PERFORMANCE OF THE INDIAN TSUNAMI EARLY WARNING SYSTEM

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Abstract

The Indian Tsunami Early Warning System (ITEWS) based at Indian National Center for Ocean Information Services (INCOIS), Hyderabad is responsible for issuing tsunami advisories to authorized officials from the Ministry of Home Affairs (MHA) and Ministry of Earth Sciences (MoES) in India. The centre operates on 24x7 basis and has the functions of monitoring seismological stations, bottom pressure recorders (BPRs) and tidal stations throughout the Indian Ocean Basin to evaluate potentially tsunamigenic earthquakes and disseminating tsunami warning information. A database of all possible earthquake scenarios for the Indian Ocean is used to identify the regions under risk at the time of event. Timely tsunami advisories (Warning/Alert/Watch/Information) are generated following pre-set decision support rules and standard operating procedure (SOP). The end-to-end system performance was very well tested for the first time after its establishment against the earthquake and tsunami event on September 12, 2007 Off the west coast of Sumatra. The Indian system equipped with world-class computational, communication and technical support facility is capable of detecting tsunamis in the Indian Ocean. With this capability INCOIS has begun providing regional tsunami watch services on a trial basis from its national system for the Indian Ocean region.

1. Introduction

The objective of the ITEWS is to detect, locate, and determine the magnitude of potentially tsunamigenic earthquakes occurring in the Indian Ocean Basin and to provide timely advisories to the vulnerable community following a standard operating procedure (SOP) by means of various available communication methods (Gupta 2005)

1.1 Components of the Indian Tsunami Warning System

The Indian Tsunami Early Warning System comprises a real-time network of seismic stations, Bottom Pressure Recorders (BPR), tide gauges and a 24X7 operational tsunami warning centre to detect tsunamigenic earthquakes, to monitor tsunamis and to provide timely advisories with back-end support of scenario database, vulnerability modeling and Decision Support System The performance of the system was tested on September 12, 2007 when an earthquake of magnitude 8.4 occurred Off the Java coast.

1.1.1 Observation Networks

Earthquake information is provided by monitoring real time data from 17 land-based seismic stations (Figure 1) operated by India Meterological Department (IMD) and nearly 300 seismic stations from international sources within 15 minutes of occurrence.

In order to confirm whether an earthquake has actually triggered a tsunami, it is
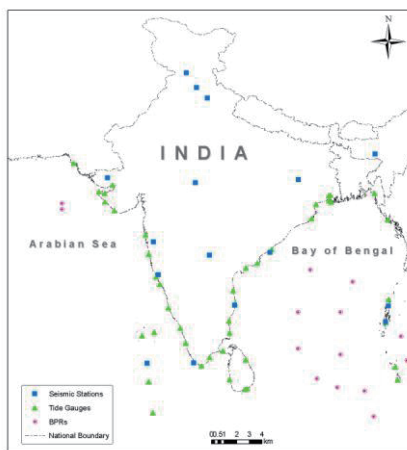

Figure 1: Real time Observational networks

essential to measure the changes in water level near the fault zone with high accuracy. Bottom pressure recorders (BPRs) are used to detect the propagation of tsunami waves in open-ocean and consequent sea-level changes. A network of BPRs (Figure 1) has been installed close to the tsunamigenic source regions to detect tsunamis, by the National Institute of Ocean Technology (NIOT). These BPRs can detect changes of 1 cm at water depths up to 6 km.

A network of tidal gauges (Figure 1) along the coast helps to monitor the progress of a tsunami and to validate the model scenarios. Near-real time data from national and international centres is being received through VSAT communication and internet respectively.

1.1.2 Tsunami Modelling

The Tunami N2 (Tohoku University's Numerical Analysis Model for Investigation of Near field tsunamis version 2) model (Imamura, 2006) customized for the Indian Ocean is used for estimating possible tsunami travel times and run-up heights for different earthquakes. This model uses available earthquake parameters and assumes worst slip rate (Mansinha and Smylie 1971). The centre maintains a large database of pre-run scenarios for timely dissemination of the advisories as it takes nearly 60 minutes to produce the output. The surge heights and the travel time at nearly 1800 coastal points along the Indian Ocean can be picked easily from the data base for early warning purpose.

