

# **Tsunamis**

**Detection, Monitoring, and Early-Warning Technologies**

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## Synopsis

A general introduction on tsunamis, their generation and historical aspects, tsunami data base, tsunami dynamics, and their special features have been provided. Tsunamis at Islands and the influence of mid-ocean ridges and continental shelves on their propagation, focusing and amplification have been briefly touched upon. Attention has been drawn to the recent trend of tsunami generation and its widespread propagation in the Indian Ocean and beyond. A brief history of the past prominent tsunamis and their striking power; tsunami impact on coastal and island habitats, and protective role of coastal ecosystems have been given adequate attention.

With these introductory aspects of general interest, the focus has been diverted primarily to the methods of earthquake detection and monitoring for early-warning of seismogenic tsunamis; and the technology aspects highlighting instrumented methods for early-tsunami warning, together with the role of IOC-UNESCO in administering a global network for tsunami early-warning. This is followed by a fairly comprehensive exposure of early-warning systems of various IOC-UNESCO member countries. In this, the topics covered are various techniques used for detection of earthquake, tsunami and inundation. Additional topics briefly touched upon, which are relevant to tsunami warning, include public announcement siren systems and numerical models. Special attention has been paid to the submarine cable-mounted systems.

Due importance has been attached to the instrumented era which began some time prior to the Sumatra tsunami; especially because of the world's attention to the climate change and the role of sea-level monitoring in understanding the trend of climate variability. In this, various methodologies used for tsunami detection from Open Ocean regions, islands, and coastal waters, and the significant progress made in this area over the years have been addressed. Additionally, a brief description of some theoretically sound physical principles, which have been confirmed through observations, has been provided because of their potential to be possibly implemented in future for remote detection of tsunamis in the open ocean. The technological advancement made over the years in the field of sea-level measurements which brought to light the global extent of the December 2004 Sumatra tsunami has been highlighted. It has been emphasized that sea-level gauges incorporating stilling-wells with very small orifice-to-well diameter ratio and long narrow pipes as water intake mechanisms (e.g., some types of float-driven, bubbler, guided air-acoustic gauges) suffer from various inadequacies for measurement of large amplitude short-period sea-level oscillations such as tsunamis. A fairly recently introduced downward-looking aerial microwave radar gauge appears to be a promising technology; having advantages such as relative ease in installation and insensitivity to ambient temperature changes. However, its inherent height limit can be an impediment to tsunami height measurements if its allowed maximum range is not adequately utilized during its installation. Also, while preparing the deployment site for radar gauges, adequate precautions need to be taken to minimize/eliminate the possibility of contamination of sea-level measurements by surfactants such as floating debris, ice, etc. It can be genuinely believed that although pressure gauges are sensitive to large flows and suspended sediments, the use of sub-surface pressure sensor having adequately large measuring range as a backup to the microwave radar gauge is desirable in coastal sea-level measurements because of its ability to record any water level which exceeds the limited height of the radar sensor. Also, the pressure gauge measurements are least affected by surfactants. Further, the pressure sensor has advantages such as the ability to be sampled at a higher rate, and linear response to large-amplitude short-period waves such as tsunamis. Consequently, carefully installed sub-surface pressure sensor can be regarded as the main 'tsunami sensor', suitable for tsunami network applications. Thus, delivery of scientific inferences on tsunami signals derived from sub-surface pressure measurements in an "open" environment (*i.e.*, without the use of stilling-wells or long and narrow water intake pipes) is expected to be more realistic than those inferred from conventional stilling-well and tube-mounted gauges, such as float-driven, bubbler and perhaps even guided air-acoustic gauges.

Increased experience in tsunami analysis resulted in a deep-rooted realization and consensual opinion that real-time deep-sea and mid-ocean sea-level measurements, which are free of coastal contamination, are vital for realistic tsunami forecasting and source identification. This realization, in turn, resulted in the great vision and concept of the use of buoy-mounted systems having two-way communication facilities via geostationary satellites.

This was made possible and deep-ocean buoy systems specifically designed for operational use have been practically implemented. Successful acoustic transmission of seafloor pressure measurements from 5000 m depth at 4800 bits/s with an error probability of  $10^{-6}$  have been reported. Commercially available deep-ocean crystal pressure sensors with extremely high resolution and low noise levels such as those produced by Hewlett-Packard and Paroscientific Inc., have enabled precise measurements of deep seafloor pressure. However, inability to provide continuous electrical power supply precludes continuous long-term measurements with buoy-based tsunami warning systems.

