings will be as effective as possible. Effective warning system design consists of four main steps:

- Define the desired message effects, especially the behavioral objectives of the system. What actions do authorities want the end-users to take?
- Identify any distinctively different segments of the target population. How do people differ in terms of their abilities to receive a warning, attend to it, comprehend its content, personalize the threat, choose an appropriate protective action, and implement that protective action?
- Identify the channels through which warning messages will be transmitted. What technologies and what intermediate sources are needed?
- Define who the initial message sources will be and develop their perceived credibility by taking steps to ensure their expertise and trustworthiness.

Warning Channels

As noted in the section on dissemination, centers should identify all the communications channels to which different segments of the population have access. It is especially important to identify the channels that people monitor routinely, as well as those that can reach people rapidly during emergencies. Use multiple methods and channels to disseminate messages. These include print and electronic media, the Internet, and even face-to-face presentations from credible original and intermediate sources. Encourage people to tune to reliable sources of local broadcast news.

Warning Message Content

NTWCs and RTWPs should be as specific as possible about the nature of the threat, the anticipated impact location, and the expected time of impact. Decision makers in business, government, and NGOs need to have as much information as possible so they can weigh the consequences of alternative actions (including inaction) before expending significant resources on protective measures.

Tip

Create standard forms for text messages and oral messages for use in times of emergency.

Recommend one or more specific protective actions. One of the major incentives is protection of persons and property from the hazard. Determine how to describe the hazard so that the message generates a high level of protection motivation. Explain to those who are not at risk why they are not believed to be at risk and why they do not need to take protective action. Use terminology in warning messages that is consistent across time for a given hazard and, to the greatest extent possible, compatible with the terminology that is used for other hazards Let people know when the threat has ended so they can resume normal activities as soon as possible. As much as possible, RTWPs and NTWCs should create standard forms for text messages and oral messages and store them for future use during events. Figure 8-10 provides an example of a preformatted message for watch standers to read directly on radio, television, etc.

Warning Sources

Centers must recognize that no single source has complete credibility regarding all aspects of the threat and protective actions. Federal, state, and local government agencies vary in their credibility, as do news media, business, and NGOs. Identify in advance which organizations (and individuals within those organizations) will be responsible for communicating with those at risk, as well as with other population segments that are not at risk. Identify procedures by which information from different sources can be combined to ensure that each individual source's messages are consistent with all other sources' messages and that, together, all official sources' messages are accurate, complete, specific, internally consistent, timely, novel, and relevant.

Recognize that source credibility can be established initially by credentials such as agency mission and educational degrees, but is enhanced by preparing objective (transparent) procedures in advance rather than improvising during an incident, by obtaining endorsement by external experts (peer review), and by establishing a satisfactory record of performance over time. Build credibility and understanding that the warnings are based on the best available professional practice. Develop credible, articulate authorities to use consistently.

Tip

Develop and utilize trusted personalities who the public know and respect.

LOCAL TSUNAMI INFORMATIN BULLETIN

Attention all stations. Repeat. Attention all stations.

This is the Pacific Tsunami Warning Center.

A local earthquake has just occurred.

---

epicenter location – for example, "on the southeast coast of the Big Island"

No tsunami is expected. Repeat. No tsunami is expected.

Once Again.

This is the Pacific Tsunami Warning Center.

A local earthquake has just occurred.

---

epicenter location – for example, "on the southeast coast of the Big Island"

No tsunami is expected. Repeat. No tsunami is expected.

A hardcopy message with more detailed information will be transmitted shortly.

State Warning Point, Contact All County Warning Points. Please Acknowledge.

Time Read on HAWAS: ___________________ Initial: _______

___ Notify State Civil Defense Duty Person (see current SCD Emergency Notification Sheet)

___ Notify ____

___ Notify ____

Source: Pacific Tsunami Warning Center Operations Manual

Figure 8-10. Example of a Preformatted Oral Message (Information Bulletin)

Warning System Context

Federal authorities who are responsible for warning frequently think only of disseminating threat information to the general public, but it is important to recognize that the target audience is much more complex than this. Centers need to recognize that "the public" is not a homogeneous entity. Households, businesses, government agencies, and NGOs vary in size, demographic composition, geographic location, and economic resources.

Centers should identify the ways in which population segments differ in their perceptions of the credibility of different sources, their access to different warning channels, their reactions to warning message content, and the incentives, disincentives, and constraints they are likely to experience in attempting to take protective actions.

Important Points to Remember about Notification

- An effective warning system is one that causes the maximum appropriate protective actions to be taken.
- The news media and the emergency management community frequently act as intermediaries between the center issuing warnings and a complex target audience including the general public, institutional decision makers, and emergency responders.
- It is critically important for centers to test their message dissemination communication channels frequently, and identify dissemination problems, so the tsunami messages reach the end users when a real tsunami event occurs.
- RTWPs and NTWCs should create standard forms for text messages and oral messages and store them for future use during events.

NTWC and RTWP Community Preparedness Programs

Community preparedness can be thought of as the advance capacity of a community to respond to the consequences of a tsunami (or other adverse event) by having plans in place so that people know what to do and where to go if a tsunami warning is issued or a tsunami is observed. This result can be achieved through the development of programs like the United States' TsunamiReady program, in which communities have plans, enhanced communications, and heightened awareness among their citizens. This type of program will increase resilience to tsunami events, reduce economic losses, and shorten recovery periods.

Tip

Preparedness is having plans in place to respond properly to a warning.

Effective community preparedness programs also address hazard mitigation: sustained actions taken to reduce or eliminate the long-term risk to human life and property based on tsunami risk assessments. This includes planning and zoning to manage development in areas particularly at risk for tsunami, embracing tsunami resistant construction, and protecting critical facilities and infrastructure. The United States' concept of tsunami resilient communities, and the Coastal Community Resilience (CCR) program are an example of this type of tsunami mitigation program.

Outreach and communication with the public is crucial to their understanding of the nature of the tsunami hazard, the risks to personal safety and property, and the steps to reduce those risks. Key components include raising public awareness and effecting behavioral change in the areas of mitigation and preparedness; the deployment of stable, reliable, and effective warning systems; and the development of effective messaging for inducing favorable community response to mitigation, preparedness, and warning communications.

Many tsunami warning system requirements (data communications, data processing, products, dissemination, etc.) are, in part, driven by the characteristics of a center's partners and customer base. Since partners and customers can vary significantly from center to center, it is difficult here to precisely identify these groups. However, some general guidelines and techniques apply to most situations, as described below.

Much of the discussion in this section is based on the publication, "Tsunami Risk Reduction for the United States: A Framework for Action by the National Science and Technology Council, A Joint Report of the Subcommittee on Disaster Reduction and the United States Group."

Identifying Partners and Customers

Partners are generally other government and nongovernmental groups that play some role in the end-to-end tsunami warning system chain. These will include:

- Domestic and international data providers
- Government and private groups (including the mass media) that serve as communications conduits for product dissemination
- Government and private-sector groups that train and educate other center partners and customers

Customers are those groups and individuals that rely on a tsunami warning center and its partners for timely and accurate tsunami watches and warnings for protection of their lives and the opportunity to minimize the impact on their property. Customers include:

- The general public
- NGOs and other private-sector groups that must respond to events
- Government agencies that must respond to events

A center's outreach and education program must recognize these two distinct classes of constituents since each has unique requirements. The center may even have to employ different techniques to identify and deal with the major groups that comprise each of these two categories.

Tip

A center needs a **PUBLIC AFFAIRS OFFICER** to coordinate with the media during events.

The goal and focus of outreach should be to educate the public and other partners about tsunami safety and preparedness and promote the center's tsunami warning program through public events, media workshops, and the public school system. During actual tsunami events, the center should have a designated public affairs officer to coordinate media response. During annual tsunami exercises, the public affairs officer is responsible for notifying the media.

A center's public affairs officer should also provide media training and guidance to agency representatives, respond to media requests, organize news conferences, coordinate briefings and tours at the warning centers, develop informational materials, assist with congressional briefings, and plan outreach activities.

Hawaii Tsunami Technical Review Committee

In Hawaii, for example, a Tsunami Technical Review Committee composed of tsunami experts from academia, government, and the private sector meets on a regular basis to review research, exchange information, and coordinate projects. Several committees have been formed, including a Public Affairs Working Group. The public affairs group meets regularly to plan and coordinate outreach events. Membership includes technical experts and public affairs, outreach, and education officers from government agencies, the Hawaii Tourism Board, the Pacific Tsunami Museum, and academia. This committee plays an important role in coordinating tsunami-related projects, community awareness events, etc., and could serve as a model forum for use in other countries.

Media training workshops should be held on a regular basis to keep media informed about changes and improvements in the tsunami warning program; help media understand the operations of the NTWC or RTWP and the end-to-end system, including the relationship between the warning center and emergency managers; and help media understand the differences in the watch and warning messages, and how the information should be presented to the public.

Well coordinated plans and procedures for working with the media and public/governmental officials are essential for the staff at a center. Providing media outreach training to the operational staff should be routine, and should not wait until a major tsunami has occurred. This may require coordination of public outreach/affairs personnel from within different agencies at all levels of government.

Important Points to Remember about Community Preparedness Programs

- Outreach and communication with the public is crucial to their understanding the nature of the tsunami hazard, the risks to personal safety and property, and the steps to reduce those risks.
- During actual tsunami events, a tsunami warning center should have a designated public affairs officer to coordinate media response.
- Well coordinated plans and procedures for working with the media and public/governmental officials are essential for the operational staff at a center.

U.S. TsunamiReady Program

The United States' TsunamiReady program promotes tsunami hazard readiness as an active collaboration among Federal, state and local emergency management agencies, the public, and the National Weather Service's tsunami warning system. This collaboration supports better and more consistent tsunami awareness and mitigation efforts among communities at risk.

TsunamiReady Program Objectives

The main goal of TsunamiReady is improvement of public safety during tsunami emergencies. To meet this goal, the following objectives need to be achieved:

- Create minimum standard guidelines for a community to follow for adequate tsunami readiness.
- Encourage consistency in educational materials and response among communities and states.
- Recognize communities that have adopted TsunamiReady guidelines.
- Increase public awareness and understanding of the tsunami hazard.
- Improve community preplanning for tsunami disasters.

TsunamiReady Benefits

Benefits of becoming a TsunamiReady community include:

- Increased community preparedness.
- Regularly scheduled education forums.
- Increased contact with experts (emergency managers, researchers, NWS personnel).
- Identification of community readiness resource needs.
- Improved positioning to receive State and Federal funds.
- Enhanced core infrastructure to support other community concerns.
- Transparency in hazard program use of public tax money.

TsunamiReady Community Requirements

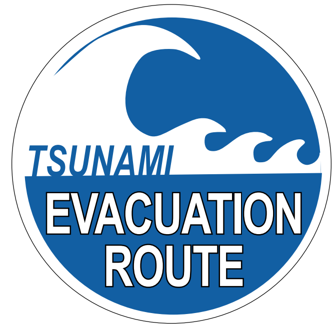
TsunamiReady establishes minimum guidelines for a community to be awarded the TsunamiReady recognition. Communities that accept the challenge to become tsunami ready and meet requirements set by the program are designated as TsunamiReady communities. Table 8-1 presents the guidelines to achieve TsunamiReady recognition. Each guideline is discussed in detail following the table. Four community categories (based on population) are used to measure tsunami readiness.

Table 8-1. Requirements for Recognition as a TsunamiReady Community

Guideline	Population < 2,500	2,500–14,999	15,000–40,000	> 40,000
1: Communications & Coordination				
24 hr Warning Point (WP)	X[1]	X[1]	X	X
Emergency Operations Center (EOC)	X[1]	X[1]	X	X
2: NWS Warning Reception				
Number of ways for EOC/WP to receive NWS tsunami messages (If in range, one must be NWR with tone-alert, NWR-SAME is preferred)	3	4	4	4
3: Hydrometeorological Monitoring[2]				
Number of systems to monitor hydrometeorological data	1	2	3	4
4: Warning Dissemination				
Number of ways for EOC/WP to disseminate warnings to public	1	2	3	4
NWR tone-alert receivers in public facilities (where available)	X	X	X	X
For county/borough warning points, county/borough communication network ensuring information flow between communities	X	X	X	X
5: Community Preparedness				
Number of annual tsunami/weather safety programs	1	2	3	4
Designate/establish tsunami shelter/area in safe zone	X	X	X	X
Designate tsunami evacuation areas and evacuation routes, and install evacuation route signs	X	X	X	X
Provide written, locality specific, tsunami hazard response material to public	X	X	X	X
Schools: encourage tsunami hazard curriculum, practice evacuations, and provide safety material to staff and students	X	X	X	X
6: Administrative[2]				
Develop formal tsunami hazard operations plan	X	X	X	X
Yearly meeting/discussion by emergency manager with NWS	X	X	X	X
Yearly meeting/discussion by emergency manager with NWS	X	X	X	X

Notes:

1. For cities or towns with fewer than 15,000 people, a 24-hour warning point and EOC are required; however, another jurisdiction within the county may provide that resource. For smaller communities in Alaska and Pacific Regions with fewer than 2,500 residents and no county agency to act as a 24-hour warning point, the community must designate responsible persons who are able to receive warnings 24 hours per day and have the authority to activate local warning systems.
2. In 2002, the NWS approved a new TsunamiReady application form that combines both the U.S. NWS StormReady and TsunamiReady programs. Since that time, all communities applying for TsunamiReady recognition must pass both StormReady and TsunamiReady requirements. The StormReady requirements that were not part of the original TsunamiReady program are Guideline 3, and part of Guideline 6.



Guideline 1: Communications and Coordination Center

A key to effective hazards management is effective communication. This is especially true in tsunami emergencies, since wave arrival times may be measured in just minutes. Such a "short-fused" event requires an immediate but careful, systematic, and appropriate response. To ensure such a proper response, communities must have established the following:

1. *24-Hour Warning Point.* To achieve recognition under the TsunamiReady Program, an applying agency will need to have a 24-hour warning point that can receive NWS tsunami information and provide local reports and advice. Typically, this might be a law enforcement or fire department dispatching point. For cities or towns without a local dispatching point, another jurisdiction within the county could act in that capacity for them. For communities in the Alaska and Pacific Regions with fewer than 2,500 residents and no county agency to act as a 24-hour warning point, the community must designate responsible persons who are able to receive warnings 24 hours per day and have the authority to activate local warning systems. The warning point will need to have:

- 24-hour operations.
- Warning reception capability.
- Warning dissemination capability.
- Ability and authority to activate local warning system(s).

2. *Emergency Operations Center.* All agencies must have an emergency operations center (EOC). For communities with fewer than 15,000 residents, the EOC may be provided by another jurisdiction within the county. The EOC must be staffed during tsunami events to execute the warning point's tsunami warning functions. Tsunami-related requirements of an EOC include:

- Must be activated based on predetermined guidelines related to NWS tsunami information and/or tsunami events.
- Must be staffed with emergency management director or designee.
- Must have warning reception/dissemination capabilities equal to or better than the warning point.

- Must be able to communicate with adjacent EOCs/warning points.
- Must be able to communicate with the local NWS office or tsunami warning center.

Guideline 2: NWS Warning Reception

Warning points and EOCs each need multiple ways to receive NWS tsunami warnings. TsunamiReady guidelines to receive NWS warnings in an EOC or warning point require a combination of the following, based on population:

- NOAA Weather Radio (NWR) receiver with tone alert: Specific Area Message Encoding (SAME) is preferred. Required for recognition only if within range of transmitter.
- NOAA Weather Wire drop: Satellite downlink data feed from NWS.
- EMWIN receiver: Satellite feed and/or VHF radio transmission of NWS products.
- Statewide Telecommunications System: Automatic relay of NWS products on statewide emergency management or law enforcement system.
- Statewide warning fan-out system: State authorized system of passing message throughout warning area.
- NOAA Weather Wire via internet NOAAport Lite: Provides alarmed warning messages through a dedicated Internet connection.
- Direct link to NWS office: e.g. amateur or VHF radio.
- Email from tsunami warning center: Direct email from warning center to emergency manager.
- Pager message from tsunami warning center: Page issued from warning center directly to EOC or warning point.
- Radio/TV via Emergency Alert System: Local Radio/TV or cable TV.
- U.S. Coast Guard broadcasts: EOC/warning point monitoring of Coast Guard marine channels.
- National Warning System (NAWAS) drop: Federal Emergency Management Association (FEMA)-controlled civil defense hotline.

Guideline 3: Hydrometeorological Monitoring

This Guideline relates solely to the StormReady requirements for the combined Storm/TsunamiReady program. While receipt of warnings is crucial to the success of any EOC or warning point, there should also be a means of monitoring weather information, especially radar data. To obtain combined Storm/TsunamiReady recognition, each EOC/WP (based on population) should have some combination of the following recommended means of gathering weather information:

- Internet
- Television/Cable TV/Radio

- Two-way radio
- EMWIN
- Local systems for monitoring weather

Guideline 4: Warning Dissemination

Upon receipt of NWS warnings or other reliable information suggesting a tsunami is imminent, local emergency officials should communicate the threat with as much of the population as possible. To be recognized as Storm/TsunamiReady, a community must have NOAA Weather Radio in the following facilities (when in range of an NWR transmitter):

Required Locations:

- 24-hour warning point
- Emergency operations center
- City Hall
- School superintendent office

Recommended Locations:

- Courthouses
- Public libraries
- Hospitals
- All schools
- Fairgrounds
- Parks and recreation areas
- Public utilities
- Sports arenas
- Transportation departments

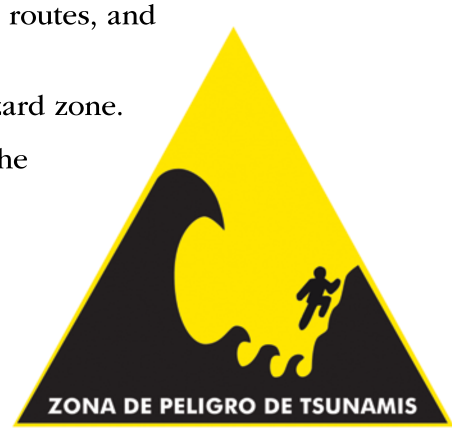
In addition, recognition will be contingent upon having one or more of the following means (based on population) of ensuring timely warning dissemination to citizens:

- Cable television audio/video overrides.
- Local flood warning systems with no single point of failure.
- Other locally controlled methods like a local broadcast system or sirens on emergency vehicles.
- Outdoor warning sirens.
- Phone messaging (dial-down) systems.
- Counties only: A countywide communications network that ensures the flow of information between all cities and towns within its borders. This would include acting as a warning point for the smaller towns.

