Indian Ocean Tsunami Warning System: Example from the 12th September 2007 Tsunami

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The Indian Ocean experienced its most devastating natural disaster through the action of a Tsunami, resulting from of an earthquake off the coast of Sumatra on 26th of December 2004. This resulted in widespread damage both to property and human lives with over 250,000 deaths in the region and many millions made homeless. As a result, the destructive nature of the tsunamis is now well known and the public interest and awareness in tsunamis has increased markedly. The ocean around Sri Lanka consists of a very narrow continental shelf with the mean distance between the coast to the 200m depth contour being 20 km – at some locations Along the southern coast, this distance is reduced to < 5km off Mirissa. The narrow continental shelf means that Sri Lanka is extremely vulnerable to the action of tsunamis as the wave transformation from deep to shallow water occurs over a shorter distance and there is a negligible amount of energy dissipated over the continental shelf region. Also there are significant topographic features such as islands, seamounts etc between Sri Lanka and the tsunami generation region. The 2004 event has been followed by annual occurrence of ocean-wide tsunamis (i.e. those which influence area far from the generation region) in 2005, 2006 and 2007 (Table 1).

As a consequence of the 2004 tsunami, the Indian Ocean Tsunami Warning and Mitigation System (IOTWS) were established under the auspices of the UNESCO's Intergovernmental Oceanographic Commission (IOC). The Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS) which includes representatives from all of the Indian Ocean rim countries serves as the regional body to plan and coordinate the design and implementation of an effective and durable tsunami warning and mitigation system. The overall objective of the IOTWS is to efficiently identify and effectively mitigate the hazards posed by local and distant tsunamis. To achieve this objective, an end-to-end tsunami warning system is being developed that includes hazard detection and forecast, threat evaluation and alert formulation, alert dissemination of public safety messages, and preparedness and response. Here, working of a tsunami warning system is described with reference to the tsunami generated by a sub sea earthquake off the coast of Sumatra on 12th September 2007.

Tsunami generation: Background

Tsunamis are generated by a sudden movement of the sea floor which in turn changes the sea surface level and the process of the sea level returning to its equilibrium state generates waves which propagate away from the generation. The most common analogy is the effect of dropping a small pebble on a pond where small waves propagate away from point of contact of the pebble with the water surface. The sudden movement of the sea floor is usually caused by (1) sub-sea earthquake; (2) underwater volcanic eruption; or a sub-sea landslide, which could be generated by an earthquake. The Krakatoa eruption in 1883 is an example of a tsunami generated by a volcanic eruption which impacted Sri Lanka and caused a single casualty. The Papua New Guinea tsunami on July 17, 1998 was generated by a magnitude 7.0 sub-sea earthquake causing 2,100 deaths. The highest recorded tsunami wave of 525m which

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occurred on July 9, 1958 in Lituya Bay, Alaska was caused by a landslide triggered by a large, 8.3 magnitude earthquake. Tsunamis which may impact Sri Lanka are generated by sub-sea earthquakes off the coast of Indonesia and therefore the discussion is limited to tsunamis generated by sub-sea earthquakes along the continental plate boundary located offshore Indonesia (Figure 1). An ocean-basin tsunami has been generated due to earthquakes along this plate boundary in 2004, 2005, 2006 and 2007 (Table 1) and all of these tsunamis have been recorded in sea level gages in Sri Lanka except the 2006 tsunami off Java (Figure 1).

For a tsunami to be generated by a sub-sea earthquake, the movement of the sea bed resulting from the earthquake should be sufficient to disturb the sea surface. This is controlled by (1) magnitude of the earthquake i.e. Richter Scale; (2) the focal depth – depth of the earthquake epicentre below the sea surface; and, (3) the area of the sea bed disturbance – for the 2004 tsunami resulted from an area of 1000kmx250km. Only the magnitude and depth information is available immediately (i.e. 5-10minutes) after the earthquake and thus the first assessment whether a tsunami is generated has to be based to these two parameters. Analysis of historical earthquakes has revealed that tsunamis are generated only by earthquakes exceeding 6.5 on the Richter scale with a focal depth less than 50 kilometers beneath the seafloor. The main energy of the tsunami is usually directed perpendicular to the plate boundary or fault line.