1.1.3 Decision Support System (DSS)

An exclusive decision support system built up to enable the centre to pick up the closest scenario from the database helps in generating the tsunami advisories, at the time of an event. That is, the DSS picks the nearest earthquake scenario and the associated Tunami N2 model estimates of possible water levels and arrival times along the Indian Ocean. This enables the centre to assess the possibility of tsunami generation, and the likely severity due to the rise in water level at various locations along the coasts of Indian Ocean and the generation of appropriate advisories for the use of disaster management authorities.

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1.1.4   Standard operating procedure (SOP)

The criteria for generation of different types of advisories like Warning/Alert/Watch/All Clear/ Cancellation (Nayak and Srinivasa Kumar, 2009). for a particular region of the coast are based on the available warning time (i.e. time taken by the tsunami wave to reach the particular coast) as well as confirmation of tsunami generation based on water- level changes from BPRs and tide gauges (Nayak and Srinivasa Kumar, 2008). The warning criteria are based on the premise that coastal areas falling within 60 minutes travel time from a tsunamigenic earthquake source need to be warned based solely on earthquake information, since enough time will not be available for confirmation of water levels from BPRs and tide gauges. Those coastal areas falling outside the 60 minutes travel time from a tsunamigenic earthquake source could be put under a watch status and upgraded to a warning only upon confirmation of water-level data. To reduce the rate of false alarms even in the near source regions, alerts are generated by analysing the pre-run model scenarios, so that warnings are issued only to those coastal locations that are at risk. Within the Tsunami warning areas, based on the estimated water levels and directivity maps, the coastal areas will be categorized under different risk zones viz. Major Tsunami, Medium Tsunami and Minor Tsunami.

The end-to-end 24 X 7 operations of the centre right from data reception, display, analysis, modelling, and decision support system for the generation of tsunami advisories is set up taking the advantages of the development in application software around GIS technology.

2.   Methodology

The performance of a tsunami early warning system is evaluated against a set of parameters preset by the international community. These parameters are considered crucial for disseminating the tsunami advisories to the administrators and general public to act right for a tsunamigenic earthquake avoiding false alarms and unnecessary panic. One of the most critical aspects of tsunami warning system is to estimate earthquake parameters with reasonable accuracy in shortest possible time (i.e., within 15 minutes). The earthquake location and its magnitude are two critical parameters to be estimated so that right scenario can be chosen. An acceptable error of +/- 0.2 in magnitude and 30 km in location during initial estimates is considered good for tsunami warning applications and it is also extremely important to be able to do this consistently.

All earthquakes in tsunamigenic source regions do not trigger tsunamis. In order to confirm whether the earthquake has actually triggered a Tsunami or not, it is essential to measure the change in water level in the open ocean with high accuracy in real time. Bottom pressure recorders (BPRs) are used to detect the sea level changes near to tsunamigenic source regions and consequent propagation of Tsunami waves in the Open Ocean.

The tsunami advisory bulletins are evaluated by comparing with the bulletins issued by other warning agencies like the PTWC, JMA etc and also by considering how appropriate the message was conveyed to the end users. In this paper the performance of the Indian system against the September 2007 earthquake is described in detail.

3.   Results and Discussion

3.1 Evaluation of Earthquake Parameters

Performance assessment calls for a statistically significant number of samples; all global earthquakes of M > 6.0 irrespective of the location (Land/Sea) have been auto-located and reported by the warning centre. Since it started RTWP service Level I in July 2008, the early warning centre reported 273 earthquakes of magnitude ≥ 6.0 till May 2010. During the period from January 2009 to May, 2010, 199 earthquakes were monitored and reported. Out of this, 60 were under-sea events of M > 6.5 which is the minimum threshold for tsunami bulletins to be issued by warning centres (JMA, PTWC, JATWC, INATEWS). These events were taken up for detailed analysis vis-a-vis the estimates put out by other warning centres against the performance targets (IOC-ICG/IOTWS-V/13, 2008) set forth by the ICG/IOTWS Working Group V. A summary of the results is given below in Table 1 which clearly indicates that the desired performance levels have been achieved and are being sustained.