Guideline 5: Community Preparedness

Public education is vital in preparing citizens to respond properly to tsunami threats. An educated public is more likely to take steps to receive tsunami warnings, recognize potentially threatening tsunami events, and respond appropriately to those events. Communities seeking recognition in the Storm/TsunamiReady Program must:

- Conduct or sponsor tsunami and weather safety awareness programs in schools, hospitals, fairs, workshops, and community meetings (number of talks per year is based on population). These may be part of multi-hazard presentations affecting local communities or regions (e.g., flood, tsunami, wildfire).
- Define tsunami evacuation areas and evacuation routes, and install evacuation route signs.
- Designate a tsunami shelter area outside the hazard zone.
- Provide written tsunami hazard information to the populace, including:
  - Hazard zone maps
  - Evacuation routes
  - Basic tsunami information



These instructions can be distributed through mailings (e.g., utility bills and within phone books), and posted at common meeting points such as libraries and public buildings throughout the community.

In addition, local schools should be encouraged to meet the following guidelines:

- Include tsunami information in primary and secondary school curriculums. (NWS will help identify curriculum support material.)
- Practice tsunami evacuation drills at least once every 2 years when located within the defined hazard zone.
- Provide written safety material to all staff and students.

Guideline 6: Administrative

No program can be successful without formal planning and proactive administration. To be recognized in the StormReady/TsunamiReady Program:

1. Tsunami warning and hazardous weather plans must be in place and approved by the local governing body. These plans must address the following:
   - Hazard/risk assessment.
   - Warning point procedures.

- EOC activation guidelines and procedures.
- Tsunami hazard zone map with evacuation routes.
- Procedures for canceling an evacuation for less-than-destructive tsunamis.
- Procedures for reporting storm and tsunami damage to the local NWS office in near real-time.
- Storm spotter activation criteria and reporting procedures, if applicable.
- Storm spotter roster and training record, if applicable.
- Guidelines and procedures for activation of sirens, cable TV override, and/or local system activation in accordance with state Emergency Alert System (EAS) plans, and warning fan-out procedures, if necessary.
- Annual exercises.

2. Local community officials must conduct a biyearly visit/discussion with local NWS Forecast Office Warning Coordination Meteorologist or tsunami warning center personnel. This can be a visit to the NWS office, phone discussion, or email contacts.

Why Do We Need a TsunamiReady Program?

- To create minimum standard guidelines for a community to follow for adequate tsunami readiness.
- To encourage consistency in educational materials and response among communities and states.
- To recognize communities that have adopted TsunamiReady guidelines.
- To increase public awareness and understanding of the tsunami hazard.
- To improve community pre-planning for tsunami disasters.

Who Decides if a Community Is TsunamiReady?

- In the United States, oversight of the TsunamiReady program is accomplished within the NWS by the National StormReady Board.
- The Board is responsible for changes in community recognition criteria. Proposed criteria changes shall be directed to the Board for action.
- Local boards decide if a community has attained Storm/TsunamiReady status. The local board consists of the local NWS office Meteorologist-in-Charge and Warning Coordination Meteorologist, the tsunami warning center Director, a representative from the state department of emergency services, and a representative from the National Tsunami Hazard Mitigation Program.

Important Points to Remember about the TsunamiReady Program

- TsunamiReady promotes tsunami hazard readiness as an active collaboration among Federal, state and local emergency management agencies, the public, and the NWS tsunami warning system.
- TsunamiReady creates minimum standard guidelines for a community to follow for adequate tsunami readiness.
- TsunamiReady encourages consistency in educational materials and response among communities and states.

Coastal Community Resilience Program

The US Indian Ocean Tsunami Warning System (US IOTWS) Program as part of it's contribution to an end-to-end warning system for the Indian Ocean region worked with partner organizations to enhance coastal community resilience in the region. Enhancing coastal community resilience requires integrating and maintaining an optimal balance of three community-based frameworks typically viewed as independent and separate domains: community development, coastal management, and disaster management. Community development provides the enabling governance and socioeconomic and cultural conditions for resilience. Coastal management establishes the environmental and natural resource conditions for resilience and its relationship to the human and built environment. Disaster management focuses on preparedness, response, recovery and mitigation to reduce human and structural losses from disaster events.

Coastal community resilience serves as a unifying framework for community-based plans and programs. One of the products of the US IOTWS Program is a guide to coastal community resilience (US IOTWS 2007). This section describes the resilience elements and tools used in the program and Guide.

Elements of Coastal Community Resilience

Resilient coastal communities take deliberate action to reduce risk from coastal hazards with the goal of avoiding disaster, accelerate recovery in the event of a disaster, and adapt to changes through experience and applying lessons learned. A resilient coastal community is one that can carry out recovery activities in ways that minimize social disruption and mitigate the effects of future events and impacts. Eight elements of resilience are considered essential for coastal community resilience. Enhancing resilience in each of these elements is needed to reduce risk from coastal hazards, accelerate recovery, and adapt to change. The desired outcome or overarching vision for each element of coastal community resilience can be described as follows:

A. **Governance:** Leadership, legal framework, and institutions provide enabling conditions for resilience through community involvement with government.

B. **Society and Economy:** Communities are engaged in diverse and environmentally sustainable livelihoods resistant to hazards.

C. **Coastal Resource Management:** Active management of coastal resources sustains environmental services and livelihoods and reduces risks from coastal hazards.

D. **Land Use and Structural Design:** Effective land use and structural design compliment environment, economic and community goals and reduce risks from hazards.

E. **Risk Knowledge:** Leadership and community members are aware of hazards risk and the risk information is utilized when making decisions.

F. **Warning and Evacuation:** Community is capable of receiving notifications and alerts of coastal hazards, warning at-risk populations, and acting on alert.

G. **Emergency Response:** Emergency response mechanisms and networks are established and maintained to respond quickly to coastal disasters and address emergency needs at the community level.

H. **Disaster Recovery:** Plans are in place to accelerate disaster recovery, engage communities in the recovery process, and minimize negative environmental, social, and economic impacts from recovery.

Each resilience element is associated with benchmarks that define four core capacities of resilient communities: policy and planning, physical and natural features, social and cultural conditions, and technical and financial resources. These benchmarks serve as the basis for conducting assessments of coastal community resilience.

CCR Assessment

A coastal community assessment can serve as a powerful tool that allows the stakeholders of a given community together with government, nongovernmental organizations, and other stakeholders to begin the process of enhancing resilience. Assessment is the first step in providing inputs to planning to address one or more of the primary issues of concern of a community. Keeping the eight elements of resilience in the forefront during the assessment and planning process ensures that a balanced approach to development implementation will ensue. For example, if a community is primarily concerned about minimizing the impacts of storm surge to which it is vulnerable, by assessing the elements of resilience, all the factors that can minimize the impact of storm surge will be brought into the planning discussion.

Mangroves may be at risk from various forces that need to be addressed to restore their role in minimizing storm surge and inundation.

A coastal community resilience assessment provides an opportunity to initiate dialogue among key stakeholders in the area. Dialogue is crucial to encourage the stakeholder community to recognize the need for better resilience and to better understand what forces need to be addressed to lessen vulnerability through planning. Such dialogue is also an educational process whereby the various stakeholders can learn together through a guided assessment of coastal community resilience.

The CCR Guide provides an assessment approach to evaluating coastal community resilience. CCR assessments are conducted to highlight strengths and identify weaknesses and gaps in resilience that can be addressed by the community together with government and nongovernmental organizations.

Reasons to Conduct an Assessment of Coastal Community Resilience

- Initiate a dialogue between the community, government and non-governmental institutions, and other stakeholders on the goals and key elements of coastal community resilience
- Increase awareness and understanding of the risks associated with both episodic and chronic coastal hazards and the need to build resilience capacity at the community level
- Characterize the resilience status and trends at the community level
- Determine the capacity of your organization to provide assistance in each resilience element
- Provide input to local and national planning for community development, coastal management, and disaster management measures to enhance the resilience of coastal communities
- Identify strengths, weaknesses, and gaps in resilience capacity that need to be addressed to achieve the long-term desired outcome of coastal community resilience

Community Vulnerability Assessment Tool

The NOAA Community Vulnerability Assessment Tool (CVAT) is a peer-reviewed methodology for conducting multi-hazard risk and vulnerability assessments at the community level. The general methodology of CVAT is a tutorial that steps the user through a “community-level” process of analyzing the vulnerability factors with respect to multiple hazards: physical, social, environmental, and economic. In addition to demonstrating the vulnerability assessment methodology, GIS is illustrated as a valuable resource for conducting hazards-related analyses in a case study format. CVAT follows a seven-step process:

1. Hazard identification
2. Hazard analysis
3. Critical facilities analysis
4. Societal analysis
5. Economic analysis

6. Environmental analysis
7. Mitigation opportunities analysis

These tools have been applied at various NOAA Coastal Services Center funded assessments, such as:

- Maui County, Hawaii, USA–County-wide Assessment
- Oregon and Washington, USA–Community Assessment focused on Ports and Harbors
- Rhode Island, USA–Statewide Assessment
- Brevard and Volusia Counties, Florida, USA–County-wide Assessments
- Tutuila, American Samoa–Island-wide Assessment

And in various independent assessments such as:

- Caribbean–Grenada and Barbuda National Assessments
- New Hampshire, USA–Statewide and County-wide Assessment
- Hawaii, USA–Statewide and County-wide Assessments

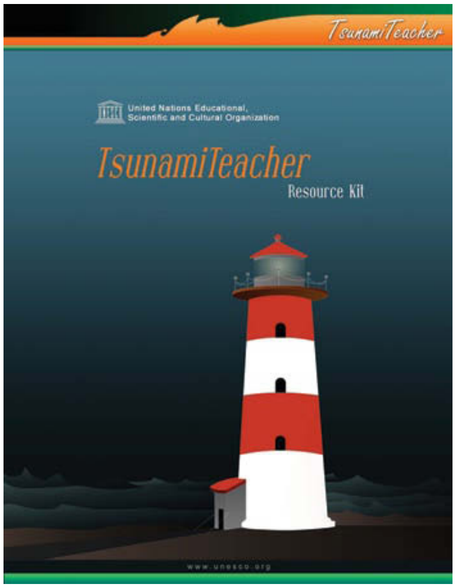
Important Points to Remember about the Coastal Community Resilience Program

- Under the USAID-funded IOTWS Program, CCR promotes tsunami and other hazard readiness as an active collaboration among national, provincial, and local emergency management agencies and the local communities.
- A resilient coastal community is a community with the ability to mitigate tsunamis and other hazards and recurring coastal risks.
- The NOAA CVAT is a methodology for conducting multi-hazard risk and vulnerability assessments at the community level.

Training Materials for Outreach and Education

There are several excellent sources of training information that are invaluable to NTWC and RTWP education and outreach efforts. The most comprehensive training comes at the international level through the UNESCO/IOC International Tsunami Information Center (ITIC) "Tsunami Teacher" program.

As a contribution to the building of training to support the communication of tsunami risk to the public, the IOC of UNESCO has developed the TsunamiTeacher Information and Resource Toolkit. The Toolkit brings together a wealth of new and existing information on tsunamis into a single, reliable, and verified global resource that is widely accessible to people, groups, and governments around the world. TsunamiTeacher aims to build awareness and capacity to respond and mitigate the impact of tsunamis through the sharing of knowledge, research, and best practices.



Materials are available that can be adapted to develop locally relevant responses. A feature of the Toolkit is the ability to customize training modules for different audiences.

Training modules target the media, educational systems, and the public and private sectors, including governments, NGOs, businesses, and community groups. Within the government sector, a large amount of training material has been assembled on earthquake and tsunami science and research, tsunami events, and the building of tsunami warning and mitigation systems. These topics include hazard and risk assessment; operational warning and dissemination systems; tsunami emergency response, alerting, and preparedness; environmental and engineering mitigation and policy; and education and outreach. Resource materials are provided as examples and guidance for decision-makers.

TsunamiTeacher is supported both as a dynamic, electronic, on-line resource (**http://ioc.unesco.org/TsunamiTeacher**) that will be continually reviewed, updated, and added to by experts, and as an off-line set of DVDs which will run on PC and Macintosh platforms. The base language is English, with translations presently planned into Bahasa Indonesia, Bangladesh Bangla, French, Spanish, and Thai. Other training materials are also available on the ITIC website at **http://www.tsunamiwave.info**. This site also has a searchable library of training materials. Additionally, ITIC has produced a CD with educational materials. The CD can now be downloaded directly from **http://ioc3.unesco.org/itic/printer.php?id=349**.

ITIC partnered with Servicio Hidrografico y Oceanografico de la Armada de Chile to publish a high school level text book titled "Earthquakes and Tsunamis." This book is also available on-line for downloading.

At the national level, several nations, including the Japan Meteorological Agency, the Chilean Navy, and NOAA have on-line training materials. Some websites include:

- **http://www.tsunami.noaa.gov/education.html**
- **http://www.jma.go.jp/en/tsunami/**
- **http://www.shoa.cl/**

At state and local levels, several western U.S. states have extensive outreach and training materials. The state of Washington has published a media training guidebook titled "Broadcasters Tsunami Emergency Guidebook" which contains, in addition to definitions and examples of warning products, detailed inundation maps for major towns and cities on the Washington coast. Additional information can be found on numerous websites. Here are a few:

- **http://emd.wa.gov/5-prog/prgms/eq-tsunami/tsunami-idx.htm**
- **http://www.dnr.wa.gov/geology/hazards/tsunami/evac/**
- **http://www.oregon.gov/OOHS/OEM/plans_train/tsunami_in_or.shtml**
- **http://wsspc.org/tsunami/OR/Ore_wave.html**
- **http://www.redcross.org/services/disaster/0,1082,0_592_,00.html**
- **http://www.pep.gov.bc.ca/hazard_preparedness/Tsunami_Brochure/Prepare_for_Tsunami.html**
- **http://www.seismic.ca.gov/Tsunami.htm**
- **http://www.cityofsitka.com/lepc/tsunami.html**
- **http://www.pdc.org/iweb/tsunami.jsp**
- **http://www.honolulu.gov/ocda/**

Important Points to Remember about Training Materials for Outreach and Education

- The UNESCO/IOC International Tsunami Information Center has developed excellent outreach and education materials called the "Tsunami Teacher" program.
- At the national level, several countries have training materials posted on the internet.
- Training materials are also available at the state and local levels. One example is the state of Washington, USA, "Broadcasters Tsunami Emergency Guidebook."

Chapter 9

Community Connections

Community connections can be defined as the relationships necessary to develop, implement, and maintain an effective end-to-end tsunami warning system. A tsunami warning center can only be successful if the warnings it produces reach individuals at risk and are easy to understand and respond to. To assure the most effective communication of warnings, staff of the tsunami warning center must establish trusted partnerships among international organizations, governmental agencies, community leaders and organizations, businesses, and local citizens prior to any warning being issued.

The purpose of this chapter is to provide tsunami warning center staff, including personnel from both the operations and policy sides, with guidance on developing community education and outreach tools in order to create more effective tsunami warning systems. Specifically, this chapter provides insight on ways to identify and establish community partnerships that can lead to better, more effective education and outreach. It also highlights communication models and case studies helpful in increasing a community's knowledge about tsunami risks and warnings.

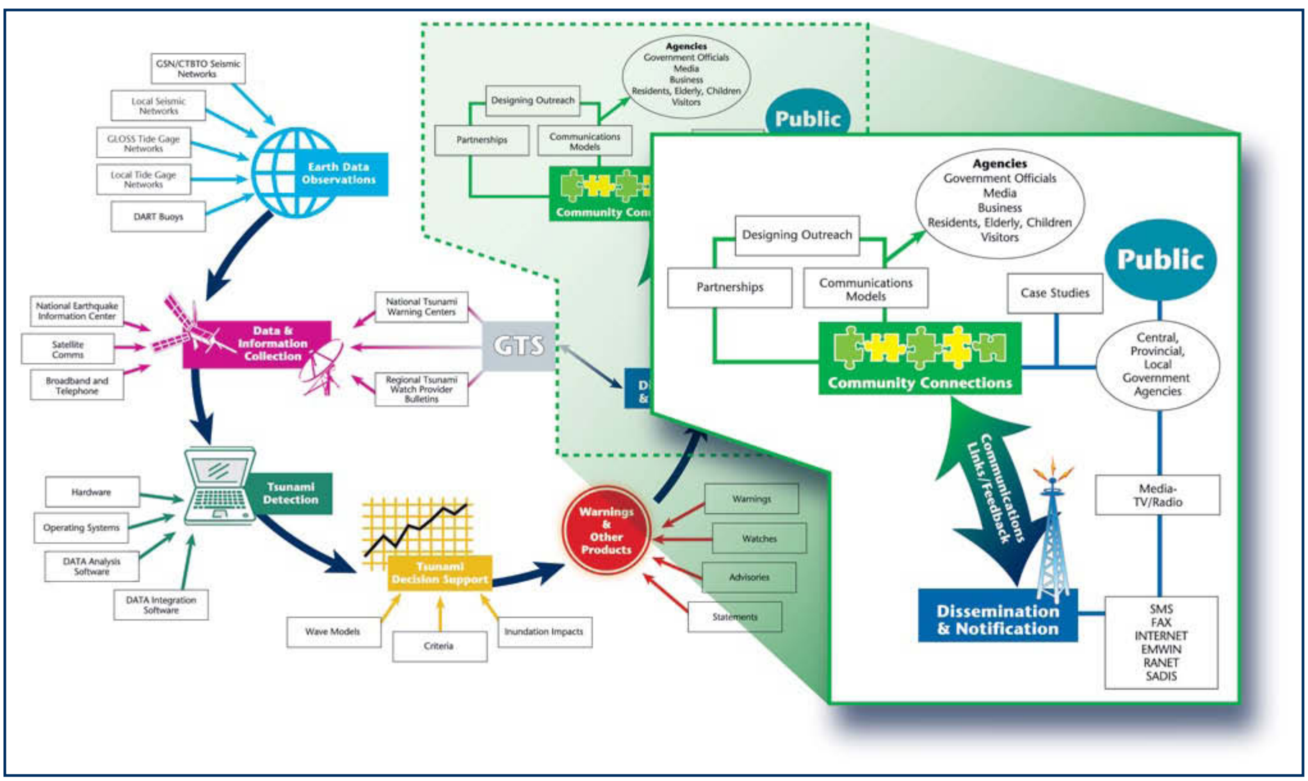


Figure 9-1. Components of a National Tsunami Warning Center's Community Connections

Concepts in this chapter build upon current knowledge and research in risk communication as well as successful communication and outreach models both within and outside the hazards field in the United States. Examples of communication and outreach models may or may not apply in every community as each one has unique qualities. Figure 9-1 highlights how warning messages are disseminated through a community.

How Do Community Connections Fit into an End-to-End Tsunami Warning System?

A tsunami warning system cannot be effective unless the end users of the warning know what to do with the information. This local awareness and understanding can only come from community partnerships and proactive education and outreach efforts BEFORE warnings are issued. Effective education and outreach can best be achieved by fostering partnerships among community organizations and local agencies that can help the tsunami warning center educate the public about the warning system and how to respond.