One of the limitations associated with buoy-based tsunami warning systems is reported to be a high level of vandalism. The lacunae, which are inherent with all types of buoy-based deep-sea tsunami warning systems, has been alleviated to a certain extent by the implementation of submarine cable mounted seafloor observation systems. This technology has been introduced by the Japanese and effectively used by the Japanese and the Russians. Continuous observations of seafloor pressure variations at 2200 m depth, 110 km offshore, are routinely made by several research institutions and the meteorological agency of Japan. The Sakhalin Complex Scientific Research Institute in Russia has operated a similar installation at 113 m depth, 8 km offshore Shikotan Island, where a small tsunami was recorded in 1980. However, the cable systems are prohibitively expensive. So far, the spatial extent of cable-mounted systems is limited to a few hundred km from the coast.

Whereas subsurface pressure sensor capsules and submarine cable mounted seafloor observation systems are practical means for detecting sea level changes including those due to tsunami and storm surge, the impracticability of deploying spatially dense arrays of such devices is a genuine concern for time-series measurements from the open ocean regions. However, this limitation is circumvented to a large extent with the use of satellite altimetric measurements. The advent of satellite altimetric methods for recording sea level elevation has significantly expanded the capabilities of oceanography, particularly in terms of their applicability to the study of rare catastrophic events such as tsunamis and typhoons/tornados in the ocean. Currently, the application of satellite altimetry for high-precision radio measurements of sea level elevation from Geosat, Topex/Poseidon, ERS-1, ERS-2, Jason, and Envisat satellites ensures a cardinal solution to the problem of determining sea-level variation from the open ocean, with precise correlation to the unified geodesic reference system. Clear detection of the 26 December 2004 Indian Ocean tsunami through satellite altimetric method has demonstrated the feasibility of remotely monitoring such events from space. However, this technology suffers from a limitation that it can measure only along the satellite tracks and cannot provide a full picture of an event. Also, the altimeter data must be corrected for height-variations due to mesoscale eddies and other error sources.

As emphasized before, the December 2004 Indian Ocean tsunami has been a major driving force in accelerating the implementation of a tsunami forecast system within and beyond the Pacific Ocean. Before this tsunami episode, only limited nations such as US, Japan, and Russia had operational tsunami warning systems. However, at present several other nations have either established or are in the process of establishing such systems.

In specialized applications such as monitoring of tsunami, sea-level data needs to be received in real-time/near-real-time from several locations so that the received information can be used for efficient alert and warning purposes and will help faster implementation of appropriate emergency measures. Whereas satellite-based reporting is one option, a simple and cost-effective methodology for real-time reporting of tsunami from coastal regions and islands is cellular based GPRS technology.

From an operational point of view, an obvious advantage that accompanies real-time or near-real-time data reporting is the possibility to identify instrumental malfunctions, if any, and to initiate remedial measures more rapidly. This permits remote diagnostics and might also provide the ability to re-program the system remotely.

Storm surges are as much, or more of, a problem in the Indian Ocean as hurricanes Sidr, Nargis etc. have shown recently (also many 100 thousands people killed). The various

`tsunami' technology including telemetry and warning systems addressed in this book can be used equally for other marine hazards such as surges rather than tsunamis per se. Technology for `multi hazard' is becoming recognized as an important aspect. In addition to hazard monitoring and management of coastal oceanogenic natural disasters such as storm-surges and tsunamis, a network of real-time reporting sea-level communication systems has several routine operational benefits. These include safe navigation in shallow coastal waters, faster hydrographic survey (automatic sounding correction), dredging operations, as well as port operations.

Although tsunami service has improved considerably after the December 2004 global tsunami event, it is still not completely free from its "regional" nature. Taking into account the limited capacities of a number of developing countries to provide a level of early forecast, and considering the scale of such catastrophies, it seems reasonable to develop a system which allows real-time observation of such catastrophies happening anywhere in the world. Many lives can be saved by providing real-time graphical display of the time-series of such events through Internet, and broadcasting the relevant information via audio-visual media of those countries which are likely to be immediately affected by such catastrophies.

Recent developments in numerical modeling of tsunamis and remote sensing technologies have enabled identification and determination of detailed features of tsunami damage. Numerical models with high-resolution bathymetry/topography grid can predict the local hydrodynamic features of tsunami, such as inundation depth and current velocity. Also, high-resolution satellite imagery provides detailed information of tsunami-affected areas. In recent years, a couple of nations have been expanding capabilities to comprehend the impact of major tsunami disasters by integration of numerical modeling (e.g., determination of tsunami inundation) and remote sensing technologies (e.g., assessment of post-tsunami disaster using the information obtained from satellite imagery). Such an integrated approach is expected to allow determining suitable relationship(s) between hydrodynamic features of tsunami inundation flow and damage probabilities, the so-called fragility functions.

Rapid progress in the development of new generation of tools and methods in information technologies has begun to accelerate the decision-making process by the emergency management personnel during the currency of a disastrous tsunami event. Consequently, emergency management issues in terms of preparedness and response are constantly being improved.