Table 1. Performance Indicators versus Achievement of different parameters

S. No	Parameter	Targets	Status
1	Elapse Time from EQ to Initial EQ Info Issuance (Local/Distant)	10/15 Min	06 Min
2	Elapse time from any product issuance to potential receipt by TWFPs	5 Min	To be assessed after getting inputs from the focal points receiving the advisories
3	Probability of Detection of IO EQ with Mw >= 6.5	100 %	Achieved
4	Percent of IO Countries issued a timely Product	100%	Currently being exchanged with other RTWPs, IAS & IOC
5	Accuracy of Hypocenter Location	within 30 km	12 km USGS; 11 km Geofon
6	Accuracy of Hypocenter Depth	within 25 km	12 km USGS; 13 km Geofon; 20 km JATWC; 16 km INATEWS 07 km PTWC; 05 km JMA;
7	Accuracy of Earthquake Mw Magnitude	0.2	0.22 USGS (MwP); 0.26 Geofon (Mw(mB)); 0.25 JATWC (MwP); 0.20 INATEWS; 0.18 PTWC; 0.23 JMA;
8	Accuracy of Tsunami Forecast Amplitude / Height	factor of 2	Results analysed for 6 events of > 7 M in the Indian Ocean for the last 1 Year. Results are within the target for few near-source locations. More events

			required to validate this Indicator.
9	Reliability of RTWP Operations (Power, Computer, Communications):	99.5%	Achieved
10	Contact Information updated & Quarterly Communication Tests		Communication Tests to be initiated

3.2 Evaluation of the Performance of Models and BPRs for September 12, 2007 Event:

For the earthquake on September 12, 2007, the sea-floor was displaced by low angle dip-slip earthquake generated a tsunami where the maximum wave energy direction was towards southwest of Indian Ocean (Figure 2), that nevertheless propagated through the Indian Ocean and was well recorded, by the Indian BPR network.

This event resulted in the issue of an Alert for Andaman and Nicobar based on the model predictions as well as tsunami wave observations near the source. Upon further analysis of the model estimates at the Indian coastal locations as well as the very small wave observed on the BPRs the Alert was downgraded to a "No Threat", thus avoiding coastal evacuation of the public.
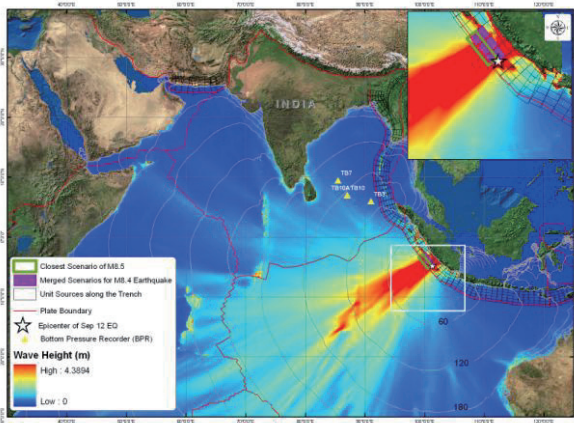

Figure 2: Model output for September12 M8.4 earthquake from Unit Source scenario database for Indian Ocean

The data from BPR network was available in near real time with delay of 5 to 15 minutes at the warning center. The tsunami wave took three to four hours to reach the BPR network. The surface waves of the earthquake travel significantly faster than tsunami waves, so the BPRs TB03, TB10 TB10A & TB07 got into 'Tsunami Response Mode' by the passage of seismic Rayleigh through them and started reporting for every 1 min observations. The tsunami wave arrival can be clearly distinguishable at each location of BPR from the seismic noise by the crustal disturbance and Rayleigh wave. The BPRs are in tsunami response mode for three hours from seismic wave arrival. After three hours all BPRs came into normal mode, though the later successive tsunami wave arrivals are present at BPR locations. Because of small amplitudes (<30 mm) of later successive tsunami arrivals, BPRs are not triggered in to tsunami response mode.

The water level observations of BPRs are filtered with high pass filter to remove the long period tidal frequencies. The Model output from the merged scenario is resampled for 1 min interval from 15 sec samples. The Model scenarios results are plotted along with the filtered BPR data to identify the tsunami wave arrival.

The expected tsunami wave arrival from the TUNAMI N2 model scenario for TB03 and TB10 BPR location compared well with real time observations (Figure 3). The initial
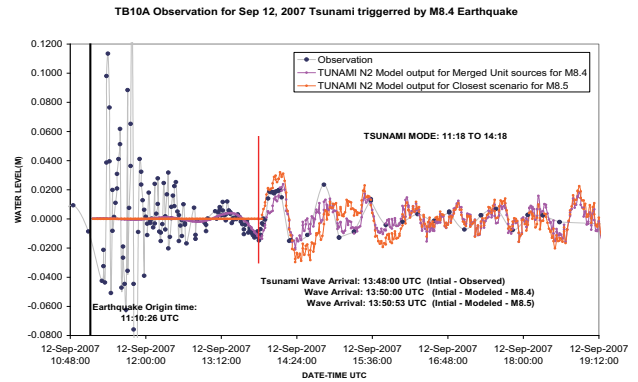

Figure 3: Validation of TUNAMI N2 Scenario Model results with BPR real time observations for the tsunami of the September 12, 2007

scenario results for M8.5 – worst case is also plotted along with the results of scaled scenario for M8.4. With the aid of numerical modelling results from scenario database, it is evident that the tsunami wave arrival is clearly distinguishable from the seismic Rayleigh waves which are in the same tsunami frequency band.