What Is in this Chapter?

This chapter contains sections that discuss the following topics:

- **The communication model:** This section describes a simple communication model that is the basis for the chapter's discussion about education and outreach.
- **Developing partnerships:** This section describes the importance of developing both media and community partnerships and also outlines steps on how to go about forming these partnerships.
- **Connecting with the public:** This section uses the communication model to describe how to reach the public with tsunami warning messages and outreach.
- **Designing and implementing warning system outreach:** This section outlines sample strategies for reaching certain audiences in any community.
- **Making it local:** This section provides insight on how to take the general concepts in this chapter and apply them to the specific needs and issues in your community.
- **Resources:** This section briefly describes existing resources on public outreach/ stakeholder involvement, gender and vulnerable populations, and tsunami resources.

What Are the Most Important Points to Remember about Community Connections for NTWS and RTWPS?

- Tsunami warnings can only be effective if the audience receives and understands the warning message.
- Community partnerships, developed before the event, can help create a warning system that is effective in reaching the public.
- Partnerships with the media are required for an effective warning system.
- Existing communication models and strategies can be used to quickly and effectively reach target audiences.
- No one message can reach everyone in a community. Messages and message delivery strategies must be specialized and diverse at the same time.

The Communication Model

Effective education and outreach must be based on a thorough understanding of the process that individuals go through when they make decisions about modifying their personal behavior. Warning specialists must understand human behavior in order to design and implement better tsunami warnings. Figure 9-2 shows the key stages in the continuum of persuasive communication that leads to behavior change. The success of tsunami warning rests in the public's and a given individual's awareness, understanding, and acceptance of their risk.

For example, in order to motivate residents to heed tsunami evacuation warnings, the residents must first be aware of their risk with regard to tsunamis. Second, they must understand the impacts a tsunami may have on their family and their community. Third, they must accept the idea that not following a warning message can result in injury or death. Finally, they must take action and heed the warning to evacuate. If the intent is behavior change or ACTION, then public outreach must focus on moving the public through the initial stages of awareness—understanding and acceptance.

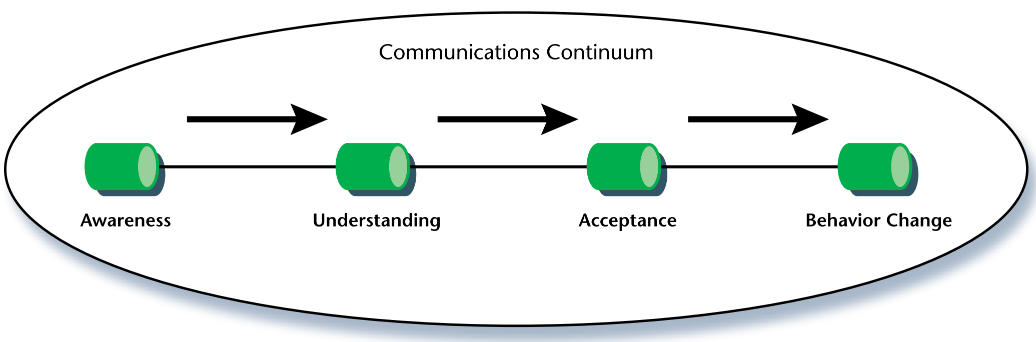


Figure 9-2. Stages of Persuasive Communication
(Source: Nichols, Mary. 1993. Lessons from Radon. EPA Journal 19(4): 36–37)

Developing Partnerships and Connecting to the Public

The development of community partnerships and creation of education and outreach information are tasks that may not typically be led by tsunami warning center staff. In some cases, other government agencies or an outside contractor might be involved in any outreach activities related to the tsunami warning center. This chapter emphasizes the importance of creating specialized education and outreach efforts that take local needs, characteristics, and issues into consideration. Because of the importance of this community-based approach, local tsunami warning center staff must be actively involved in the partnership and education and outreach efforts.

Developing Media Partnerships

Effective community outreach starts with **partnerships**. Beginning with agencies and organizations that have an established and trusted relationship with the public can simplify the process of moving through the communications continuum and persuading the public to respond to warnings. Further, community organizations may be better able to get warning messages and outreach directly to residents, visitors, and businesses in the community. Community partners can also help create messages in formats and languages their clients will understand. An essential partner in the warning system is the media.

Media personnel are experts in communication and can help tsunami warning center staff develop effective outreach. Media can also serve as a link between scientific

Figure 9-3. Print and Broadcast Media Roles
(Source: Rydell 2007)

experts and the community. Without the media, rapid dissemination of warnings cannot occur. This community partner can also relay, interpret, and supplement warning information from the warning center. The media also has the ability to localize the preparedness and warning message for individual communities.

Following are tips on establishing relationships with the media from (Rydell 2007):

- Meet your media partners and get to know them **before** an emergency. Exchange contact information, invite them to visit the office and meet your staff, and establish a working relationship.
- Educate media partners about the hazard. Provide them with scientific information. Provide detailed warning process information, including desired responses and outcomes, as well as workshops, pamphlets, brochures, fliers and handouts.
- Working with news directors and editors can be fruitful as these are the individuals who make decisions about what gets air time. In Hawaii, during Tsunami Awareness month, outreach efforts focused on directors and editors and resulted in increased coverage of the issue.
- Include media partners in practice drills.
- Anticipate the story. Create and provide background video and canned interviews with scientists for later use. Coordinate who will be knowledgeable and available to speak with media during an emergency.
- If experts don't provide information in an emergency, others will.

Tip

Media Guidebook

The State of Washington developed a Broadcasters Tsunami Emergency guidebook that provides a concise overview of the notification process used to send tsunami alerts to public information broadcasters, local jurisdictions, and the public. It includes a Tsunami Warning Flow Chart that shows how information is sent to broadcasters, a contact list of tsunami experts who can provide credible tsunami information during a tsunami event, and Washington coastal community maps of regions most susceptible to tsunamis. Two DVDs accompanied the guidebook: Tsunamis in Washington (running time: 4:31:26); and U.S. National Tsunami Hazard Mitigation Program Selected Interviews.

Building Broad Community Partnerships

In addition to working with the media, it is critical that the right community partners are identified. They must represent the full range of a community demographically. One place to start in thinking about how to target the right organizations is to consider the elements that make a community function on a day-to-day basis. If all of these day-to-day functions can continue after an event, the community will truly be disaster resilient. The Coastal Community Resilience Guide (US IOTWS Program 2007) developed as part of the U.S. Indian Ocean Tsunami Warning System Program provides a framework for enhancing coastal community resilience through collaboration and partnerships with government, nongovernmental organizations, and communities. The eight elements of coastal community resilience defined in the Guide are:

A. **Governance:** Leadership, legal framework, and institutions provide enabling conditions for resilience through community involvement with government.

B. **Society and Economy:** Communities are engaged in diverse and environmentally sustainable livelihoods resistant to hazards.

C. **Coastal Resource Management:** Active management of coastal resources sustains environmental services and livelihoods and reduces risks from coastal hazards.

D. **Land Use and Structural Design:** Effective land use and structural design compliment environment, economic and community goals and reduce risks from hazards.

E. **Risk Knowledge:** Leadership and community members are aware of hazards risk and the risk information is utilized when making decisions.

F. **Warning and Evacuation:** Community is capable of receiving notifications and alerts of coastal hazards, warning at-risk populations, and acting on alert.

G. **Emergency Response:** Emergency response mechanisms and networks are established and maintained to respond quickly to coastal disasters and address emergency needs at the community level.

H. **Disaster Recovery:** Plans are in place to accelerate disaster recovery, engage communities in the recovery process, and minimize negative environmental, social, and economic impacts from recovery.

Developing partnerships with the organizations that either have authority or that work in these fields on a daily basis would give the tsunami warning center a good start on developing diverse community partnerships.

Creating relationships with community organizations will not occur overnight: it is a deliberate process that requires commitment over time. It will require staff from the tsunami warning center to meet with the various organizations to discuss the mutual benefits of the partnership. Taking the time to establish these relationships early on will result in more effective outreach strategies that reach the identified audience and ultimately help create a more effective tsunami warning system.

Key Components to Developing Partnerships. An important step in developing community partnerships is to identify what community planning activities are taking place in the area. Specifically, the tsunami warning center will want to identify activities being overseen by diverse committees or working groups. These committees or working groups do not have to be engaged in activities directly related to hazards;

any diverse committee or working group addressing any community issue may be a helpful partner. It may be useful to meet with local government representatives to identify these groups. Committees addressing various community activities could include those listed below. (This is merely an example list; there may be a different set of active organizations in a given tsunami watch center's community.)

- Emergency response and planning committees
- Natural hazard mitigation steering committees
- Planning commission (land use)
- Citizen advisory boards
- School boards
- Others

By working with these entities, the tsunami warning center may be able to reach more than one segment of the community at once. For instance, a local emergency response or planning committee might be made of up individuals from the local governments, private sector, media, state or federal agencies, schools, and private citizens.

If there are no diverse committees or working groups actively working in the community, the tsunami warning center should begin to identify other community organizations or social service providers such community nongovernmental organizations that work with specific community groups or focus on specific community issues such as health, economic development, housing, and/or legal services that may meet on a regular basis. These groups may include:

- Regular meetings of local elected officials
- Downtown business associations or Chambers of Commerce
- Service organizations such as Rotary, Lions, or Kiwanas Clubs
- Associations of churches or ministers
- Social service provider agencies or advocacy groups
- Homeowners, renters, or builder's associations
- Others

Tip

Trust & Partnerships

Building partnerships requires trust. Often, it is not as easy as, "if you build it, they will come." It will benefit the tsunami warning center to do research before meeting with potential partners. It is important to set the stage and convince the organization that joining in the partnership is also in their best interest. A successful "sales pitch" involves knowing what motivates that particular organization and demonstrating the benefits of working with the tsunami warning center.

Tip

First Impressions and Partnerships

The initial meetings held with potential community organizations are critical in establishing lasting relationships that will benefit both the tsunami warning center and the organization. Select the appropriate staff to be involved in these meetings. Individuals representing the tsunami warning center should be able to translate technical information into a form that will be understandable by the organization. It is a good idea to utilize the tsunami warning center's public affairs officer, as this individual is trained in communicating with the public. The tsunami warning center may want to consider hiring a public affairs officer with a background in communications and public relations rather than training a technical staff person to fill the position.

Initial Partnership Meeting Tips

Whether meeting with the local media or other community partners, being prepared for the initial partnership meeting requires that tsunami warning center staff pull together some information and practice their sales pitch. When the active community committees and organizations have been identified, tsunami warning center staff can contact the organizations to arrange a meeting. At the initial meeting, tsunami warning center staff should present the following in a clear and concise manner:

- **What the tsunami warning center does:** Community partners may be unaware of what a tsunami warning center is and what its purpose is. Staff should be prepared to describe, in a clear and concise manner, what the tsunami warning center does and why it exists. Staff may choose to use the overall warning system graphic used in this document to talk about the components of the system. In addition to meeting with community committees and organizations, the tsunami warning center could host an open house and invite all potential partners to come together to learn more about the tsunami warning center and to discuss opportunities for partnerships.

- **Why the tsunami warning center is interested in partnering:** Tsunami warning center staff must clearly present to the potential partner why the partnership is important. When talking with the media, the reasons for partnering are fairly clear: The media is a component of the dissemination of tsunami warnings. The media can also help disseminate outreach messages about the tsunami warning system so that residents are better prepared to heed warnings in the future. Describing partnerships between the center and community organizations may not be as clear. Staff should focus on how the organization can help the center conduct outreach or disseminate warning messages. For example, when meeting with a nonprofit that works with the elderly, focus on why the center is interested in getting messages to the elderly. When the potential partner sees that you are also interested in helping their clients, they may be more likely to want to help.

- **How the tsunami warning center can help the organization do its job:** Organizations are more likely to partner when they know that the partnership does not create additional work, but helps them do their existing work. For the media, giving them examples of the types of stories you can provide for them helps directors or editors do their job. Staff can also provide contact lists of technical experts that media can contact for future stories. For community organizations, staff can offer to provide content for the organization's newsletters or websites.

- **What the organization might gain from partnering with the tsunami warning center:** Benefits to an organization may include increased visibility within the community, ability to assist in saving lives by participating in a vital link in a tsunami warning system, and providing clients a new or different service.

Connecting with the Public: Communication Model

Establishing connections with community partners is an important first step in connecting with the public because it creates new channels for distributing warning messages. Once those channels are established, how can the warning message be crafted and delivered effectively? A simple communication model can help establish local strategies for effectively distributing tsunami warning information to the public. The following is a brief explanation of key components of a communication model and an explanation of how it can be used to build awareness and understanding of tsunami warnings prior to an event.

As the model illustrates, for a warning message to be credible, it must have the following five essential components:

- The **source** of the message must be credible.
- The **message** must be appropriately designed.
- The **channel** for communicating the message must be carefully selected.
- The **audience** must be clearly defined.
- The recommended action must be clearly stated, and a **feedback** channel established for questions, comments and suggestions.

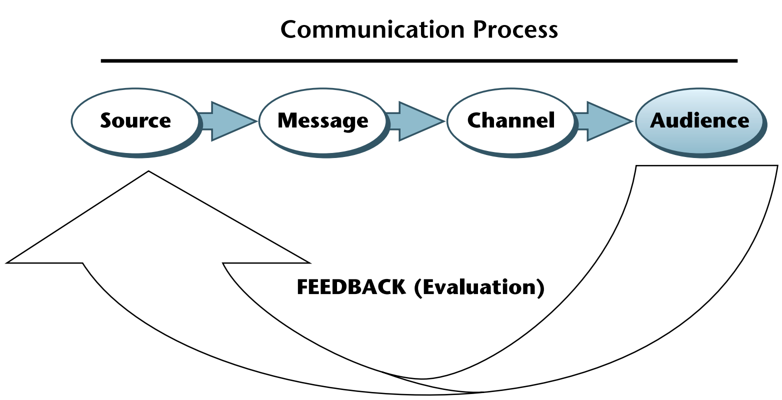


Figure 9-4. Communication Model
(Source: Adapted from EPA Radon Division outreach program)

Applying the concepts of this model to tsunami warnings is an important step in developing a warning system. In order for education and outreach about the warning system to be effective, all of these components must be clearly defined, established, and exercised prior to an event. When developing warning system education and outreach strategies, it is best to start by defining the audience (e.g. tourist, local businesses, school-age children, etc.). Defining the audience will assist the tsunami warning center and community partners in determining the appropriate message and channel. In the case of the tsunami warning system, it is assumed that the primary source of the information will come from the tsunami warning center. The following defines the components in greater detail, starting with the audience and working back to the source.

Audience

When a tsunami occurs and an evacuation order is issued, all people in the path of the tsunami must respond to the order. However, the people in the path of the tsunami will not be one homogenous group: they will include tourists from multiple countries speaking multiple languages, permanent residents who know the landscape and transportation systems of the area, permanent residents who lack the financial resources to heed an evacuation order, and others. Each of these audiences requires messages sent in slightly different channels in order to be able to make informed decisions about evacuation if a warning is issued. In addition, audiences can be broken into subsets related to language, knowledge of tsunami risk, work schedules, or physical capabilities, among others. There is no one message or channel that is going to effectively distribute the message to all people in the community.

Tip

Understand Vulnerable Populations

In effect, populations are vulnerable when they have lesser capabilities than others around them. Some populations experience greater risk from hazard events not because of their geographic proximity to the hazard, but because of decreased resources and capabilities arising from their socioeconomic status and/or physical abilities. People living near or below the poverty line, the elderly, disabled, women, children, ethnic minorities, and renters have all been shown to experience, to some degree, more severe effects from disasters than the general population. They are more likely to die in an event and, if they survive, they are less likely to recover financially. Thinking about vulnerable populations when developing tsunami warning system related education and outreach tools is extremely important because these groups may require specialized messages.

Channel

The *channel* is the method in which outreach messages are distributed to the audience. Channels may include the media (TV and radio, billboards, etc.), social service providers, schools, churches, and other community organizations that work with community members on a daily basis. Selecting an appropriate and trusted channel helps ensure that the intended audience will receive the message.

The most effective outreach efforts use **existing channels in the community**. For instance, organizations that work with a certain subset of the population on a daily basis typically make good channels because they already have communication methods (brochures, newsletters, websites, phone lists) in place and have established a trusting relationship with the subset. As an example, a social service organization that provides services to the elderly would be a good organization to partner with to get tsunami related messages out to the elderly.

Tip

Identify and Use Existing Channels

Some communities may have already developed and implemented tsunami-related outreach strategies. If so, this can serve as a good starting point for creating an outreach program about the tsunami warning system. There may be opportunities to partner with those organizations that have already taken the lead on educating the public about tsunamis.

Message

Messages should be targeted to the specific audience and packaged in a way that is clear and understandable for the selected audience. Having diversified community partnerships can assist the tsunami warning center as it creates and disseminates clear messages that reach the intended audience.

An example of an ineffective message would be to only provide information in the community's native language. Oftentimes, a community is composed of people who speak many different languages and dialects. In tourist communities, the range of languages can be even wider. Staff must consider the languages spoken in the community when designing tsunami warning messages.

Tip

Craft Audience-Appropriate Messages

Crafting messages that are audience appropriate can be difficult. It is a good idea to enlist a professional with marketing or public relations expertise to help design the message. These professionals can help translate technical or scientific information into a format and language that is understandable for the intended audience.

Source

The source is the entity or entities that provide the information for the outreach campaign. In this case, the tsunami warning center is one of the primary sources of education and outreach messages because it is the technical expert on the warning system. Local and State government emergency management departments may also be sources for tsunami warning system education and outreach.

Model of a Multi-Stakeholder Outreach Source

Example: In Hawaii, a Tsunami Technical Review Committee composed of tsunami experts from academia, government, and the private sector meets on a regular basis to review research, exchange information, and coordinate projects. Several committees have been formed, including a Public Affairs Working Group that meets regularly to plan and coordinate outreach events. Membership includes technical experts and public affairs, outreach, and education officers from government agencies, the Hawaii Tourism Board, the Pacific Tsunami Museum, and academia. This committee plays an important role in coordination of tsunami-related projects, community awareness events, etc. and could serve as a model forum for use in other countries.

Designing and Implementing Warning System Outreach

This section outlines strategies for designing and implementing warning system outreach to various audiences in the community. The ideas presented below are provided as examples only. The communities in which the tsunami warning center operates may have additional audiences to think about and plan for.

Strategies by Sample Audience

Once community partnerships have been established, the tsunami warning center should begin to identify the audiences that need to be reached. As described earlier, this is best done by working with local government departments and other community partners to identify the types of audiences present in the community. Potential audiences might include:

- Elderly
- Children
- Local businesses
- Visitors
- Non-native speakers
- Residents

In this part of the chapter, possible strategies for reaching these audiences are provided merely as an example of how the tsunami warning center might accomplish the creation and dissemination of an appropriate message. In general, the tsunami warning center should think creatively about how to leverage partnerships to assure that the message is reaching as many people as possible.