TABLE 1 – Details of Indian Ocean Tsunamis 2004-2007

Year	Date	Magnitude of Earthquake	Epicenter Location	Maximum Tsunami Height in Sri Lanka
2004	26 December	9.2	3.32° N 95.854° E	10.1 m Hambantota
2005	28 March	8.6	2.07° N 97.01° E	2.7 m Kirinda
2006	17 July	7.7	9.22° S 107.32° E	0.0 m
2007	12 September	8.4	4.52° N 101.37° E	0.6 m Trincomalee

Tsunami Warning System

At present, tsunami warnings for the Indian Ocean are issued by the Pacific Tsunami Warning Centre (PTWC) located in Hawaii, USA who has been providing tsunami warnings to the countries in the Pacific Ocean rim for more than 40 years. The warning is transmitted to focal points established in each IOTWS participating country. In Sri Lanka, the Department of Meteorology is the nominated focal point for receiving tsunami warnings. As a result of planning initiated by the different working groups of ICG/IOTWS, a network of real-time seismic and sea level stations have been established across the Indian Ocean. These instruments transmit data through satellites in real-time to shore stations. The seismic stations facilitate the identification of the location and magnitude of earthquakes whilst the sea level stations will indicate whether a tsunami has been generated and also its magnitude (wave height).

The PTWC system function begins with the occurrence of an earthquake of sufficient size to alert the duty personnel at PTWC – the threshold is set at a magnitude above 5.5 Richter Scale. At this time, the earthquake's exact magnitude, focal depth, and origin time are determined. If the earthquake is within or near the Indian Ocean basin and its magnitude is higher than 6.5, but less than or equal to 7.0 then a Tsunami Information Bulletin is issued to the IOTWS focal points informing them that there is no threat of a widespread tsunami, but in some cases a local tsunami may occur. A similar bulletin is issued if the earthquake is of a larger magnitude but is deep within the earth (i.e. high focal depth) or is located clearly on land. A Local Tsunami Watch is issued to IOTWS focal points for earthquakes of magnitude 7.1 to 7.5 and a Regional Tsunami Watch is issued for magnitudes 7.6 to 7.8. The Local or Regional Tsunami Watch is an alert to the possibility that a destructive local or regional tsunami may have been generated that could affect coasts located within several hundred to 1000 km of the epicenter. An Ocean-wide Tsunami Watch is issued for earthquakes of magnitude 7.9 and greater. The tsunami Watch bulletins are usually accompanied by prediction of tsunami arrival times for geographic areas defined by the distance the tsunami could travel in a subsequent time period (Figure 2). Tsunami travel times can be calculated as the speed of propagation depends only on the local water depth. Subsequently the sea level recorders are monitored to determine whether a tsunami has been generated and its magnitude. Computer models results are also used to support the tsunami predictions. This information is routinely transmitted to the IOTWS focal points until the Watch is cancelled.

