## Research

Although not directly a part of the mitigation activities, tsunami-related research is nevertheless essential to improve mitigation. Research that yields evidence of paleotsunamis, expands a historical database, or quantifies the effects of a recent tsunami can improve the accuracy of the hazard assessment. The same is true for research that leads to improved numerical modeling of tsunamis. Techniques for warning systems to more rapidly and accurately assess the tsunamigenic potential of earthquakes from seismic data are developed through research. So are better water level instrumentation and techniques for forecasting the impact of tsunamis in real time. Research can also provide improved ways of designing educational campaigns to keep the public as well as emergency personnel informed about tsunamis so they carry out the proper actions when the need arises. Creating effective evacuation procedures, particularly in consideration of additional hazards that could exist if the tsunami was locally generated by a large earthquake, may require research. Research can also help guide land-use planning in potential inundation zones and can lead to more tsunami-resistant designs for structures and facilities located there.

### *Structure*

There is no formal research program that operates under the aegis of ITSU, nor does a formal research coordination process exist between the Member States of ITSU. Most tsunami research is carried out through research programs of the individual Member States. However, tsunami research often involves a significant amount of international collaboration and exchange of data. The most important meeting with regard to scientific research on tsunamis is the biannual Tsunami Symposium, organized by the Tsunami Commission of the International Union of Geodesy and Geophysics. Numerous other geophysical, oceanographic, and general hazard mitigation meetings also take place that include tsunamis in their programs. In addition, workshops to address specific tsunami problems or the tsunami problem in specific coastal areas are often held. Research articles are published in a wide variety of geophysical and natural hazards journals, and in the *Science of Tsunami Hazards*, the journal of the Tsunami Society. Communications between tsunami scientists worldwide is facilitated through the Tsunami Bulletin Board, an email distribution service initially set up by the USA and now operated by ITIC for ITSU. Summary information regarding recent tsunamis, upcoming meetings, meeting reports, and recent publications are published for ITSU by ITIC with IOC support in the biannual Tsunami Newsletter. A tsunami website is also under development at ITIC that will contain information on research needs and the results of certain research projects.

### *Areas for Research*

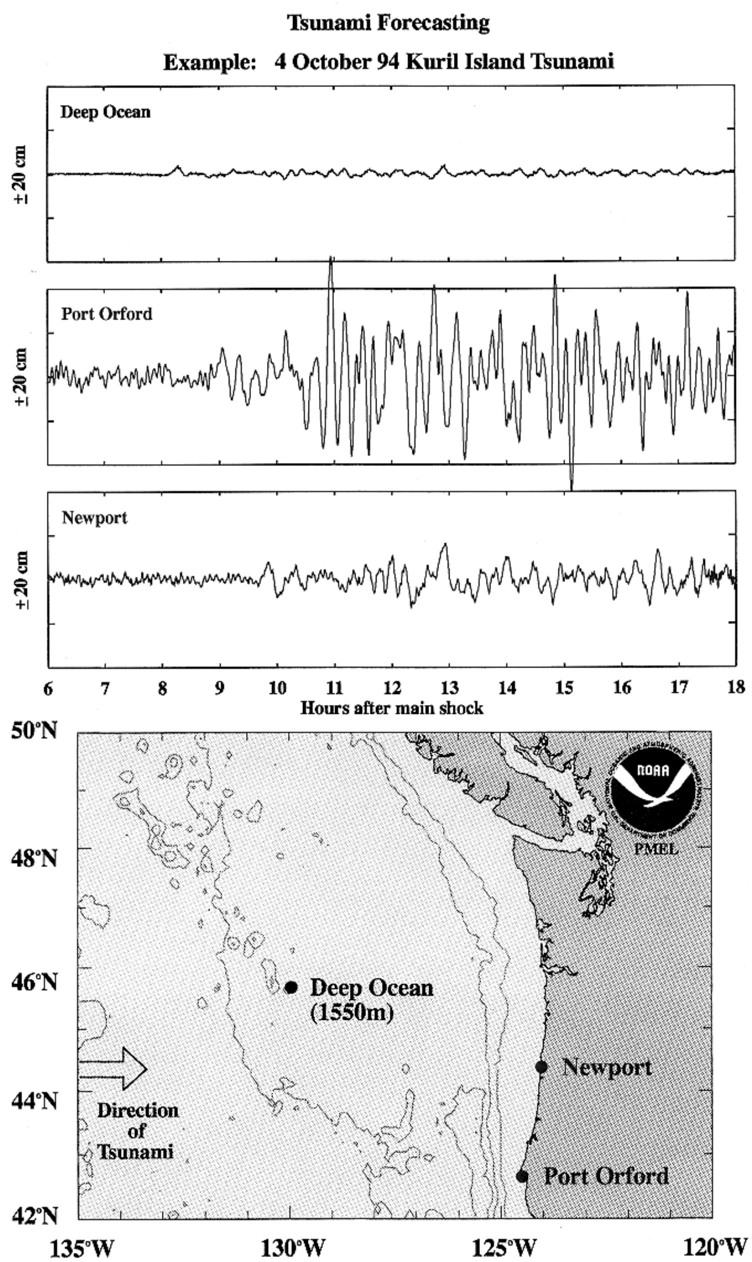
Present techniques for real time tsunami prediction are still severely limited. Although the potential for a tsunami exists whenever a shallow earthquake of sufficient size and with an appropriate mechanism occurs near or under the ocean, the only way to quickly determine with certainty if an earthquake is accompanied by a tsunami is to detect the presence of the waves using a network of water level stations or to receive reliable observations by eyewitnesses. It is not yet possible to precisely determine the areal extent, amplitude, or time history of the seafloor deformation that initiates a tsunami from seismic or water level data. Furthermore, while it is possible to predict when the initial tsunami energy will arrive at coastal locations, it is not yet possible to predict with much certainty the wave height, number of waves, duration of hazardous conditions, or forces to be expected from such waves, even with readings from water level gauges between the source and those locations.