Elderly

The elderly in the community often lack the ability to evacuate quickly and may lack the financial resources necessary to recover from a catastrophic disaster. Ensuring that the elderly are aware of and understand what to do when a tsunami warning is issued may be a priority in the community. The following is a list of potential channels for getting education and outreach messages to elderly populations in the community.

- **Senior centers:** The communities in which the tsunami warning center works may have senior centers that provide a place for seniors to gather and to participate in various activities. These centers typically provide information in the form of brochures and fliers, and may have regular meetings that the tsunami warning center could attend to directly provide information to seniors. Alternatively, the senior center could host an open house where tsunami warning center staff could talk about the warning system and what steps elderly residents can take to be better prepared to evacuate when a warning is issued. At a minimum, outreach to the senior center's leadership about how to assist seniors with evacuation should a warning be issued during the senior center's hours of operation would be useful.
- **Churches:** Many of the community's elderly population may be members of the various churches in the community. Churches often provide a number of social services to their congregations, and they could be used to distribute tsunami warning outreach as well.

The following figure illustrates an example communication strategy for reaching the elderly using the communication model.

Source	Message	Channel	Audience
Tsunami Warning Center	Special evacuation considerations for the elderly	Workshop for seniors on how to interpret and react to warnings and evacuations	Elderly

Children

Children are also considered a vulnerable population because they typically rely upon adults to assist them in emergencies and may not have the capacity to make informed decisions. Ensuring that children are aware of and understand warnings is critical because children are the community's future. The following is a list of potential channels for getting education and outreach messages to children in the community.

- **Schools:** Children can be one of the easier audiences to reach because they typically attend school on a regular basis. Schools can be used to distribute outreach materials about tsunami warnings. The messages for children may take the form of classroom curriculum, poster contests, coloring books, cartoons, or special assemblies. Often, children will take information home to their parents, an additional benefit of implementing outreach.
- **Parks and Recreation Departments:** Parks can be an effective means of getting tsunami warning outreach to children. Partnering with Parks and Recreation Departments to develop public information centers or kiosks in parks would be an effective means of reaching children. These centers or kiosks should be designed using language and images that children can relate to, such as cartoons.

The following figure illustrates an example communication strategy for reaching children using the communication model.

Source		Message		Channel		Audience
Tsunami Warning Center and Local Schools	➡	Tsunami hazard awareness	➡	Poster contest	➡	Children

Local Businesses

Local businesses are a key audience to reach. Collectively, they can employ large numbers of the community's residents; in addition, they provide goods and services to the community. When local businesses are informed about the tsunami warning system, they can serve as educators to visitors and residents who might patronize the business. The following is a list of potential channels and modes for getting education and outreach messages to local businesses in communities.

- **Business associations/chambers of commerce:** Partnering with business associations and chambers can allow the tsunami warning center to reach a large business audience in one effort. These organizations often provide training to their members. Tsunami warning center staff could work with the association or the chamber to host a training or seminar. The associations and chamber could also provide information to their members through websites.
- **Banks:** Most businesses conduct daily business transactions with banks (making deposits, getting change, etc). The banking industry provides an opportunity to reach businesses on a one-on-one level. Banks can provide information in the form of brochures or fliers about the tsunami warning process and how it relates

to running a business. Banks might also be a potential partner with the ability to fund the development and dissemination of tsunami warning education and outreach material.

The following figure illustrates an example communication strategy for reaching businesses using the communication model.

Source		Message		Channel		Audience
Tsunami Warning Center	➲	Business' role in evacuation	➲	Brochure distributed to businesses when completing banking transactions	➲	Businesses

Visitors

Visitors or tourists should be considered because they may not be familiar with the tsunami hazard or the warning system and they most likely would not know what to do if a warning was issued. The following is a list of potential channels and modes for getting education and outreach messages to visitors in the community.

- **Visitor's bureaus:** Some communities have a visitor's bureau where potential visitors can get information about the community. This presents an opportunity to provide potential visitors with information about the tsunami warning system. The bureau's website could be used to provide information about the warning system. This can be done in a way that does not dissuade people from visiting the community. Developing relationships with visitor's bureaus and the tourism industry early on is important because of the perception that providing risk information will negatively impact tourism.
- **Local businesses:** Local businesses that would be patronized by visitors may serve as an effective channel for getting information out to visitors. Brochures or fliers could be available at local businesses. Employees of local businesses can also be trained to assist visitors with evacuation if a warning is issued.

The following figure illustrates an example communication strategy for reaching visitors using the communication model.

Source		Message		Channel		Audience
Tsunami Warning Center and Local Government	➲	Awareness of tsunami inundation area	➲	Inundation and evacuation maps in hotel rooms	➲	Visitors

Non-Native Speakers

Non-native speakers can be considered vulnerable populations because they may not have access to warning information in an understandable language. Information about warnings that is not translated is like not having any information at all. The following are potential methods for reaching non-native speakers.

- **Local government agencies:** Local government agencies can be a channel for getting information out to non-native speakers. Agencies can provide brochures or fliers in their offices, can post information on their websites, or can host open houses along with tsunami warning center staff to educate residents about the warning system. All of this information can be translated into the languages commonly spoken in the community.
- **Social service providers:** There may be groups or organizations, typically non-profit or culture-based organizations, that already provide services to non-native speakers. These groups can serve as a channel for getting the message out. Examples of social service providers could include a nonprofit groups that provide legal services, housing assistance, or financial advice to non-native speakers.

The following figure illustrates an example communication strategy for reaching non-native speakers using the communication model.

Source		Message		Channel		Audience
Tsunami Warning Center and Social Service Providers	➲	Tsunami evacuation information	➲	Brochures translated and distributed when individuals visit social service providers	➲	Non-native Speakers

Residents

In addition to the vulnerable populations described above, it is also important to ensure the average citizen in the community is aware of the warning system and what to do when a warning is issued. Again, it is best to try to segment the general population into specific audiences, but in general, the following are example channels and methods for reaching the average citizen.

- **Media:** The local newspaper or television station may be a potential channel for getting outreach messages to residents in the community. The messages may take the form of a newspaper article, a story on the evening news, or a public service announcement.
- **Utility companies:** Utility companies can make good channels because they can often include outreach information, such as brochures, in monthly bills that are sent out to customers. This method could assist the tsunami warning center in reaching the general population.

- **Local government agencies:** Local government agencies can be a channel for getting information out to residents. Agencies can provide brochures or fliers in their offices, can post information on their websites, or can host open houses along with tsunami warning center staff to educate residents about the warning system.

The following figure illustrates an example communication strategy for reaching residents using the communication model.

Source	Message	Channel	Audience
Tsunami Warning Center and Media	Steps individuals and homeowners can take to be better prepared	Media sponsored website with information accompanying news series/stories	Residents

Elected Officials

Elected officials can be an asset during an emergency, so they must be informed before the event ever happens. Officials are often seen as a trusted source of information for the general public. The following are example channels and methods for reaching the elected officials.

- **Elected official work session:** One of the best ways to reach elected officials is to schedule a work session with them. In this case, tsunami warning center staff would have their direct attention and could talk one on one about the roles that elected officials can play in providing the public with information about tsunamis.
- **Associations for elected officials:** In some cases, elected officials may be members of an association or professional group. For instance, in Oregon, County elected officials are often members of the Association or Oregon Counties. This organization holds an annual conference and regularly sends out newsletters. Tsunami warning center staff could take advantage of these existing channels to provide elected officials with information about their role in tsunami warning and preparedness.

The following figure illustrates an example communication strategy for reaching elected officials using the communication model.

Source	Message	Channel	Audience
Tsunami Warning Center	Role of elected officials in tsunami warning and preparedness	Article in elected official association newsletter or website	Elected Officials

Making it Local

The example audiences and channels discussed above may or may not be appropriate in the communities in which the tsunami warning center operates. The audiences and channels are provided as an example to help the center think about strategies that make sense for the local characteristics. Tsunami warning center staff should meet with community partners to identify the various audiences that exist within the community. Once the audiences have been identified, appropriate channels and messages can be assigned.

Appendix A

Acronmyns

ADPC	Asian Disaster Preparedness Center
AFTAC	Air Force Technical Applications Center
AIT	Asian Institute of Technology
ANSS	Advanced National Seismic System
AOR	area of responsibility
ASCII	American Standard Code for Information Interchange
ASL	Albuquerque Seismic Laboratory
AusAID	Australian Agency for International Development
AWIPS	Advanced Weather Information Processing System
BDSN	Berkeley Digital Seismic Network
BGR	Federal Institute for Geosciences and Natural Resources in Hannover, Germany.
BODC	British Oceanographic Data Centre
BPR	bottom pressure recorder
BUFR	binary universal form for the representation of meteorological data
CCR	Coastal Community Resilience
CERC	Coastal Engineering Research Center
CONOPS	concept of operations
CREX	character form for the representation and exchange of data
CTBT	Comprehensive Nuclear Test Ban Treaty
CVAT	Community Vulnerability Assessment Tool
DAC	data assembly centers
DART™	Deep Ocean Assessment and Reporting of Tsunami™
DCP	Data Collection Platforms
DMC	Data Management Center
DOD	Department of Defense
EMLPP	Enhanced Multilevel Precedence and Pre-emption Services

EMRS	Engineering and Maintenance Reporting System
EMWIN	Emergency Manager's Weather Information Network
ET	electronics technician
ETA	estimated time of arrival
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FMCW	frequency modulated continuous waves
FTP	file transfer protocol
GCN	Global Core Network
GEO	Group on Earth Observations
GEOFON	GeoForshungsZentrums Potsdam
GEONETCAST	GEONETCast is a Task in the GEO Work Plan and is led by EUMETSAT, the United States, China, and the World Meteorological Organization (WMO)
GEOSCOPE	Institut de Physique du Globe de Paris
GEOSS	Global Earth Observation System of Systems
GFDC	GLOSS Fast Data Center
GIS	Geographic Information Systems
GLOSS	Global Sea Level Observing System
GMDSS	Global Marine Distress and Safety System
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GPRS	General Packet Radio System
GPS	Global Positioning System
GSM	General Switched Messaging
GSN	Global Seismic Network
GTS	Global Telecommunications System
Guide	Tsunami Warning Center Reference Guide
Hz	hertz
ICAO	International Civil Aviation Organization
ICG	Intergovernmental Coordination Group
ICG/PTWS	Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System
ICSU	International Council for Science

ID	identification
IDA	International Deployment of Accelerometers
IMD	India Meteorological Department
IMS/CTBTO	International Monitoring System of the Comprehensive Nuclear Test Ban Treaty Organization
INMARSAT BGAN	International Mobile Satellite Organization Broadband Global Area Network
INSAT	India Satellite
IOC	Intergovernmental Oceanographic Commission
IOTWS	Indian Ocean Tsunami Warning and Mitigation System
IRIS	Incorporated Research Institutions for Seismology
ISCS	International Satellite Communications System
ISP	Internet Service Provider
IT	information technology
ITO	information technology officer
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology
JMA	Japan Meteorological Agency
KB	kilobyte
kbps	kilobytes per second
Km	kilometer
LAN	local area network
LEO	low earth orbit
M	magnitude
Mac OS X	Apple/Macintosh operating system
Mb	megabyte
MD	Maryland
MEO	Mid-altitude earth orbit
Mm	millimeter
MOST	Method of Splitting Tsunamis
MSS	message switching system
MTN	Main Telecommunications Network
NCDSN	China Earthquake Administration
NDBC	National Data Buoy Center

NDMO	National Disaster Management Office
NDWC	National Disaster Warning Center
NEIC	National Earthquake Information Center
NERC	Natural Environment Research Council
NESDIS	National Environmental Satellite Data Information Service
NGDC	NOAA National Geophysical Data Center
NGO	nongovernmental organization
NGWLMS	Next-Generation Water Level Measurement System
NMC	national meteorological centers
NMHS	national meteorological and hydrological services
NMTN	National Meteorological Telecommunications Network
NPT	network time protocol
NRT	near-real-time
NOAA	National Oceanic and Administration
NOS	National Ocean Service
NTHMP	National Tsunami Hazard Mitigation Program
NTP	network time protocol
NTWC	National Tsunami Warning Center
NWS	National Weather Service
NWSTG	National Weather Service's Telecommunications Gateway
NZAID	New Zealand's international aid and development agency
OFDA	Office of U.S. Foreign Disaster Assistance
OTT	OTT Messtechnik Company
PC	personal computer
PDC	Pacific Disaster Center
PEACESAT	Pan-Pacific Education and Communication Experiments by Satellite
PMEL	Pacific Marine Environmental Laboratory
POL	Proudman Oceanographic Laboratory
PSMSL	Permanent Service for Mean Sea Level
PSTN	Public Switched Telephone Network
PTWC	Pacific Tsunami Warning Center
PTWS	Pacific Tsunami Warning and Mitigation System

QC	quality control
R&M	reliability and maintainability
RANET	Radio and Internet for the Communication of Hydro-Meteorological and Climate-Related Information
RISC	Reduced Instruction-Set Computer
RMTN	Regional Meteorological Telecommunications Networks
RSS	Really Simple Syndication
RT	real time
RTH	Regional Telecommunications Hubs
RTQC	real-time quality control
RTWP	Regional Tsunami Watch Provider
RUDICS	Router-based Unrestricted Digital Internetworking Connectivity Solution
SADIS	Satellite Distribution System
SEBA	name of a radar tide gauge
SEED	Standard for Exchange of Earthquake Data
SHOA	Chilean Hydrographic and Oceanographic Service of the Chilean Navy
SMS	Short Message Service
SOP	Standard Operating Procedure
Sps	Samples per second
SRD	Sonar Research and Development
TCC	Tsunami Coordination Committee
TCP	Transmission Control Protocol
UCSD	University of California, San Diego
UCSD/IDA	University of California San Diego/ International Deployment of Accelerometers
UHF	ultra high frequency
UHSLC	University of Hawaii Sea Level Center
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UPS	Uninterruptible power supply
USAID	United States Agency for International Development
USGS	U.S. Geological Survey
USNSN	United States National Seismographic Network

UTC	Coordinated Universal Time
UTF	Universal Transmission Format
VEGA	VEGA Controls, Ltd.
VHF	very high frequency
VPN	virtual private network
VSAT	Very Small Aperture Terminal satellite ground station
WC/ATWC	West Coast/Alaska Tsunami Warning Center
WAFS	World Area Forecast System
WAN	wide area network
WMC	World Meteorological Center
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWW	World Wide Web
XML	eXtensive Markup Language
XML/CAP	eXtensive Markup Language/Common Alerting Protocol

Appendix **B**

Glossary

A

Arrival time

Time of the first maximum of the tsunami waves.

B

Breaker

A sea-surface wave that has become so steep (wave steepness of 1/7) that the crest outraces the body of the wave and it collapses into a turbulent mass on shore or over a reef. Breaking usually occurs when the water depth is less than 1.28 times the wave height. Roughly, three kinds of breakers can be distinguished, depending primarily on the gradient of the bottom:

- Spilling breakers (over a nearly flat bottom) which form a foamy patch at the crest and break gradually over a considerable distance.
- Plunging breakers (over fairly steep bottom gradients) which peak up curl over with a tremendous overhanging mass and then break with a crash.
- Surging breakers (over very steep bottom gradients) which do not spill or plunge but surge up the beach face.
- Waves also break in deep water if they build too high while being generated by the wind, but these are usually short-crested and are termed whitecaps.

Breakwater

An offshore or onshore structure, such as a wall, water gate, or other in-water wave-dissipating object that is used to protect a harbor or beach from the force of waves.

C

Cotidal

Indicating equality with the tides or a coincidence with the time of high or low tide.

Crest length

The length of a wave along its crest. Sometimes called crest width.

Deep-ocean Assessment and Reporting of Tsunamis (DART)

An instrument for the early detection, measurement, and real-time reporting of tsunamis in the open ocean. Developed by the US NOAA Pacific Marine Environmental Laboratory, the DART system consists of a seafloor bottom pressure recording system capable of detecting tsunamis as small as one cm, and a moored surface buoy for real-time communications. An acoustic link is used to transmit data from the seafloor to the surface buoy. The data are then relayed via a satellite link to ground stations, which demodulate the signals for immediate dissemination to the NOAA tsunami warning centres. The DART data, along with state-of-the-art numerical modelling technology, are part of a tsunami forecasting system package that will provide site-specific predications of tsunami impact on the coast.

Drop

The downward change or depression in sea level associated with a tsunami, a tide or some long term climatic effect.

E

EarlyBird

Seismic data processing system used for both real-time and post-processing of seismic data by RTWPs and NTWCs. EarlyBird is a combination of standard USGS Earthworm modules, WC/ATWC-developed earthworm modules, and stand-alone seismic processing software.

EarthVu

Geographic display software developed at the WC/ATWC and used by RTWPs and NTWCs.

Eddy

By analogy with a molecule, a “glob” of fluid within a fluid mass that has a certain integrity and life history of its own; the activities of the bulk fluid being the net result of the motion of the eddies.

Elapsed time

Time between the maximum level arrival time and the arrival time of the first wave.

Estimated time of arrival (ETA)

Time of tsunami arrival at some fixed location, as estimated from modeling the speed and refraction of the tsunami waves as they travel from the source. ETA is estimated with very good precision if the bathymetry and source are well known (less than a couple of minutes).

Evacuation map

A drawing or representation that outlines danger zones and designates limits beyond which people must be evacuated to avoid harm from tsunami waves. Evacuation routes are sometimes designated to ensure the efficient movement of people out of the evacuation zone to evacuation shelter.

Epicenter

This is the point on the Earth's surface directly above the focus (or hypocenter).

Earthquake (Magnitude)

This is a measure of the relative size of an earthquake. A number of different magnitude scales exist besides the Richter scale, including the moment magnitude, which measures the energy released and gives the most reliable estimate for large earthquakes.

Because the scale is logarithmic, an increase in one unit of magnitude corresponds to a 10-fold increase in seismic wave amplitude and a 30-fold increase in released energy. And a change of 0.3 units equals a three-fold increase in intensity.

In other words, the 9.3 Sumatra earthquake that generated the 2004 Indian Ocean tsunami was three times more powerful than the 9.0 earthquake it was originally thought to be.

Moment magnitude is measurable nearly immediately thanks to the advent of modern seismometers, digital recording, and real-time communication links. It allows warning centers to provide initial tsunami advisories within minutes of an earthquake occurrence. In Japan, earthquake warnings get broadcast to the public within 30 seconds of them happening.

End-to-end

In recent years new shorthand terminology has been used to describe the entire process required to detect, warn, and elicit protection measures for a natural hazard. Increasingly this comprehensive process is referred to as "end to end", meaning from initial to final steps required for a successful system. The term "end to end" does not always translate accurately, and some cultures prefer to refer to the process as "beginning to end". In the case of a tsunami system this of course means from the beginning, i.e. earthquake detection, to the end, i.e. evacuation or cancellation of the warning.