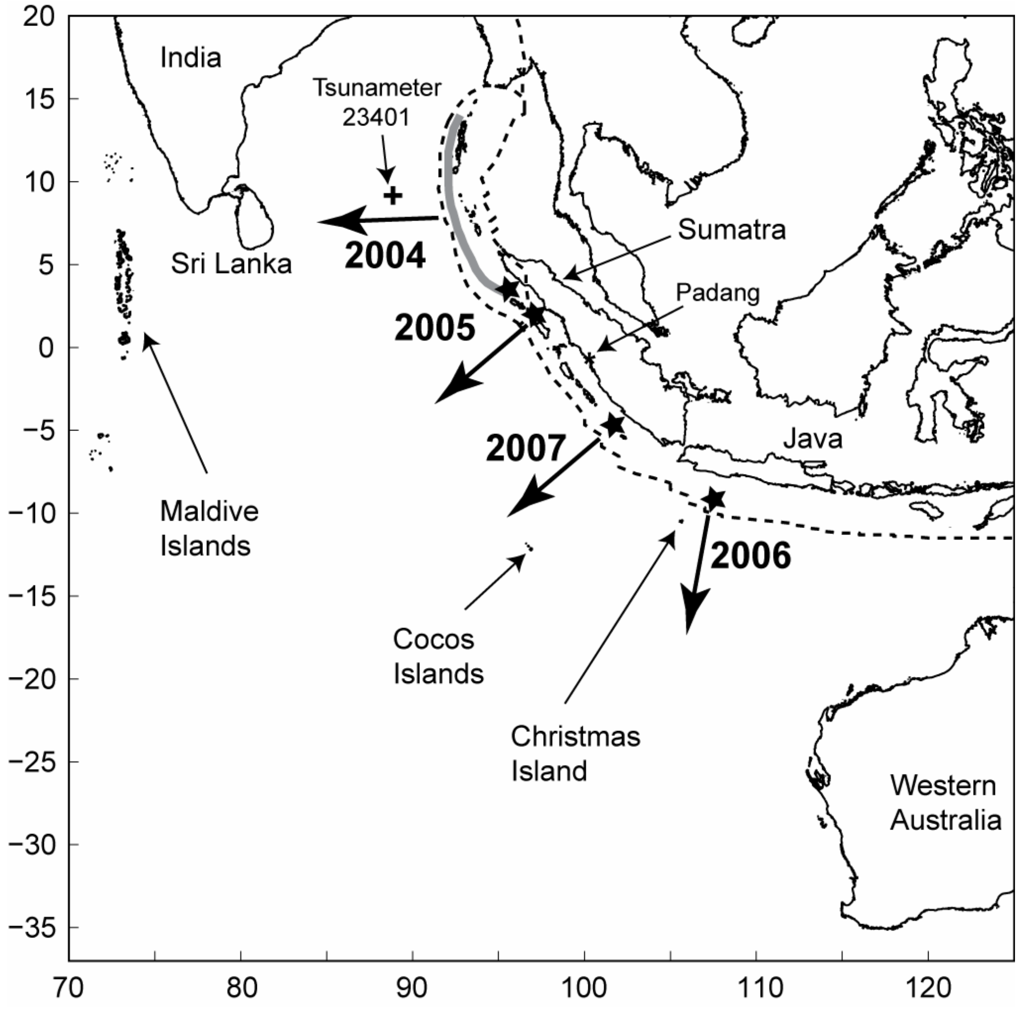

Figure 1 – Map of the eastern Indian Ocean showing the location of: the earthquake epicentres ('star') and direction of the primary wave propagation for the 2004, 2005, 2006 and 2007 tsunamis; Real-time sea level measurement stations at Padang, Cocos Islands, Christmas Island and the deep water tsunameter. The plate boundary is shown by the dashed line and area of rupture for the 2004 tsunami is shown by the grey line.

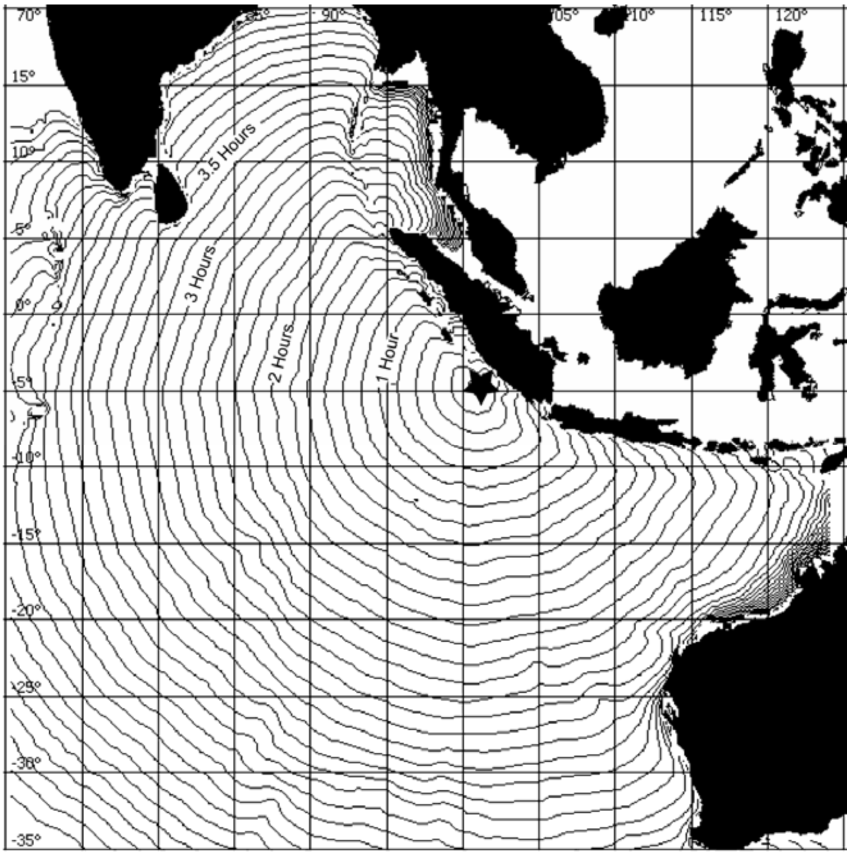

Figure 2 – A plot of isochrons (lines of equal time) of tsunami propagation as a result of the 12 September 2007 earthquake off Sumatra. The contour lines are in 10 min intervals.