Numerical models continue to be developed and improved to address the tsunami problem. Traditional finite difference models are useful for modeling tsunami waves in the deep ocean, but are generally inadequate for resolving coastal geometry and bathymetry with the required precision. Finite element models, however, with their irregular triangular grids can provide the needed resolution. These types of models should be used to compute run up, inundation limits, and horizontal currents for known and hypothetical source events. The interaction of the tsunami with the tides should be considered in determining the total water level and how it varies with time during the entire duration of the tsunami. The information from models regarding horizontal currents can provide input for the computation of forces on structures, as well as hazardous conditions in harbors. Techniques should also be developed to run models in real time during tsunamis to help warning centers and emergency managers predict the impact.

There is a need for advance modeling of tsunami signals on key water level instruments to assist warning centers in making more rapid and accurate assessments of tsunami severity. For example, there are about twenty gauges most strategically located in the interior and along the borders of the Pacific Basin, and there are only a few major source areas for Pacific-wide events. Theoretical mareograms for appropriate combinations of sources and gauges are needed as a reference for warning centers to help in evaluating potential damaging tsunamis as they spread across the Pacific Basin.

In recent years, some unusual tsunamis (e.g. 1992 Nicaragua, 1994 Indonesia, and February 1996 Peru) have motivated a new dimension to tsunami research. The maximum amplitudes of these tsunamis are much too large relative to the sizes of the earthquake that caused them. Seismologists know that the earthquake magnitude scale based on 20-second-period surface waves saturates beyond a value of about 8 and does not accurately represent the size of the largest earthquakes. So this might account for the discrepancy. But even seismic moment, a more representative parameter for earthquake size that is based on much longer-period seismic waves that don't saturate, cannot seem to explain why certain tsunamis have such large amplitudes. It is suggested that these earthquakes belong to special class referred to as "tsunami earthquakes" or "slow earthquakes". Their rupture process may take one to several minutes in contrast to just a few seconds to several tens of seconds for an ordinary or impulse earthquake, and their depth of faulting may be very close to the seafloor. During this slow rupture it is quite possible that a larger percentage of the seismic energy couples into the tsunami mode, as compared to only about 10% of the seismic energy being transferred to the tsunami during a normal impulse earthquake. At present, there is no completely satisfactory explanation for the occurrence of these disproportionately large tsunamis, but it is an area that will require further research by tsunami scientists.