F

Fault

A fault is a fracture or zone of fractures between two blocks of rock. Faults allow the blocks to move relative to each other. This movement may occur rapidly, in the form of an earthquake—or may occur slowly, in the form of creep. Faults may range in length from a few millimeters to thousands of kilometers. Most faults produce repeated displacements over geologic time.

Focus

The point within the Earth where a rupture first occurs and where the first seismic waves originate. It is also referred to as the hypocenter. The epicenter lies above the focus, on the surface of the earth.

Forecast Point

The location where the Tsunami Warning Centre may provide estimates of tsunami arrival time or wave height.

G

Gravity wave

A wave generated in a fluid or at the interface between two mediums (e.g. the atmosphere or ocean) which has the restoring force of gravity or buoyancy. When a fluid parcel is displaced on an interface or internally to a region with a different density, gravity restores the parcel toward equilibrium resulting in an oscillation about the equilibrium state. Gravity waves on an air-sea interface are called surface gravity waves or surface waves while internal gravity waves are called internal waves. A tsunami is an example of a gravity wave.

GTS

Global Telecommunications System of the World Meteorological Organization (WMO) that directly connects national meteorological and hydrological services worldwide. The GTS is widely used for the near real-time transmission of sea level data for tsunami monitoring. The GTS and other robust communications methods are used for the transmission of tsunami warnings.

H

Historical tsunami

A tsunami documented to occur through eyewitness or instrumental observation within the historical record.

Historical tsunami data

Historical data are available in many forms and at many locations. These forms include published and unpublished catalogs of tsunami occurrences, personal narratives, marigraphs, tsunami amplitude, runup and inundation zone measurements, field investigation reports, newspaper accounts, film, or video records.

Hypocenter

The point within the earth where an earthquake rupture starts. The epicenter is the point directly above it at the surface of the Earth. The hypocenter is also commonly termed the **focus**.

I

Initial rise

Time of the first minimum of the tsunami waves.

Intensity

Extreme strength, force, or energy.

Inundation

The horizontal distance inland that a tsunami penetrates, generally measured perpendicularly to the shoreline.

Inundation (maximum)

Maximum horizontal penetration of the tsunami from the shoreline. A maximum inundation is measured for each different coast or harbour affected by the tsunami.

Inundation area

Area flooded with water by the tsunami.

Inundation line

Inland limit of wetting, measured horizontally from the mean sea level (MSL) line. The line between living and dead vegetation is sometimes used as a reference. In tsunami science, the landward limit of tsunami runup.

L

Leading wave

First arriving wave of a tsunami. In some cases, the leading wave produces an initial depression or drop in sea level, and in other cases, an elevation or rise in sea level. When a drop in sea level occurs, sea level recession is observed.

Local tsunami

A tsunami from a nearby source for which its destructive effects are confined to coasts within 100 km of the source. A local tsunami is usually generated by an earthquake, but can also be caused by a landslide or a pyroclastic flow from a volcanic eruption.

Low water

The lowest water level reached during a tide cycle. The accepted popular term is low tide.

M

Magnitude

A number assigned to a quantity by means of which the quantity may be compared with other quantities of the same class.

Master Plan

The principal long-term guide for improving the TWS. The Plan provides a summary of the basic elements which comprise the TWS, a description of its existing components, and an outline of the activities, data sets, methods, and procedures that need to be improved in order to reduce tsunami risk. The first edition of the ICG/PTWS Master Plan was released in 1989. The second edition was released in 1999.

Magnitude (Earthquake)

This is a measure of the relative size of an earthquake. A number of different magnitude scales exist besides the Richter scale, including the moment magnitude, which measures the energy released and gives the most reliable estimate for large earthquakes. Because the scale is logarithmic, an increase in one unit of magnitude corresponds to a 10-fold increase in seismic wave amplitude and a 30-fold increase in released energy. And a change of 0.3 units equals a three-fold increase in intensity. In other words, the 9.3 Sumatra earthquake that generated the 2004 Indian Ocean tsunami was three times more powerful than the 9.0 earthquake it was originally thought to be. Moment magnitude is measurable nearly immediately thanks to the advent of modern seismometers, digital recording, and real-time communication links. It allows warning centers to provide initial tsunami advisories within minutes of an earthquake occurrence. In Japan, earthquake warnings get broadcast to the public within 30 seconds of them happening.

Maremoto

Spanish term for tsunami

Mareogram or Marigram

1) Record made by a mareograph.
2) Any graphic representation of the rise and fall of the sea level, with time as abscissa and height as ordinate, usually used to measure tides, may also show tsunamis.

Mareograph

A recording sea level gauge. Also known as a marigraph or tide gauge.

Mean height

Average height of a tsunami measured from the trough to the crest after removing the tidal variation.

Mean sea level

The average height of the sea surface, based upon hourly observation of tide height on the open coast or in adjacent waters which have free access to the sea. These observations are to have been made over a “considerable” period of time. In the United States, mean sea level is defined as the average height of the surface of the sea for all stages of the tide over a 19-year period. Selected values of mean sea level serve as the sea level datum for all elevation surveys in the United States. Along with mean high water, mean low water, and mean lower low water, mean sea level is a type of tidal datum.

Microtsunami

A tsunami of such small amplitude that it must be observed instrumentally and is not easily detected visually.

MOST Model

A numerical model that computes all three stages of an earthquake-generated tsunami—generation, propagation, and run-up—providing a complete tsunami simulation capability.

O

Ocean-wide tsunami

A tsunami capable of widespread destruction, not only in the immediate region of its generation but across an entire ocean. All ocean-wide tsunamis have been generated by major earthquakes. Synonym for teletsunami or distant tsunami.

Ocean-wide Tsunami Warning

A warning issued to all participants after there is confirmation of tsunami waves capable of causing destruction beyond the local area. Ocean-Wide Tsunami Warnings contain estimated tsunami arrival times (ETAs) at all Forecast Points. Ocean-Wide Tsunami Warning Bulletins also normally carry information on selected wave heights and other wave reports. The Warning will be cancelled when it is determined that the tsunami threat is over. As local conditions can cause wide variations in tsunami wave action, the all-clear determination should be made by the local action agencies and not the TWC. In general, after receipt of a Tsunami Warning, action agencies can assume all-clear status when their area is free from damaging waves for at least two hours, unless additional ETAs have been announced by the TWC (for example for a significant aftershock) or local conditions, that may include continued seiching or particularly strong currents in channels and harbours, warrant the continuation of the Tsunami Warning status.

Overflow

A flowing over, inundation.

P

Paleotsunami

Tsunami occurring prior to the historical record or for which there are no written observations. Paleotsunami research is based primarily on the identification, mapping, and dating of tsunami deposits found in coastal areas, and their correlation with similar sediments found elsewhere locally, regionally, or across ocean basins. In one instance, the research has led to a new concern for the possible future occurrence of great earthquakes and tsunamis along the northwest coast of North America. In another instance, the record of tsunamis in the Kuril-Kamchatka region is being extended much further back in time. As work in this field continues it may provide a significant amount of new information about past tsunamis to aid in the assessment of the tsunami hazard.

Post-tsunami survey

Tsunamis are relatively rare events and most of their evidence is perishable. Therefore, it is very important that reconnaissance surveys be organized and carried out quickly and thoroughly after each tsunami occurs, to collect detailed data valuable for hazard assessment, model validation, and other aspects of tsunami mitigation. In recent years, following each major destructive tsunami, a post-tsunami reconnaissance survey has been organized to make measurements of runups and inundation limits and to collect associated data from eyewitnesses such as the number of waves, arrival time of waves and which wave was the largest. The surveys have been organized primarily on an ad-hoc basis by international academic tsunami researchers. A Post-Tsunami Survey Field Guide (**http://ioc3.unesco.org/itic/contents.php?id=28**) has been prepared by the PTWS to help with preparations of surveys, to identify measurements and observations to be taken, and to standardize data collections. The Tsunami Bulletin Board e-mail service has also been used for quickly organizing international surveys and for sharing of the observations from impacted areas.

Probable maximum water level

A hypothetical water level (exclusive of wave run-up from normal wind-generated waves) that might result from the most severe combination of hydrometeorological, geoseismic and other geophysical factors that are considered reasonably possible in the region involved, with each of these factors considered as affecting the locality in a maximum manner. This level represents the physical response of a body of water to maximum applied phenomena such as hurricanes, moving squall lines, other cyclonic meteorological events, tsunamis, and astronomical tide combined with maximum probable ambient hydrological conditions such as wave level with virtually no risk of being exceeded.

R

Recession

Drawdown of sea level prior to tsunami flooding. The shoreline moves seaward, sometimes by a kilometer or more, exposing the sea bottom, rocks, and fish. The recession of the sea is a natural warning sign that a tsunami is approaching.

Reference sea level

The observed elevation differences between geodetic benchmarks are processed through least-squares adjustments to determine orthometric heights referred to a common vertical reference surface, which is the reference sea level. In this way, height values of all benchmarks in the vertical control portion of a surveying agency are made consistent and can be compared directly to determine differences of elevation between benchmarks in a geodetic reference system that may not be directly connected by lines of geodetic leveling. The vertical reference surface in use in the United States, as in most parts of the world, approximates the geoid. The geoid was assumed to be coincident with local mean sea level at 26 tidal stations to obtain the Sea Level Datum of 1929 (SLD 290). National Geodetic Vertical Datum of 1929 (NGVD 29) became a name change only, the same vertical reference system has been in use in the United States since 1929. This important vertical geodetic control system is made possible by a universally accepted, reference sea level.

Refraction diagrams

Models using water depths, direction of wave, separation angle, and ray separation between two adjacent rays as input, produce the path of wave orthogonals, refraction coefficients, wave heights, and travel times.

Regional tsunami

A tsunami capable of destruction in a particular geographic region, generally within about 1,000 kilometers (625 miles) of its source. Regional tsunamis also occasionally have very limited and localized effects outside the region. Most destructive tsunami can be classified as local or regional, meaning their destructive effects are confined to coasts within a 100 km, or up to a 1,000 km, respectively, of the source—usually an earthquake. It follows many tsunami related casualties and considerable property damage also comes from these tsunamis. Between 1975 and 2005 there were 22 local or regional tsunamis in the Pacific and adjacent seas that resulted in deaths and property damage. For example, a regional tsunami in 1983 in the Sea of Japan or East Sea, severely damaged coastal areas of Japan, Korea, and Russia, causing more than $800 million in damage, and more than 100 deaths. Then, after nine years without an event, 11 locally destructive tsunamis occurred in just a seven year period from 1992 to 1998, resulting in over 4,200 deaths and hundreds of millions of dollars in property damage. In most of these cases, tsunami mitigation efforts in place at the time were unable to prevent significant damage and loss of life. However, losses from future local or regional tsunamis can be reduced if a denser network of warning centers, seismic and water-level reporting stations, and better communications are established to provide a timely warning, and if better programs of tsunami preparedness and education can be put in place.

Rise

The upward change or elevation in sea level associated with a tsunami, a tropical cyclone, storm surge, the tide, or other long term climatic effect.

Run-up

1) Difference between the elevation of maximum tsunami penetration (the inundation line) and the sea level at the time of the tsunami.

2) Elevation reached by seawater measured relative to some stated datum such as mean sea level, mean low water, sea level at the time of the tsunami attack, etc., and measured ideally at a point that is the local maximum of the horizontal inundation.

3) In practical terms, runup is only measured where there is clear evidence of the inundation limit on the shore.

Run-up distribution

Set of tsunami run-up values measured or observed along a coastline.

S

Sea level

The height of the sea at a given time measured relative to some datum, such as mean sea level.

Sea level station

A system consisting of a device such as a tide gauge for measuring the height of sea level, a data collection platform (DCP) for acquiring, digitizing, and archiving the sea level information digitally, and often a transmission system for delivering the data from the field station to a central data collection center. The specific requirements of data sampling and data transmission are dependent on the application. The GLOSS program maintains a core network of sea level stations. For local tsunami monitoring, one-second sampled data streams available in real-time are required. For distant tsunamis, warning centers may be able to provide adequate warnings using data acquired in near-real time (one-minute sampled data transmitted every 15 minutes). Sea level stations are also used for sea level rise and climate change studies, where an important requirement is for the very accurate location of the station as acquired through surveying techniques.

Seiche

A seiche may be initiated by a standing wave oscillating in a partially or fully enclosed body of water. It may be initiated by long period seismic waves (an earthquake), wind and water waves, or a tsunami. The resonant oscillation of the water is a seiche.

Seismic sea wave

Tsunamis are sometimes referred to as seismic sea waves because they are most often generated by earthquakes.

Seismic waves

When an earthquake fault ruptures, it causes two types of deformation: **static**; and **dynamic**. Static deformation is the permanent displacement of the ground due to the event. The second type of deformation, dynamic motions, are essentially sound waves radiated from the earthquake as it ruptures. While most of the plate-tectonic energy driving fault ruptures is taken up by static deformation, up to 10% may dissipate immediately in the form of **seismic waves**. The dynamic, transient seismic waves from any substantial earthquake will propagate all around and entirely through the Earth. There are several different kinds of seismic waves, and they all move in different ways. The two main types of waves are **body waves** and **surface waves**. Body waves can travel through the earth's inner layers, but surface waves can only move along the surface of the planet like ripples on water. Earthquakes radiate seismic energy as both body and surface waves.

Seismometer

An instrument that measures ground motion (caused by seismic waves) at a specific location.

Significant wave height

The average height of the one-third highest waves of a given wave group. Note that the composition of the highest waves depends on the extent to which the lower waves are considered. In wave record analysis, the average height of the highest one-third of a selected number of waves, this number being determined by dividing the time of record by the significant period. Also called characteristic wave height.

Spreading

When referring to tsunami waves, it is the spreading of the wave energy over a wider geographical area as the waves propagate away from the source region. The reason for this geographical spreading and reduction of wave energy with distance traveled, is the sphericity of the earth. The tsunami energy will begin converging again at a distance of 90 degrees from the source. Tsunami waves propagating across a large ocean undergo other changes in configuration primarily due to refraction, but geographical spreading is also very important depending on the orientation, dimensions, and geometry of the tsunami source.

Subsidence (uplift)

The permanent movement of land down (subsidence) or up (uplift) due to geologic processes, such as during an earthquake.

T

Teletsunami or distant tsunami

A tsunami originating from a far away source, generally more than 1,000 km away. Less frequent, but more hazardous than regional tsunamis, are ocean-wide or distant tsunamis. Usually starting as a local tsunami that causes extensive destruction near the source, these waves continue to travel across an entire ocean basin with sufficient energy to cause additional casualties and destruction on shores more than 1,000 kilometers from the source. In the last 200 years, there have been at least 21 destructive ocean-wide tsunamis. The most destructive Pacific-wide tsunami of recent history was generated by a massive earthquake off the coast of Chile on 22 May 1960. All Chilean coastal towns between the 36th and 44th parallels were destroyed or heavily damaged by the action of the tsunami and the quake. The combined tsunami and earthquake toll included 2,000 killed, 3,000 injured, two million homeless and $550 million damage. Off the coast of Corral, Chile, the waves were estimated to be 20 meters (67 feet) high. The tsunami caused 61 deaths in Hawaii, 20 in the Philippines and 138 in Japan. Estimated damages were US $50 million in Japan, US $24 million in Hawaii and several millions of dollars along the west coast of the United States and Canada. Distant wave heights varied from slight oscillations in some areas to 12 meters (40 feet) at Pitcairn Island, 11 meters (37 feet) at Hilo, Hawaii, and six meters (20 feet) at some places in Japan. The worst tsunami catastrophe in history occurred in the Indian Ocean on 26 December 2004, when a M9.3 earthquake off the northwest coast of Sumatra, Indonesia, produced an ocean-wide tsunami that hit Thailand and Malaysia to the east, and Sri Lanka, India, the Maldives, and Africa to the west as it traversed across the Indian Ocean. Nearly 250,000 people lost their lives and more than a million people were displaced, losing their homes, property, and livelihoods. The magnitude of death and destructiveness caused immediate response by the world's leaders and led to the development of the Indian Ocean tsunami warning and mitigation system in 2005. The event also raised awareness of tsunami hazards globally, and new systems were established in the Caribbean, the Mediterranean, and Atlantic.

Tidal wave

1) The wave motion of the tides.
2) Often incorrectly used to describe a tsunami, storm surge, or other unusually high and therefore destructive water levels along a shore that are unrelated to the tides.

Tide

1) The rhythmic, alternate rise and fall of the surface (or water level) of the ocean, and of bodies of water connected with the ocean such as estuaries and gulfs, occurring twice a day over most of the Earth and resulting from the gravitational attraction of the moon (and, in lesser degrees, of the sun) acting unequally on different parts of the rotating Earth.
2) The periodic movements of the seas which have a coherent amplitude and phase relationship to some periodic geophysical force.

Tide amplitude

One-half of the difference in height between consecutive high water and low water; hence, half of the tidal range.

Tide gauge

A device for measuring the height (rise and fall) of the tide. Especially an instrument for automatically making a continuous graphic record of tide height versus time.

Tide station

A place where tide observations are obtained.

Travel time

Time required for the first tsunami wave to propagate from its source to a given point on a coastline.

Travel time map

Map showing isochrons or lines of equal tsunami travel time calculated from the source outwards toward terminal points on distant coastlines.

Tsunameter

An instrument for the early detection, measurement, and real-time reporting of tsunamis in the open ocean. Also known as a tsunamimeter. The DART system is a tsunameter.

Tsunami

Japanese term meaning wave ("nami") in a harbor ("tsu"). A series of traveling waves of extremely long length and period, usually generated by disturbances associated with earthquakes occurring below or near the ocean floor. (Also called a seismic sea wave and, incorrectly, tidal wave). Volcanic eruptions, submarine landslides, and coastal rock falls can also generate tsunamis, as can a large meteorite impacting the ocean. These waves may reach enormous dimensions and travel across entire ocean basins with little loss of energy. They proceed as ordinary gravity waves with a typical period of between 10 and 60 minutes. Tsunamis steepen and increase in height on approaching shallow water, inundating low- lying areas, and where local submarine topography causes the waves to steepen, they may break and cause great damage. Tsunamis have no connection with tides; the popular name, tidal wave, is entirely misleading.

Tsunami amplitude

Usually measured on a sea level record, it is:

1) the absolute value of the difference between a particular peak or trough of the tsunami and the undisturbed sea level at the time.

2) half the difference between an adjacent peak and trough, corrected for the change of tide between that peak and trough. It is intended to represent the true amplitude of the tsunami wave at some point in the ocean. However, it is often an amplitude modified in some way by the tide gauge response.

Tsunami bore

A steep, turbulent, rapidly moving tsunami wave front, typically occurring in a river mouth or estuary.