The observed water levels at coastal tide gauge locations were also monitored for this event that matched well (within 15 – 20% error) with those predicted using the model (Nayak and Srinivasa Kumar, 2009). This event clearly brought out the usefulness of Models as well as BPR and tide gauge observations in generating accurate tsunami bulletins.

3.3 Evaluation of Tsunami Bulletins

All tsunamigenic earthquakes that occurred in Indian Ocean since establishment of the system were closely monitored and appropriate bulletins were issued. Model simulations for these events indicated no significant changes in water level for the Indian coastline and hence "No Threat" Bulletins were issued by INCOIS in contrast to "Tsunami Watch Bulletins" issued by the other tsunami warning centres. Use of model simulations as well as water level data from tide gauges for generation of tsunami bulletins has definite advantage in bringing down the number of false alarms.

Real-time observations were monitored for each event and it was found that no significant tsunami was generated at the Indian coasts, thus validating the appropriateness of the "No Threat" bulletins issued by ITEWS. This has avoided unnecessary evacuation of the public for the above events. The tsunami bulletins issued for the major tsunamigenic earthquakes are listed in Table 2.

Table 2. List of past events and the type of the bulletin issued by the Indian Tsunami Warning Centre.

Date & Time (UTC)	Mag.	Region Name	Tsunami Advisory Bulletins
12-Sep-2007 16:40	8.4	Southern Sumatra	Tsunami Alert for Andaman & Nicobar Islands and later cancelled.
25-Oct-2007 02:32	7.1	South west Sumatra	No Tsunami Threat for A&N Islands and Indian main land
20-Feb-2008 13:38	7.3	Northern Sumatra	No Tsunami Threat for A&N Islands and Indian main land
25-Feb-2008 14:06	7.4	Southern Sumatra	No Tsunami Threat for A&N Islands and Indian main land
27-Jun-2008 11:40	6.8	A&N Islands	No Tsunami Threat for A&N Islands and Indian main land
11-Sep-2008 05:30	7.6	Halmahera, Indonesia	No Tsunami Threat for A&N Islands and Indian main land
11-Aug-2009 19:55	7.6	A&N Islands	No Tsunami Threat for Indian Ocean
16-Aug-2009 07:38	7.1	Southern Sumatra	No Tsunami Threat for Indian Ocean
02-Sep-2009 07:55	7.8	Java Islands	No Tsunami Threat for Indian Ocean
30-Sep-2009 10:16	8.0	Southern Sumatra	No Tsunami Threat for Indian Region.
30-Mar-2010 16:54	6.9	A&N Islands	Tsunami Watch for Northern Andaman and later cancelled.
06-Apr-2010 22:15	7.7	Northern Sumatra	No Tsunami Threat for Indian Ocean.
09-May-2010 5:59	7.4	Northern Sumatra	No Tsunami Threat for Indian Ocean.
31-May-2010 19:51	6.5	A&N Islands	No Tsunami Threat for Indian Ocean.

4. Conclusions

A tsunami early warning centre is established at INCOIS with all the necessary computational and communication infrastructure. A host of communication methods are being employed for timely dissemination of advisories. Seismic and sea-level data are continuously monitored in the warning centre using a custom-built DSS software application that generates alarms/alerts in the warning centre whenever a pre-set threshold is crossed. Geospatial technology has immensely helped in the design of early warning system for tsunami. Use of model simulations as well as water level data from tide gauges for generation of tsunami bulletins has definite advantage in bringing down the number of false alarms.

The performance of end-to-end capabilities of this warning system has been well proven during all the tsunamigenic earthquakes that occurred since September 2007. Timely advisories generated for the above events avoided false alarms and unnecessary public evacuations. The performance of the warning centre was assessed against a set of performance indicators and found to be performing as per the design standards.

5. Acknowledgements

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