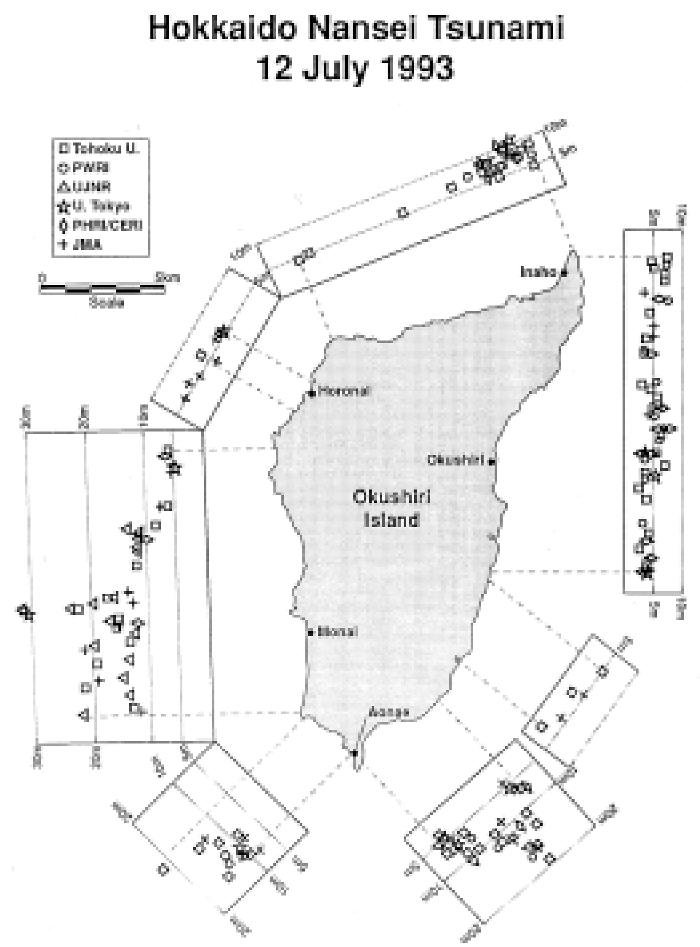
Another area that needs research attention is the




*Bottom pressure gauges in the deep ocean provide a more direct measurement of a tsunami than shore-based tide gauges, and these signals are more useful for predicting a tsunami's impact at the coast. This example shows the recent Shikotan tsunami recorded in the deep ocean and near shore, and it illustrates that there can be large differences between signals of the same tsunami recorded on closely spaced shore-based gauges.*

role of resonance amplification in explaining why along the coastlines of bays and gulfs the tsunami amplitudes are so large while at other nearby locations the amplitudes are considerably smaller.

For many areas of the Pacific, the historical tsunami record is very limited or even nonexistent. Research to find and analyze evidence of paleotsunamis may help to extend the tsunami record in certain coastal regions much further back in time and lead to a better understanding of the tsunami hazard in those and nearby areas as well as perhaps the entire Pacific region.




*Runup values for the tsunami that struck Okushiri Island, Japan, the night of July 12, 1993.*

## ***Recent Research Applications***

There are many examples in the recent past of contributions to tsunami mitigation made through research efforts. The following are just a few of them.

*Tsunami Inundation Mapping*: The technology now exists to produce inundation maps as a basis for emergency preparedness. The ITSU supported project Tsunami Inundation Modeling Exchange (TIME) has provided the transfer of a numerical inundation model developed by Professor Shuto of Japan, and training in how to use it, to many of the Member States. Scientists in the USA have enhanced the mapping technique for local events by incorporating the other earthquake effects of ground shaking, liquefaction, and landslides. These technologies offer new tools for identifying the coastal areas at risk and the level of hazard they may encounter in the event of a local or distant tsunami.

*Tsunami Runup Data*: The accuracy of the models mentioned above relies on observations of tsunami to compare with numerical simulations. Since 1992, there have been 8 destructive tsunamis that have been surveyed by scientists from all over the world. Data collected by these surveys have provided a wealth of new information on the runup phase of tsunami dynamics. These data are being used to validate and improve numerical models.

*Deep Ocean Tsunami Data*: As tsunamis interact with coastlines and harbors, their amplitudes and periods are transformed and modified by the local bathymetry and topography. Consequently, a tsunami signal recorded within a harbor by a tide gauge yields only low quality information for predicting the tsunami impact at other locations. To provide an accurate forecast, more direct measurements of the tsunami in the open ocean are needed. A network of recently developed real time reporting deep ocean pressure gauges is now being deployed off USA coasts to provide this capability.

*Earthquake Location and Magnitude Technology*: France has developed a single station, 3-component broadband seismic system for tsunami warning purposes called TREMORS (Tsunami Risk Evaluation through seismic MOment from a Real-time System). It quickly and automatically estimates an earthquake's location, and then computes its seismic moment, a better estimator of tsunamigenic potential. TREMORS success in Tahiti demonstrates that other countries might use this technology and these systems have recently been installed in Chile, Indonesia, Brunei, Peru, Korea, and PTWC, and also in Europe and Portugal.

***Continued tsunami research is needed to support and improve all aspects of the mitigation process. Member States are encouraged to support all areas of research that improve the understanding of the tsunami phenomenon, aid in the assessment of the tsunami hazard, help warning centers respond more quickly, accurately, and reliably, make educational programs more effective, and give emergency managers and policy makers better tools for preparing and responding. Newly developed technologies that improve mitigation should be transferred into operation as quickly as possible.***