Tsunami damage

Loss or harm caused by a destructive tsunami. More specifically, the damage caused **directly** by tsunamis can be summarized into the following:

1) Deaths and injuries.

2) Houses destroyed, partially destroyed, inundated, flooded, or burned.

3) Other property damage and loss.

4) Boats washed away, damaged or destroyed.

5) Lumber washed away.

6) Marine installations, destroyed.

7) Damage to public utilities such as railroads, roads, electric power plants, water supply installations etc.

Indirect secondary tsunami damage can be:

1) Damage by fire of houses, boats, oil tanks, gas stations, and other facilities.
2) Environmental pollution caused by drifting materials, oil, or other substances.
3) Outbreak of disease of epidemic proportions, which may be serious in densely populated areas.

Tsunami dispersion

Redistribution of tsunami energy, particularly as a function of its period, as it travels across a body of water.

Tsunami earthquake

An earthquake that produces an unusually large tsunami relative to the earthquake magnitude (Kanamori, 1972). Tsunami earthquakes are characterized by a very shallow focus, fault dislocations greater than several metres, and fault surfaces smaller than those for normal earthquakes. They are also slow earthquakes, with slippage along their faults occurring more slowly than in normal earthquakes. The last events of this type were in 1992 (Nicaragua) and 1996 (Chimbote, Peru).

Tsunami edge wave

Wave generated by a tsunami that travels along the coast.

Tsunami forerunner

A series of oscillations of the water level preceding the arrival of the main tsunami waves, mainly due to the resonance in bays and shelves that could occur before the arrival of the main tsunami.

Tsunami generation

Tsunamis are most frequently caused by earthquakes, but can also result from landslides, volcanic eruptions, and very infrequently by meteorites or other impacts upon the ocean surface. Tsunamis are generated primarily by tectonic dislocations under the sea which are caused by shallow focus earthquakes along areas of subduction. The upthrusted and downthrusted crustal blocks impart potential energy into the overlying water mass with drastic changes in the sea level over the affected region. The energy imparted into the water mass results in tsunami generation, i.e. energy radiating away from the source region in the form of long period waves.

Tsunami generation theory

The theoretical problem of generation of the gravity wave (tsunami) in the layer of elastic liquid (an ocean) occurring on the surface of elastic solid half-space (the crust) in the gravity field can be studied with methods developed in the dynamic theory of elasticity. The source representing an earthquake focus is a discontinuity in the tangent component of the displacement on some element of area within the crust. For conditions representative of the Earth's oceans, the solution of the problem differs very little from the joint solution of two more simple problems: the problem of generation of the displacement field by the given source in the solid elastic half-space with the free boundary (the bottom) considered quasi-static and the problem of the propagation of gravity wave in the layer of heavy incompressible liquid generated by the known (from the solution of the previous problem) motion of the solid bottom. There is the theoretical dependence of the gravity wave parameters on the source parameters (depth and orientation). One can roughly estimate the quantity of energy transferred to the gravity wave by the source. In general, it corresponds to the estimates obtained with empirical data. Also, tsunamis can be generated by other different mechanisms such as volcanic or nuclear explosions, landslides, rock falls, and submarine slumps.

Tsunami hazard

The probability that a tsunami of a particular size will strike a particular section of coast.

Tsunami hazard assessment

Documentation of tsunami hazards for a coastal community is needed to identify populations and assets at risk, and the level of that risk. This assessment requires knowledge of probable tsunami sources (such as earthquakes, landslides and volcanic eruptions), their likelihood of occurrence, and the characteristics of tsunamis from those sources at different places along the coast. For those communities, data on earlier (historical and paleotsunamis) tsunamis may help quantify these factors. For most communities, however, only very limited or no past data exist. For these coasts, numerical models of tsunami inundation can provide estimates of areas that will be flooded in the event of a local or distant tsunamigenic earthquake or a local landslide.

Tsunami impact

Although infrequent, tsunamis are among the most terrifying and complex physical phenomena and have been responsible for great loss of life and extensive destruction to property. Because of their destructiveness, tsunamis have important impacts on the human, social and economic sectors of societies. Historical records show that enormous destruction of coastal communities throughout the world has taken place and that the socio-economic impact of tsunamis in the past has been enormous. In the Pacific Ocean where the majority of these waves have been generated, the historic record shows tremendous destruction with extensive loss of life and property. In Japan, which has one of the most populated coastal regions in the world and a long history of earthquake activity, tsunamis have destroyed entire coastal populations. There is also a history of severe tsunami destruction in Alaska, the Hawaiian Islands, and South America, although records for these areas are not as extensive. The last major Pacific-wide tsunami occurred in 1960. Many other local and regional destructive tsunamis have occurred with more localized effects.

Tsunami intensity

Size of a tsunami based on the macroscopic observation of a tsunami's effect on humans, objects including various sizes of marine vessels and buildings. The original scale for tsunamis was published by Sieberg (1923), and later modified by Ambraseys (1962) to create a six-category scale. Papadopoulus and Imamura (2001) proposed a new 12-grade intensity scale which is independent of the need to measure physical parameters like wave amplitude, sensitive to the small differences in tsunami effects, and detailed enough for each grade to cover the many possible types of tsunami impact on the human and natural environment. The scale has 12 categories, similar to the Modified Mercalli Intensity Scale used for macroseismic descriptions of Earthquake intensity.

Tsunami magnitude

Size of a tsunami based on the measurement of the tsunami wave on sea level gauges and other instruments. The scale, originally descriptive and more similar to an intensity, quantifies the size by using measurements of wave height or tsunami runup. Iida et al. (1972) described the magnitude (m) as dependent in logarithmic base 2 on the maximum wave height measured in the field, and corresponding to a magnitude range from -1 to 4:

$$m = \log 2\ Hmax$$

Hatori (1979) subsequently extended this so-called Imamura-Iida scale for far-field tsunamis by including distance in the formulation. Soloviev (1970) suggested that the mean tsunami height may be another good indicator of tsunami size, so that the mean tsunami height is equal to 1/square root (Hmax), and the maximum intensity would be that measured nearest to the tsunami source. A variation on this is the Imamura-Soloviev intensity scale I (Soloviev, 1972). Shuto (1993) has suggested the measurement of H as the height where specific types of impact or damage occur, thus proposing a scale which can be used as a predictive quantitative tool for macroscopic effects. Tsunami magnitudes have also been proposed that are similar in form to those used to calculate earthquake magnitudes. These include the original formula proposed by Abe (1979) for tsunami magnitude, M t:

$$M\ t = \log H + B$$

where H is the maximum single crest or trough amplitude of the tsunami waves (in meters) and B is a constant, and the far-field application proposed by Hatori (1986) which adds a distance factor into the calculation.

Tsunami numerical modeling

Mathematical descriptions that seek to describe the observed tsunami and its effects. Often the only way to determine the potential run-ups and inundation from a local or distant tsunami is to use numerical modeling, since data from past tsunamis is usually insufficient. Models can be initialized with potential worst case scenarios for the tsunami sources or for the waves just offshore to determine corresponding worst case scenarios for run-up and inundation. Models can also be initialized with smaller sources to understand the severity of the hazard for less extreme but more frequent events. The information is the basis for creating tsunami evacuation maps and procedures. At present, numerical modeling has only been carried out for a small fraction of coastal areas at risk. Sufficiently accurate modeling techniques have only been available in recent years, and the models require training to understand and use correctly, as well as input of detailed bathymetric and topographic data in the area being modeled. Numerical models have been used in recent years to simulate tsunami propagation and interaction with land masses. Such models usually solve similar equations but often employ different numerical techniques and are applied to different segments of the total problem of tsunami propagation from generation regions to distant areas of run-up. For example, several numerical models have been used to simulate the interaction of tsunamis with islands. These models have used finite difference, finite element, and boundary integral methods to solve the linear long wave equations. The models solve these relatively simple equations and provide reasonable simulations of tsunamis for engineering purposes. Historical data are often very limited for most coastlines. Consequently, numerical modeling may be the only way to estimate potential risk. Techniques now exist to carry out this assessment. Computer software and the training necessary to conduct this modeling are available through programs such as the IOC Tsunami Inundation Modeling Exchange (Time) Program.

Tsunami observation

Notice, observation or measurement at a particular point in time of sea level fluctuation caused by the incidence of a tsunami on a specific point.

Tsunami period

Amount of time that a tsunami wave takes to complete a cycle. Tsunami periods typically range from five minutes to two hours.

Tsunami period (dominant)

Difference between the arrival time of the highest peak and the next one measured on a water level record.

Tsunami preparedness

Readiness of plans, methods, procedures, and actions taken by government officials and the general public for the purpose of minimizing potential risk and mitigating the effects of future tsunamis. The appropriate preparedness for a warning of impending danger from a tsunami requires knowledge of areas that could be flooded (tsunami inundation maps) and knowledge of the warning system to know when to evacuate and when it is safe to return.

Tsunami propagation

Tsunamis travel outward in all directions from the generating area, with the direction of the main energy propagation generally being orthogonal to the direction of the earthquake fracture zone. Their speed depends on the depth of water, so that the waves undergo accelerations and decelerations in passing over an ocean bottom of varying depth. In the deep and open ocean, they travel at speeds of 500 to 1,000 km per hour (300 to 600 miles per hour). The distance between successive crests can be as much as 500 to 650 km (300 to 400 miles). However, in the open ocean, the height of the waves is generally less than a meter (three feet) even for the most destructive teletsunamis, and the waves pass unnoticed. Variations in tsunami propagation result when the propagation impulse is stronger in one direction than in others because of the orientation or dimensions of the generating area and where regional bathy metric and topographic features modify both the waveform and rate of advance. Specifically, tsunami waves undergo a process of wave refraction and reflection throughout their travel. Tsunamis are unique in that the energy extends through the entire water column from sea surface to the ocean bottom. It is this characteristic that accounts for the great amount of energy propagated by a tsunami.

Tsunami resonance

The continued reflection and interference of tsunami waves from the edge of a harbor or narrow bay which can cause amplification of the wave heights, and extend the duration of wave activity from a tsunami.

Tsunami Response Plan (TRP)

The Tsunami Response Plan describes the actions taken to ensure public safety by responsible agencies after notification by the Tsunami Warning Focal Point (TWFP), typically the national Tsunami Warning Centre. It includes Standard Operating Procedures and Protocols for emergency response and action, organizations and individuals involved and their roles and responsibilities, contact information, timeline and urgency assigned to action, and means by which both ordinary citizens and special needs populations (physically or mentally handicapped, elderly, transient, and marine populations) will be alerted. For tsunami response, emphasis is placed on the rapidness, efficiency, conciseness, and clarity of the actions and instructions to the public. A Tsunami Response Plan should also include post-tsunami actions and responsibilities for search and rescue, relief, rehabilitation, and recovery.

Tsunami risk

The probability of a particular coastline being struck by a tsunami multiplied by the likely destructive effects of the tsunami and by the number of potential victims. In general terms, risk is the hazard multiplied by the exposure.

Tsunami sediments

Sediments deposited by a tsunami. Finding tsunami sediment deposits within stratigraphic soil layers provides information on the occurrence of historical paleotsunamis. The discovery of similarly dated deposits at different locations, sometimes across ocean basins and far from the tsunami source, can be used to map and infer the distribution of tsunami inundation and impact.

Tsunami simulation

Numerical model of tsunami generation, propagation and inundation.

Tsunami source

Point or area of tsunami origin, usually the site of an earthquake, volcanic eruption, or landslide that caused large-scale rapid displacement of the water to initiate the tsunami waves.

Tsunami velocity (or shallow water velocity)

The velocity of an ocean wave whose length is sufficiently large compared to the water depth (i.e., 25 or more times the depth) can be approximated by the following expression:

c = sqrt (gh)

Where:

c: is the wave velocity

g: the acceleration of gravity

h: the water depth.

Thus, the velocity of shallow-water waves is independent of wave length L. In water depths between ½ L and 1/25 L it is necessary to use a more precise expression:

c = sqrt ((gL/2p)[tahh(2 p h/l)])

Tsunami Warning

The highest level of tsunami alert. Warnings are issued by the NTWCs due to confirmation of a destructive tsunami wave or the threat of an imminent tsunami. Initially the warnings are based only on seismic information without tsunami confirmation as a means of providing the earliest possible alert to at-risk populations. Warnings initially place a restricted area in a condition that requires all coastal areas in the region to be prepared for imminent flooding. Subsequent text products are issued at least hourly or as conditions warrant to continue, expand, restrict, or end the warning. In the event a tsunami has been confirmed which could cause damage at distances greater than 1,000 kilometers (625 miles) from the epicenter, the warning may be extended to a larger area.

Tsunami Watch

The second highest level of tsunami alert. Watches are issued by the RTWPs and NTWCs based on seismic information without destructive tsunami confirmation. The watch is issued as a means of alerting the affected populations located, for example, one to three hours tsunami travel time beyond the warned area. Subsequent text products are issued at least hourly to expand the watch and warning area, upgrade all areas to a warning, or end the watch and warning. A Tsunami Watch may be included in the text of the message that disseminates a Tsunami Warning.

Tsunami wave length

The horizontal distance between similar points on two successive waves measured perpendicular to the crest. The wave length and the tsunami period give information on the tsunami source. For tsunamis generated by earthquakes, the typical wave length ranges from 20 to 300 km. For tsunamis generated by landslide, the wave length is much shorter, ranging from hundreds of meters to tens of kilometers.

Tsunami zonation (tsunami zoning)

Designation of distinctive zones along coastal areas with varying degrees of tsunami risk and vulnerability for the purpose of disaster preparedness, planning, construction codes or public evacuation.

Tsunamic

Having features analogous to those of a tsunami or descriptive of a tsunami.

Tsunamigenic

Having generated a tsunami; a tsunamigenic earthquake, a tsunamigenic landslide.

W

Water level (maximum)

Difference between the elevation of the highest local water mark and the elevation of the sealevel at the time of the tsunami. This is different from maximum runup because the water mark is often not observed at the inundation line, but maybe halfway up the side of a building or on a tree trunk.

Wave crest

1) The highest part of a wave.

2) That part of the wave above still water level.

Wave trough

The lowest part of a wave.

Appendix C

Descriptions of Staff Positions at NTWCs and RTWPs

As noted in Chapter 2, NTWCs and RTWPs require at least 17 persons to conduct twenty-four hour, seven day per week operations plus other required activities such as maintenance, outreach, training and personal development, research, and product development. The extent of these additional activities beyond simply staffing shifts around the clock may necessitate greater staffing numbers at some centers.

This appendix will describe each of the positions depicted in the organizational chart in Chapter 2. These positions include:

- Center Director/Deputy Director
- Warning Coordination Scientist
- Science Officer
- Administrative Assistant
- Watch Stander (at least 10 are needed for 24 by 7 coverage)
- Electronics Technician
- Information and Communications Technology Officer

Warning Center Director/Deputy Director

The Center Director should possess a multi-disciplinary knowledge of earthquake seismology, physical oceanography, communications, computer technology, and have good organizational and managerial skills. The Director manages and provides oversight of the day-to-day operations at the center. All operational systems, procedures, and products must be kept in operational status, and staff must be trained in proper response actions. Additional responsibilities include overseeing the maintenance of a large array of electronics and electro-mechanical equipment necessary in support the tsunami warning system; operational research aimed at developing a better understanding of the physical processes involved in generation of tsunamis; development of integrated computer and ocean modeling systems for acquiring and processing data related to tsunamis and for disseminating messages to users; and community outreach and preparedness activities aimed at educating communities in protecting themselves against the effects of tsunamis.

The Director is responsible for providing supervision and leadership to the TWC staff. To issue immediate tsunami warnings at any time during the day or night, it is vital that all electronic equipment, systems, and computers function as expected. The center's electronic staff is responsible for maintaining, monitoring, integrating, and enhancing complex electronic equipment at the remote sites and at the center. The centers operate and maintain remote sites within their Area of Responsibility (AOR). Each of these remote systems contains subsystems and other electronic components that are monitored frequently to ensure continuous transmission of quality data. At an operations center, there are numerous pieces of electronic equipment, such as: communication systems, satellite dishes, micro computer systems, un-interruptible backup power systems, recording and archiving systems, alarm systems, seismometers, data acquisition systems, calibrators, data telemetry radios, and numerous display monitors which must be maintained in proper working condition.

The Director supervises the scientific staff that responds to potentially tsunamigenic events, and must be expert in tsunami warning communications, real-time seismic analysis, long wave dynamics, and tsunami history and forecasting.

Warning Coordination Scientist (WCS)

The WCS works under the general supervision of the Center Director, who provides general administrative and policy direction defining the assignment in terms of broad mission statements. The WCS plans, designs, executes and evaluates the overall preparedness program, independently determining the methods and approaches to be used. The preparedness program is evaluated in terms of results achieved and objectives met. Decisions and plans are accepted as technically authoritative.

The WCS serves as the principal interface between the center and the users of tsunami bulletins. He/She leads the effort to insure their evaluation, adjustment, and improvement. The WCS should be fully responsible for planning, coordinating, and carrying out the center's area-wide public awareness and tsunami readiness program designed to educate the public to ensure the mitigation of death, injury and property damage or loss caused by severe tsunami events. The WCS also leads and coordinates staff outreach efforts and provides direction, guidance, instructions, and assistance to the staff regarding center operational procedures. The WCS must possess an interdisciplinary knowledge of earthquake seismology, physical oceanography, communications, computer technology and have good organizational skills. Incumbent must possess a thorough understanding of the complex processes involved in seismic investigation and analysis as well as in the earth-ocean interaction involving tsunami generation, propagation, and runup. In order to function effectively, the incumbent must keep up to date on current state of the art advances in seismology, tsunami-oceanography, and computer science. The incumbent must also fulfill the tasks of a senior tsunami watch stander when necessary.

He/She is responsible for verifying that message communication paths are sound, and for determining the problems when problems arise.

Major Duties

1. ***Develops operational procedures and in-house procedural training, and conducts area-wide evaluations of TWC products and services:***
   - Responsible for the development of detailed operational procedures for ensuring an effective and responsive tsunami warning program at the TWC. Since rapid response, accuracy of work and competent professional judgments under extreme pressure are all critical to the success of the program, procedures must constantly be evaluated, tested and revised. Provides training to staff on event procedures and thresholds.
   - Reviews center-produced products and services for adherence to established policy. Interfaces with all users of tsunami products and services (e.g., public, media, foreign, national, state, and local emergency management, and military) to evaluate the adequacy and usefulness of the services provided.
   - Collaborates with the center director and with state/local agencies in developing, proposing, and implementing plans to develop, modify, or tailor products and services with the goal of service improvement or increased product usefulness.

2. ***Conducts an AOR-wide preparedness program.***
   - Identifies priority community preparedness objectives and develops area-wide warning projects to meet those objectives. In coordination with the center director, establishes schedules for outreach activities.
   - Reviews area-wide warning efforts and determines the adequacy of preparedness activities.
   - Ensures the maintenance and accuracy of communication dissemination within the Tsunami Warning System. The WCS must be familiar with the overall communication plan and routing to understand the internal communication workings of the Tsunami Warning System. Conducts drills, exercises, and regularly scheduled communication tests.
   - Develops center plans and procedures to address the community emergency action needs for dealing with tsunami events to ensure that local communities have become as prepared as possible. The WCS works closely with foreign, national, state, county, and local emergency management agencies and other related agencies concerned with disasters to ensure a planned, coordinated, and effective preparedness effort in the AOR.
   - The WCS will answer inquiries about geophysical events and maintain favorable relations with local and national press. Incumbent will be frequently quoted by the press and tape recorded for broadcast.

- Serves as technical advisor and resource for the center director on preparedness measures. Interfaces with regional and national agencies on broad preparedness activities.
- Maintains close liaison and coordination with the directors of civilian agencies, commanders of military units, and community emergency preparedness officials in order to develop and maintain an effective system for the dissemination of tsunami warnings or potential earthquake/tsunami hazards.
- Conducts an ambitious public education program to promote individual recognition of the threat of tsunamis and related phenomena, and to advise on and promote the exercise of appropriate recommended individual-specific actions for the protection of life and property.
- Addresses conventions, conferences, and meetings of emergency management agencies and community groups; appears on local radio or television as a spokesperson and expert on tsunami-related hazards.
- Encourages, promotes, and assists in the planning and conduct of community drills to test and exercise local disaster plans and center-local government interaction.
- Leads or participates in the conduct of local staff geophysical events studies and developmental projects designed to capitalize on or incorporate the benefits of new science/technology/local techniques towards enhancing preparedness objectives.

3. ***Serves as Senior Scientist on shift duty, performing the full range of responsibilities of that position. This work may comprise approximately 25% of the time.***
   - Stand-by duty may be required. This requires five minute response to the office at all times while on duty. The incumbent must carry a pager system and office cell phone while on duty. This requirement will influence where the employee lives.
   - Exercises judgment on behalf of the center director as to the need for additional staff during the shift or in preparation for the upcoming shift. Handles general office administrative matters which may occur on shift. Exercises call-back authority and authorizes expenditures of funds for overtime for additional or augmenting center staff, as appropriate.

4. ***When designated, acts for the site manager during his/her absence, with full technical, managerial, and administrative responsibility for center programs, products, and services.***

Knowledge Required by the Position:

- Professional knowledge of the principles, practices, and theory of physical oceanography and seismology as they relate to the tsunami phenomena including generation, propagation, and run-up.
- Knowledge of historic and potential earthquake and tsunami events, potential tsunami source mechanisms, and their occurrence on an area-by-area basis. This knowledge must be integrated in the planning and development of operational procedures.
- Knowledge of computers, computer systems, and functional ability with scientific programming languages.
- Must have knowledge of the NTWC or RTWP procedures, abilities required to evaluate potential tsunami-generating events, and be able to issue the proper tsunami product.
- Knowledge of the operation of all military, governmental, and community preparedness agencies which receive tsunami warnings from the center.
- Knowledge of the operation and interaction with other government and non-government agencies that are engaged in seismological and tsunami studies.
- Mastery of the principles, methods, practices and techniques of tsunami bulletin communication in order to function as the technical authority for the center within the service area, and to design, plan and execute a preparedness program of major scope and significance which conveys information about complex programs affecting a large and diverse number of people throughout the population. This includes exceptional skill in written and oral communication, particularly the ability to translate highly technical geophysical concepts into non-technical terms.
- A basic understanding of the organization and functions of the national, state, and local agencies concerned with disaster preparedness.
- Thorough knowledge of operational characteristics of complex equipment utilized in data acquisition, communications, and service programs assigned to the center. This includes the skills necessary to properly utilize sophisticated equipment and to interpret and apply its output in a real-time operational environment.
- Knowledge of applied research methods and data management techniques sufficient to participate in development efforts designed to develop or incorporate the latest advances into center operations.
- A basic understanding of the psychology of human response to emergency situations, especially relating to tsunami phenomena and official warnings calling for governmental and citizen action.
- Highly developed tact and diplomacy to function in difficult public contact situations.

Science Officer (SO)

The primary focus of the Science Officer (SO) is to ensure the scientific integrity of the products and services provided to the public by the center, to lead or participate in joint research projects and developmental efforts conducted with universities and research centers, and to implement new techniques and processes to the operational systems. The incumbent works under the general direction of the Center Director, but has considerable freedom in carrying out responsibilities, and in the daily operation of the office. Assignments are broad in nature with the SO initiating assignments and developing and modifying the objectives of the work. The incumbent will exercise a high degree of originality and judgment to define complex problems, to develop a plan of attack to perform the required research and training, and to develop results. New technologies and techniques may have little or no precedents. Therefore, the SO must exercise originality and judgment to devise best approaches for integrating new technologies into operations or suggesting new research or techniques.

The incumbent must possess a multi-disciplinary knowledge of earthquake seismology, physical oceanography, communications, computer technology and have good organizational skills The incumbent is expected to initiate and oversee the transfer of new technologies from the research community to the operational environment, to promote operational research aimed at developing a better understanding of the physical processes involved in tsunami generation mechanisms, to develop integrated computer systems for acquiring and processing seismic and sea level data related to tsunamis, to establish professional staff enrichment activities, and to evaluate and improve the professional operational activities of the center. The SO monitors and evaluates the accuracy and scientific basis of tsunami bulletins provided by the center. When so designated, the SO serves as Director of the facility during the absence of the Center Director with full technical and administrative responsibility for all operational programs, products, and services of the center.

Major Duties

1. ***Technology Transfer/Development Activities:***
   - Directs and participates in research and special studies concerned with the operation of the center including development of new techniques in seismic and tide data retrieval and processing, earthquake source studies, tsunamigenesis, tsunami forecasting and defining tsunami terminal effects.
   - Prepares and presents technical papers on all aspects of the Tsunami Warning System and represents the center at technical meetings held for the purpose of exchanging scientific information.
   - Provides technical and scientific leadership and training to the staff in such areas as analyzing seismic and tide data, earthquakes, tsunamis, computer programming, techniques development, and operational development. Assess

continuing and future training needs required to successfully incorporate new technology and science into the TWC operations.

- Ensures that center facilities and staff resources are available for full participation in developmental projects, as appropriate. Coordinates with the Center Director, channeling the results of investigations, establishing test beds, and applications mechanisms to evaluate project output.
- Coordinates and consults with scientists in other agencies, academia and the private sector worldwide to identify and/or develop opportunities for enhanced warning procedures and techniques to be used at the center. Integrates new scientific/technological advances and techniques into center operational procedures and operations.
- Maintains and enhances real-time seismic and sea level operational software at the center.

2. ***Evaluation and Improvement Activities:***
   - Evaluates the technical and scientific adequacy of all center products and services by conducting a product verification effort targeted to improving the scientific basis of products produced. Devises local evaluation methodologies and develops evaluation reports. Identifies scientific shortcomings, recommends improvement actions to the center director, and devises plans for implementing those corrective actions.
   - Monitors established performance metrics which gage the accuracy and response time of tsunami warning center products. Ensures accurate verification data and analyses and facilitates the development of local verification procedures designed to assist national and local programs, developmental efforts, and new technology implementation.

3. ***Serves as Senior Scientist on shift duty, performing the full range of responsibilities of that position.***
   - Exercises judgment on behalf of the site manager as to the need for additional staff during the shift or in preparation for the upcoming shift. Handles general office administrative matters which may occur on shift. Exercises call-back authority and authorizes expenditures of funds for overtime for additional or augmenting TWC staff, as appropriate.
   - Routinely collaborates with the center director in assessing subordinate staff performance from a scientific and technical perspective. Provides input to performance ratings of subordinate staff and recommends recognition as appropriate.

4. ***When designated, acts for the center director during his/her absence, with full technical, managerial, and administrative responsibility for all programs, products, and services.***

Knowledge Required by the Position

- Professional knowledge of the principles, practices and theory of physical oceanography and seismology as they relate to the tsunami phenomena including generation, propagation, and run-up.
- Knowledge of historic and potential earthquake and tsunami events, potential tsunami source mechanisms, and their occurrence on an area-by-area basis around the Pacific. This knowledge must be integrated in the planning and development of operational procedures.
- Knowledge of computers, computer systems, and ability to develop new operational techniques from start to finish with scientific programming languages.
- Must have knowledge of the center procedures, abilities required to evaluate potential tsunami-generating events, and be able to issue the proper tsunami product.
- The ability to remain calm and work effectively under stressful situations is essential. An ability to conduct surveys of the scientific literature, identify appropriate techniques and apply them to improve tsunami warning operations is required. The incumbent must understand program policy and the inter-relationship of the center and it's participants.
- Knowledge of real-time seismic processing systems and the ability to configure the systems, and the ability to create software which enhances the system for tsunami warning purposes.
- Knowledge of long wave modeling techniques along with the ability to create and modify such techniques as necessary to improve the forecasting ability of the center.
- Thorough knowledge of operational characteristics of complex equipment utilized in data acquisition, communications, and service programs assigned to the center. This includes the skills necessary to properly utilize sophisticated equipment and to interpret and apply its output in a real-time operational environment.
- Must be able to work well with colleagues of differing abilities and temperaments.

Administrative Assistant (AA)

As principal administrative assistant to the center director, the AA performs a wide range of administrative functions for the staff management team, including: technical aspects of all administrative programs and activities for the office related to budget, funds control, purchasing, procurement requests, contract monitoring, bankcard, convenience check program, property, vehicles, travel, training, personnel actions, time and attendance, mail, office supplies and equipment, etc.

Major Duties

1. **Administrative Programs.** ***Applies knowledge of the purposes, objectives, and requirements of various administrative programs to track progress in meeting objectives.***
   - For each program, establishes and maintain files, spreadsheets, or other records for forecasting milestones and tracking progress and relevant expenditure categories such as funds, work hours, materials, maintenance, and energy.
   - Prepares recurring and special reports and keeps management staff informed of changing requirements and trends that may lead to potential problems. Likewise, requests explanations from them when milestones and requirements are not being met. Upon completion of cycles or programs, calculates total expenditures, prepares reports and graphs as appropriate to show planned versus actual accomplishments, to be sent to higher levels.

2. ***Human Resources.***
   - Maintains a program that ensures the completion of planned personnel actions for the foreseeable future.
   - Tracks plans and requirements such as completion of probationary periods, time-in-grade, and leave category, retirement eligibility, required training, etc.
   - Based upon knowledge of HR and unit requirements, obtains relevant forms, position descriptions, and other documents necessary and assembles complete packages with background, and insures routing through higher levels, for approvals and processing in a timely manner.

Knowledge Required by the Position

- Sufficient knowledge of human resources, supply, budget, travel and related procedures, contract administration, and reports preparation to carry out the administrative functions of the office, provide credible guidance to management officials on processes to be followed, and to conduct necessary research into appropriate regulations or policy statements.
- Practical knowledge and understanding of fundamental center operations, practices, methods, techniques and terminology and mission, policies, and procedures to receive and answer or refer requests for information in person, telephone, or on paper, and to complete assignments to meet organization needs and goals.
- Knowledge of grammar, punctuation, spelling, style, format, filing, travel, time and attendance, and related requirements, procedures, and processes.
- Skill in office automation techniques including PC usage, database management, spreadsheets, word processing, and related graphics.

The Administrative Assistant (AA) provides the only administrative and secretarial support for an office of 15 staff members and must coordinate and handle a wide variety of tasks and responsibilities independently. The AA must be able to work independently and often under great demands and expectations. The office has significant responsibilities for coordinating with and providing information to other public and private organizations, the general public, and the media. The AA must be able to adequately represent the Center Director in the discharge of a significant degree of the required coordination and liaison work.

Watch Standers (at least ten for twenty-four hour coverage)

The responsibilities of a center watch stander are of broad national and international scope. The Geophysicist in this position plays a vital role in the issuance of tsunami warnings and watches for the Tsunami Warning Center. The incumbent must possess a multi-disciplinary knowledge of earthquake seismology, physical oceanography, communications, and computer technology. Areas of involvement include telecommunications hardware and software; numerical modeling; historical databases for earthquakes and tsunamis; tsunami generation mechanisms such as earthquakes, volcanoes, aerial and submarine landslides; geography; long-wave propagation theory; earthquake seismology; and geomagnetism. The Geophysicist in this position must possess the professional judgment necessary to gather and evaluate appropriate information for accuracy and completeness, and to implement the correct response in a timely manner for the protection of lives and property.

Major Duties

Tsunami Warning System Operations: The watch stander may serve as the Shift Leader on a rotational basis as part of a tsunami and earthquake investigation team with other members of the staff. If a Lead Geophysicist, the watch stander acts as a team leader, supervises the investigation, and provides technical guidance to others on the team. He/she must be able to make all observations, calculations, and interpretations, using all available geophysical, oceanographic, and geographic data, obtained by diverse methods of communications, to locate an earthquake, determine its magnitude, evaluate its potential for tsunami generation, evaluate appropriate tsunami data for degree of potential threat, and issue, with follow-up, a tsunami watch, a tsunami warning, or other information messages as necessary. Appropriate actions are based on an expert knowledge of theoretical and applied geophysics, volcanology, sedimentology, regional tectonics, geography, and oceanography of both the source region as well as potential impact areas. The Lead Geophysicist must complete any investigation with accurate and objective documentation through preparation of a Tsunami Warning Log for distribution to national and international Tsunami Warning System participants.

The watch stander is independently responsible for understanding and using a variety of communication networks applicable to different situations and for understanding and using a variety of computer hardware platforms ranging from micro-computers to mini-computers, as well as a suite of software programs designed for different situations.

The watch stander maintains favorable relations with representatives of the news media and answers questions about geophysical events. He/she seeks to upgrade the quality of tsunami warning services by conceiving and implementing original improvements.

Operational Support (Technology Transfer): The watch stander keeps informed of improvements in the theory and practice of earthquake seismology, volcanism, oceanography, geophysical fluid dynamics, remote sensing, and telecommunications as it effects operations and program policy. He/she is expected to incorporate this information into improved methods and techniques which contribute to the increased effectiveness of the Tsunami Warning System. In this respect, the watch stander may act as a technical liaison with outside academic or governmental institutions, both national and international, to effect technology transfer of mutual benefit.

Applied Research: Due to the unique operational requirements of the NTWC or RTWP, existing methods and techniques may not be applicable to many phases of operations. The watch stander conducts applied research in which original theories and conceptual models are tested against available data to evaluate their applicability to the Tsunami Warning System. This effort is expected to ultimately provide the tsunami warning system with a quantitative forecast capability. This will include more detailed and accurate travel time predictions, tsunami spectral energy propagation models which can identify coastal areas that are at higher risk, and broad band tsunami models, both linear and nonlinear, which will aid in the interpretation of remotely situated water level instruments.

Seismology Program: In addition to operational requirements of working with real time seismic data in support of tsunami warning services, the watch stander may provide support to center's mission as a seismological observatory when appropriate. Some centers may coordinate operational requirements and data submission with international seismology centers. The watch stander actively monitors local, national and international operations and seismic network research programs and periodically forwards appropriate data to the concerned agencies. The incumbent is expected to work with professional colleagues, national and international, and the data associated with these networks to advance the state of seismic research knowledge and to promote applications within the Tsunami Warning System.

National and International Interactions: As the mission of the center is international in scope, the watch stander will directly interact with participants of the Tsunami Warning System on both national and international levels. The watch stander is expected to be thoroughly familiar with all TWS components for seismic/tsunami data acquisition and for information dissemination, the International Tsunami Information Center (ITIC), and IOC/ICG and national policy to ensure knowledgeable, accurate, and authoritative representation of the center with domestic and international agencies and governments. Interactions may take the form of direct and extended training, briefing of visiting TWS participants, correspondence, or visits to other national and international activities.

Communications: The watch stander must know and be capable of modifying communications software in the absence of the computer systems programmer. The incumbent must be familiar with communication protocols, formats, hardware, and pathways. The he/she must use this knowledge in the event of communication failures to maintain the flow of data and information. On a regular basis, the watch stander should conduct and document communication tests with TWS participants, and take appropriate action to resolve any operational difficulties.

Station Management: The watch stander assists in administrative projects as the need arises. He/she also assists in facilities projects and public education activities as required. Since there is a continuing need for public education and community preparedness regarding the hazards of a tsunami, the incumbent is frequently required to provide tours or briefings at center, or at schools, agencies, or other institutions throughout the AOR. The watch stander may serve as Acting Center Director in the absence of all members of the management team.

Other: The watch stander is expected to document projects of scientific value in the form of technical reports and scientific journal articles.

From time to time, as workload and optimum utilization of employees dictates, the incumbent may be required to perform duties other than those described above.

Knowledge Required by the Position

Mastery of the theories, principles, and practices of classical physics; applied mathematics; physical oceanography with particular emphasis on long wave theories; earthquake seismology; electricity and magnetism; acoustics; time series analysis; digital signal progressing; numerical modeling of dynamic systems; Fortran, C, and Basic computer language programming; UNIX, DOS, and AOS computer operating systems; telecommunication practices; administration and management are required by the incumbent. These skills and this knowledge are not all acquired during study in a single academic discipline; a long period of on-the-job training is required for the Geophysicist to perform at an optimum level.

The ability to remain calm and work effectively under stressful situations is essential. An ability to conduct surveys of the scientific literature, identify appropriate techniques and apply them to improve tsunami warning operations is required. The incumbent must understand program policy and the inter-relationship of all RTWPs and NTWCs.

Electronics Technicians (ETs)

Center ETs provides expert-level support for scientific operations research, serving as a specialist in a narrow aspect of electronic engineering, specifically support to tide gages, seismic gages, communications equipment, computers (workstations and PCs), and Local Area Networks (LANs).

Major Duties and Responsibilities

- Develop and devise improvements and alterations to the most complex technical equipment, instruments or software; modifies and conducts complex tests, and analyzes results.
- In a research environment, perform development work and conduct research by application of established experimental and empirical methods and techniques,
- Interpret results and select or recommend approaches to design problem solutions.
- May plan, organize and execute limited projects which require the solution of both design and operational problems; and advise engineering and technical support staff on design and operational problems relating to equipment and processes.
- Specifically, the ETs maintain center recording and analysis equipment
- Provide required emergency maintenance at local and remote sites
- Make regular inspections throughout the year of all remote sites
- Cooperate with telecommunications vendors to correct telemetry and circuit problems
- Provide technical expertise in evaluation, design, specification, and installation of the center's communication/data acquisition equipment, micro computers, and associated equipment
- Provide technical expertise, coordinated with appropriate scientist, for electronics related projects
- Maintain and upgrade computer networking hardware and connections.

Knowledge Required by the Position

Knowledge of theories, concepts, practices, methods and techniques of electronics engineering gained through intensive practical applications and experience, and of the capabilities, limitations, operations, design characteristics and functional use of a wide variety of types and models of electronic equipment and systems. Knowledge of specialized techniques and practices in order to: function as a recognized expert, develop innovative approaches and techniques for specialized applications, modify, adapt and design equipment, systems and instruments; complete and execute testing programs and to analyze the results of tests.

Information and Communications Technology (ICT) Officer

This position is established to analyze/perform work necessary to plan, design, develop, acquire, document, test, implement, integrate, maintain, or modify systems for solving problems or accomplishing center work processes by using computers.

Major Duties and Responsibilities

- Analyzes and evaluates work concerned with integrated systems of computer programs and/or computer equipment.
- Applies available technologies and basic management principles to adapt computer methods to a variety of subject matter situations.
- Supports subject matter users by developing or designing applications for computers and/or in selecting, or assisting in selecting computer equipment.
- Oversees/performs equipment installation or relocation, testing and acceptance processes.
- Responds to and resolves problems with software, hardware and systems management.
- Integrates several hardware, software, and/or computer related services to provide an integrated information system.
- May evaluate vendor or employee developed software to assure that it will provide the desired results and operate properly on assigned equipment systems.

Knowledge Required by the Position

- Knowledge at a level to serve as an expert in a specialty area, e.g., applications system design, computer equipment analysis, etc., or of general data processing covering a wide range of technology and applications.
- Ability to plan advanced systems projects or resolve critical problems in existing systems which require innovative solutions, etc.
- Ability to advise top management on new developments and advanced techniques.
- Ability to plan/organize/direct studies to develop long-range forecasts and recommendations.
- Ability to coordinate development of automated data processing standards, guidelines, or policy.
- Skill to plan, organize, and direct team study work and to negotiate effectively with management to accept and implement recommendations.
- Skill in applying national/international policies and data processing standards and knowledge of technical data to evaluate alternate approaches to problem solutions.

Unique Position Requirements

In addition to the in-depth computer knowledge required as an Information Technology Specialist, it is often desirable that the incumbent have a scientific background and the ability to function as a member of a tsunami investigation team. In these instances the following additional duties are required in this position:

- Stand-by duty supporting a scientist on shift duty may be required. This requires five minute response to the office at all times while on duty. The incumbent must carry a pager system and office cell phone while on duty. This requirement will influence where the employee lives.
- Assists the SO maintaining and enhancing the real-time seismic and sea level operational software at the center.
- Assists the center by computer programming and software maintenance of the communication systems.
- Responsible for computer security, and firewall and router upkeep and programming. Installs the latest patches and upgrades system software and application programs as necessary.
- Works with the electronics technicians to ensure that the seismic and sea level acquisition software is working properly. Software will be created as necessary to enhance the data acquisition systems.
- Maintains and develops products for the center's web site.

Appendix **D**

Documentation Requirements for NTWCs and RTWPs

In June 2007 the UNESCO IOC Tsunami Co-ordination Unit recommended that NTWCs and RTWPs include, at a minimum, the following documentation:

NTWC/RTWP Concept of Operations. This is a document that is global, basin, or country in scope depending upon the AOR of the center. It should be a high level document for decision-makers and describe the system and how it functions in general terms. It should identify who is involved and clearly define their roles and responsibilities. It should be maintained by the IOC or the applicable country.

Operations Manual. This document details how a particular NTWC or Disaster Management Office (DMO) Emergency Operations Center (EOC) works to carry out its roles and responsibilities. The manual should be designed to be used by the duty people at that center. It should include information on emergency management plans and standard operating procedures (SOPs), such as criteria for action, data streams, communications links, analysis software, messaging software, notification and dissemination methods, and general troubleshooting. It should be maintained by the NTWC or EOC as appropriate. Standard Operating Procedures:

- Are a set of written instructions describing a routine, or repetitive activity conducted by an organization. The instructions are stakeholder agreed-upon steps that will be used in coordinating the Who, What, When, Where, and How aspects of the Tsunami Emergency Response Plan (TERP) described later in this chapter.
- Are a mechanism for operating effective and reliable warning systems and disaster management systems. The NTWC SOPs must be linked at all levels from international to national to local warning institutions, and must be simultaneously connected to the corresponding DMO SOPs, and vice versa.
- Cover a number of concept-of-operations activities to enable an end-to-end response process. SOPs can range from data processing, analysis and warning communication procedures to action checklists for conducting public coastal evacuations, coordinating stakeholders organizations, and establishing the roles and jurisdictions for government, non-government, and the private sector agencies.
- Should facilitate good decision-making by describing in detail the actions taken by an agency to carry out its responsibilities, as defined in the system's concept of operations document. The existence and use of SOPs are especially essential for rapid, efficient tsunami response since tsunamis are rapid-onset disasters with

little time to prepare. Because of this, all responses need to be pre-planned, well practiced, and automatically enacted to minimize loss of life through quick public notification.

Examples are PTWC and WC/ATWC Operations Manual (2006); USGS NEIC Earthquake Response Plan (2006); JMA Manual on Operations and Systems for Tsunami Warning Service (2007).

EOC examples are The Guide to the National Civil Defence Emergency Management Plan - New Zealand (2006); The British Columbia (Canada) Tsunami Warning and Alerting Plan (2001); California (USA) Local Planning Guidance on Tsunami Response (Second Edition, 2006); Wakayama Prefecture (Japan) Plan of Mobilization and Transmittal of Tsunami Forecast (2007); and Kushimoto City (Japan) Municipal Local Tsunami Response Procedures (2007).

Operations Troubleshooting Manual. This document should provide details on what actions to take when a system has failed. This can be computer hardware failure, communications link failure, software problem etc. It should be maintained by the NTWC or RTWP as appropriate.

Examples are from PTWC, and USGS NEIC Earthquake Analysts Manual (Draft 2006)

Tsunami Warning System Users Guide. This guide should contain general information for customers on tsunamis and the tsunami threat, on NTWC procedures and the criteria for action, along with sample messages. It should include a general description of that NTWC's system—seismic data, sea level data, warning centre, message dissemination, public safety actions and responses, including evacuation. Guidance on what the user or customer can expect from the NTWC, including how to interpret messages for action, definitions/lexicon of terms, what to do when warnings are issued. For RTWPs the document may be maintained by the IOC. For a national system, it should be maintained jointly by the NTWC and partners. The Users Guide can be divided into 2 parts, with each part published separately. A Local response Users Guides should supplement a National Guide.

Examples are PTWS Users Guide (new edition in August 2007), currently WC/ATWC Operations Plan (Users Guide), Communications Plan (Users Guide) for the PTWS (Apr 2006), Users Guide for the IOTWS (Feb 2007).

NTWC/RTWP Stakeholder Contacts. This document is generally comprised of contacts responsible for overall tsunami mitigation, for tsunami warning operations, and for tsunami emergency response operations.

- For RTWPs these are Tsunami Warning Focal Points (TWFP) for 24x7 action on tsunami emergencies and National stakeholders or ICG Tsunami National Contacts (TNC) responsible for tsunami mitigation. The document should be maintained by IOC for the global system—an efficient means will be by secure web site that is password protected, or other easily accessed secure method. At the international level, the stakeholder group is the ICG.

- For NTWCs, the document should be similar but involve emergency response as well. Documents should be maintained by the NTWC and EOC national, provincial, district, and/or local levels of government.

Tsunami Warning System Directives. Official, authoritative documents covering national or local procedures and responsibilities. Descriptions are in more detail than Concept of Operations, but less detail than Operations Manuals. Directives describe authority, coordination, roles, and responsibilities of services and organizations involved. They should be maintained by each country, or local authority that carries out procedures.

Examples are NOAA NWS Tsunami Directives (2006) which can be found at: **http://www.weather.gov/directives/010/010.htm** NDS 10-7 Tsunami Warning Services.

Tsunami Emergency Response Plans (TERP). NTWCs and their associated DMOs must create and customize written Tsunami Emergency Response Plans (TERP) to meet their specific needs. The documents form the basis on which to conduct routine drills to ensure response procedures can be effectively enacted by a 24x7 duty staff. These can range from stakeholder familiarization workshops, agency and multi-agency drills, tabletop scenario exercises, and functional communications tests, to full-scale response agency field deployment exercises, which may or may not include public evacuations. Documents and drills also ensure the consistency of actions as duty staff may turn over several times between actual tsunami events.

NTWC and DMO TERPs, and their accompanying Standard Operating Procedures (SOP) and Checklists should also describe procedures, protocols, and expected actions for tsunami emergencies. For the TWC, this may mean procedures followed when a tsunami alert is received from international RTWPs, or how a NTWC monitors earthquakes and evaluates their tsunamigenic potential. The goal of the NTWC is to then issue an urgent local / regional / and/or distant tsunami warning to its DMO and/or its citizens.

For the DMO, this means the immediate alerting of communities and households, and as required, the evacuation of people out of the pre-designated tsunami evacuation zone. For a local tsunami warning and evacuation order, these decisions and actions may have to take place immediately, within minutes after earthquake ground shaking.

Together, these are the *minimum requirements* for establishing a fully functioning, efficient end-to-end tsunami warning system.

Appendix **E**

References and Resources

Chapter 2: Tsunami Warning Center Requirements Overview

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Public Outreach/Stakeholder Involvement Resources

Brevard County MPO Public Involvement Evaluation Handbook
http://www.brevardmpo.com/downloads/documents/current/PIP_eval_handbook.pdf
This handbook outlines the steps to be taken to evaluate public involvement techniques, identifies measures to quantify success rates, and outlines strategies to improve the Metropolitan Planning Organization's public involvement process.

Getting in Step: A Guide for Conducting Watershed Outreach Campaigns
http://www.epa.gov/watertrain/gettinginstep/
This U.S. Environmental Protection Agency (EPA) module offers advice on how local governments, watershed organizations, and others can maximize the effectiveness of public outreach campaigns to reduce nonpoint-source pollution and protect waterways.

Community Culture and the Environment: A Guide to Understanding a Sense of Place
http://tinyurl.com/tx6sl
This technical document identified tools and methods for understanding the human dimensions of environmental protection and was designed to provide a means for better understanding community values.

Stakeholder Involvement and Public Participation at the USEPA. Lessons Learned, Barriers and Innovative Approaches
http://www.epa.gov/publicinvolvement/pdf/sipp.pdf
This document presents lessons learned based on the review of formal and informal evaluations of the public involvement process conducted by the EPA.

Engaging the American People. A Review of the EPA's Public Participation Policy and Regulations with Recommendations for Action
http://www.epa.gov/stakeholders/pdf/eap_report.pdf
This EPA report has information about using the internet, databases, training,

evaluations, and innovative involvement efforts, and analyzing agency policies, statutes, and practices

The Model Plan for Public Participation
http://www.epa.gov/compliance/resources/publications/ej/model_public_part_plan.pdf
This report includes critical elements for public participation and also includes a checklist for public participation.

International Association for Public Participation Website
http://www.iap2.org/index.cfm
The International Association for Public Participation, working through its members, helps organizations and communities around the world improve their decisions by involving those people who are affected by those decisions.

Participation Tools and Practices Website
http://www.uap.vt.edu/cdrom/tools/index.htm
This website provides an introduction to some basic participation concepts and offers a brief history of citizen participation in the United States.

Vulnerable Population Resources

FEMA Preparing People with Disabilities Publication
http://www.fema.gov/pdf/library/pfd_all.pdf
This preparedness booklet, *Preparing for Disaster for People with Disabilities and Other Special Needs*, from the Federal Emergency Management Agency (FEMA) is a supplement to FEMA's *Are You Ready* program.

How to Engage Low-Literacy and Limited English-Proficiency Populations
http://www.fhwa.dot.gov/hep/lowlim/webbook.pdf
This report documents "best practices" in identifying and engaging low-literacy and limited-English-proficiency populations in transportation decision making.

PrepareNow.org
www.PrepareNow.org
The Community Preparedness Website Project was undertaken to insure that the needs and concerns of vulnerable populations are addressed in the area of emergency preparedness and response. To achieve this, the PrepareNow website attempts to integrate community-based organizations into emergency planning and management.

HELPU Website
http://www.helpusafety.org
Similar to the PrepareNow site mentioned above, the HELPU website is intended to serve all members of the disabled community, their care-givers, attendants, fire and

rescue personnel, and emergency services departments. The site offers numerous pages with tips on emergency/disaster preparedness for various hazards.

National Organization on Disability's Emergency Preparedness Initiative
http://www.nod.org/epiconference2004/index.html
The National Organization on Disability's Emergency Preparedness Initiative has released this "virtual binder" of materials related to the National Capital Region Conference on Emergency Preparedness for People with Disabilities.

DOT Emergency Preparedness and Individuals with Disabilities
http://www.dotcr.ost.dot.gov/asp/emergencyprep.asp
In response to a 2004 executive order directing federal agencies to support safety and security for individuals with disabilities during disasters, the U.S. Department of Transportation (DOT) launched a web site containing information to help ensure safe and secure transportation for persons with disabilities in the event of a disaster or emergency.

Gender and Disaster Sourcebook
www.gdnonline.org/
The *Gender and Disaster Sourcebook* is an electronic compilation of international resources on policy, practice, and research designed to address gender concerns in disaster risk reduction.

Nobody Left Behind Project
www2.ku.edu/~rrtcpbs/
This site describes the Nobody Left Behind project, a 3-year study by researchers at the University of Kansas on how 30 U.S. counties and cities identified and planned for people with mobility impairments during disasters.

Women's Participation in Disaster Relief and Recovery
http://www.popcouncil.org/pdfs/seeds/Seeds22.pdf
This publication features detailed case studies from three earthquake-stricken areas in India and Turkey that exemplify how low-income women who have lost everything can form groups and become active participants in the relief and recovery process.

Benfield Hazards Research Centre—Disabilities and Disasters
http://www.benfieldhrc.org/disaster_studies/disability&disasters/d&d_index.htm
The Benfield Hazard Research Centre developed this Web page on disability and disasters. The primary aim is to identify publications and unpublished material on the subject (in print or online), field initiatives, and people working in the field. An annotated list of publications, outlines of known research and field projects, and details of key contacts will be updated periodically on this web page. This work will be ongoing. Details of publications, initiatives, and people working in the field are therefore welcome.

Ready New York for Seniors and People with Disabilities
http://www.nyc.gov/html/oem/pdf/seniors_disabilities_english.pdf
This guidebook was prepared by the New York City Office of Emergency Management as part of its ongoing effort to help all New Yorkers better prepare for emergencies.

Risk Communication in Southern California: Ethnic and Gender Response to 1995 Revised, Upgraded Earthquake Probabilities
http://www.colorado.edu/hazards/research/qr/qr94.html
The purpose of this study was to visit one ethnically diverse community in southern California, gather some preliminary data on the background and initial impact of the revised earthquake probabilities for southern California, and observe the role that the new information handbook played in educating the public of its risk to the earthquake hazard. This report also assessed the response of ethnic and minority groups to the revised warning message, and captured the gender response as well.

Vulnerability Network & Observatory
www.vulnerabilitynet.org
This site provides an online knowledge portal to link researchers and practitioners in various sectors of the vulnerability field. The "Document Hotel" contains hundreds of searchable journal papers, reports, and briefing notes that cover a range of topics, including vulnerability, adaptation, climate change impacts, food security, water management, renewable energy, and socio-environmental modeling.

Tsunami Information Resources

International Tsunami Training Institute Archive
http://nctr.pmel.noaa.gov/education/ITTI/
This website contains archived information and resources developed for the International Tsunami Training Institute. Resources are categorized into the following categories: Incident Command System, Coastal Community Resilience, Tsunami Alert Rapid Notification System, and Seismic.

American Red Cross Tsunami Webpage
http://www.redcross.org/services/disaster/0,1082,0_592_,00.html
This website includes a variety of tsunami-related information provided by the American Red Cross.

Prepare for Tsunamis in Coastal British Columbia
http://www.pep.gov.bc.ca/hazard_preparedness/Tsunami_Brochure/Prepare_for_Tsunami.html
This provincial website provides information on the tsunami hazard including warning and risk information.

California Seismic Safety Commission Tsunami Webpage
http://www.seismic.ca.gov/Tsunami.htm

This state website provides tsunami-related information for residents of the state of California.

Sitka Tsunami Preparedness Information
http://www.cityofsitka.com/lepc/tsunami.html
This city website provides tsunami-related information for residents of the city of Sitka, Alaska.

Tsunamis in Oregon
http://www.oregon.gov/OMD/OEM/plans_train/tsunami_in_or.shtml
This state website provides tsunami-related information for residents of the state of Oregon.

Washington Military Department, Emergency Management Division Tsunami Program Website
http://emd.wa.gov/5-prog/prgms/eq-tsunami/tsunami-idx.htm
This state website provides tsunami-related information for residents of the state of Washington.

Washington Military Department, Emergency Management Division Tsunami Evacuation Brochures
http://www.dnr.wa.gov/geology/hazards/tsunami/evac/
This state website provides tsunami related information for residents of the state of Washington.

Tsunami Teacher
http://www.tsunamiwave.info/
The TsunamiTeacher Information and Resource Toolkit brings together a wealth of new and existing information on tsunamis into a single global resource that is widely accessible to people, groups, and governments around the world. TsunamiTeacher aims to build awareness and the capacity to respond to and mitigate the impact of tsunamis through the sharing of knowledge, research, and best practices.

National Weather Service TsunamiReady Program
http://www.tsunamiready.noaa.gov/
This National Weather Service website provides information on the TsunamiReady Program, including application forms as well as publications.

Pacific Disaster Center Tsunami Hazard Webpage
http://www.pdc.org/iweb/tsunami.jsp
The Pacific Disaster Center's mission is to provide applied information research and analysis support for the development of more effective policies, institutions, programs and information products for the disaster management and humanitarian assistance communities of the Asia Pacific region and beyond.

Pacific Tsunami Warning Center
http://www.prh.noaa.gov/pTsunami Warning Center/
This website provides information on tsunami messages that have been broadcast in the past 90 days.

Wave that shook the world
http://www.pbs.org/wgbh/nova/tsunami/
This Public Broadcasting Service website reconstructs the 2004 Indian Ocean tsunami in an effort to prepare for the next big one.

Coastal Community Resilience: A Guide for Planning and Action to Address Tsunami and Other Coastal Hazards
The Coastal Community Resilience (CCR) initiative is one component of the US Indian Ocean Tsunami Warning System (IOTWS) Program. CCR provides a holistic framework to address the increasing risks from coastal hazards and to vulnerable communities living in coastal areas.

International Strategy for Disaster Reduction (ISDR), Asia–Pacific
www.unisdr.org/asiapacific/
This website of the United Nations' ISDR provides basic information on disaster risk reduction in the Asia and Pacific Islands region. The region faces a regular and increased frequency of typhoons, tsunamis, floods, droughts, fires, and other natural hazards, and the new website aims to establish an interactive relationship with regional partners throughout the Asian and Pacific region, who are invited to provide information on a regular basis.

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