The Tsunami of 12th September 2007

An earthquake of initial magnitude 7.9 (later updated to 8.4) occurred at 11:10 GMT off Southern Sumatra with a focal depth of 34 km. Based on the criteria described above, an Ocean-wide Tsunami Watch was issued for the Indian Ocean by PTWC. Based on computer modelling of travel times (Figure 2) the tsunami was predicted to reach the south-west coast of Sri Lanka at 14:40 GMT (3 hours 52min after the event); Trincomalee at 1502GMT (3 hours 52min), Colombo at 1515GMT (4 hours 5min) and Jaffna at 1625GMT (5 hours 15 min). This relatively long tsunami propagation times to Sri Lanka enabled the monitoring of sea level gages where the tsunami was predicted to have an impact before reaching Sri Lanka as well as undertaking computer modelling to predict the effect on Sri Lanka.

There were several sea level recording stations which were operational and information on the tsunami generated: they included the coastal sea level gages located at Padang (Indonesia), Cocos Island (Australia) and Christmas Island (Australia). A deep water tsunameter (previously called DART buoys) was also available. The locations of these stations are shown on Figure 1 and the characteristics of the tsunami incident on each of these locations are provided on Table 2. The first evidence that a tsunami was generated by the earthquake is revealed in the tide gage at Padang (Figure 1) where a wave of initial amplitude 0.35 m was recorded, 44 minutes after the earthquake. Records at both Cocos and Christmas Island also indicated evidence of the tsunami with initial heights ~0.10m recorded 69 and 78 minutes after the tsunami, respectively.

The tsunameter is an instrument specifically developed for monitoring tsunamis in the deep ocean. Tsunameter 23401 was deployed in 2006 through cooperation between Thailand and the USA but is ideally placed for tsunami warning for Sri Lanka as it lies between the tsunami generation region and Sri Lanka (Figure 1). Depending on the location of the earthquake the tsunami will be recorded on the tsunameter 60 to 90 minutes before impacting Sri Lankan coast. The instrument is located in 3500m water depth and includes a bottom pressure sensor which measures the sea level to a very high accuracy (order of 1 mm). The bottom sensor transmits the sea level data to a surface buoy which in turn transmit the data via satellite to NOAA's National Data Buoy Centre (USA). The bottom instrument is programmed to transmit data at 15 minute intervals but when the sensor detects an earthquake (due to shaking of the sea bed) – it automatically transmits data at 1 min intervals. The tsunameter record for the 12 September event shows the initial disturbance due to the earthquake and the subsequent tsunami (Figure 3) with only a very small tsunami (0.05m).

The real-time sea level recorders at Colombo, Trincomallee and Kirinda, operated and maintained by the National Aquatic Research and Development Agency (NARA) all recorded the tsunami with maximum wave heights of 0.6 m (Table 2).

TABLE 2 – Characteristics of the 12 September 2007 Indian Ocean Tsunami

Sea Level Station	Arrival Time GMT	Initial wave height	Maximum Wave height
Padang	11:54	0.35 m	2.27 m
Christmas Island	12:19	0.10 m	0.15 m
Cocos Island	12:28	0.11 m	0.24 m
Tsunameter 23401	13:47	0.05 m	0.046 m
Trincomallee	14:58	N/A	0.60 m
Colombo	15:12	0.3 m	0.60 m

The relatively long time lag between the earthquake and the tsunami propagation to Sri Lanka also enabled computer models to be used to predict the tsunami impact on Sri Lanka. A computer tool developed by NOAA through funding provided by USAID as part of IOTWS named ComMIT (Community Model for Tsunami Inundation) was used. The principle of model operation is that a series of hypothetical earthquakes located along the Sunda plate boundary (Figure 1) with different magnitudes have been simulated and the results are stored in a web server in Seattle. Simulation a single Indian Ocean wide tsunami requires large computing resources – several hours on a supercomputer and thus the scenarios have been pre-computed and stored. However, using the pre-computed data a single model run for a selected region at high resolution can be undertaken in about 20 minutes on a normal PC. The results of such a simulation, undertaken immediately after the earthquake revealed a predicted initial tsunami height of 0.20 m incident on the south-west coast of Sri Lanka.

The results from the sea level recorders and computer models resulted in the conclusion that a significant tsunami was unlikely to impact on Sri Lanka for this event and the tsunami warning was cancelled.

It should be noted that a second earthquake with a magnitude of 7.9 and a focal depth of 30km occurred in the same region on 12 September 2007 at 23:49 GMT i.e. some 12 hours later. This earthquake also generated a small tsunami with height ~0.10m and was recorded in Cocos and Christmas Island gages as well as in Colombo.

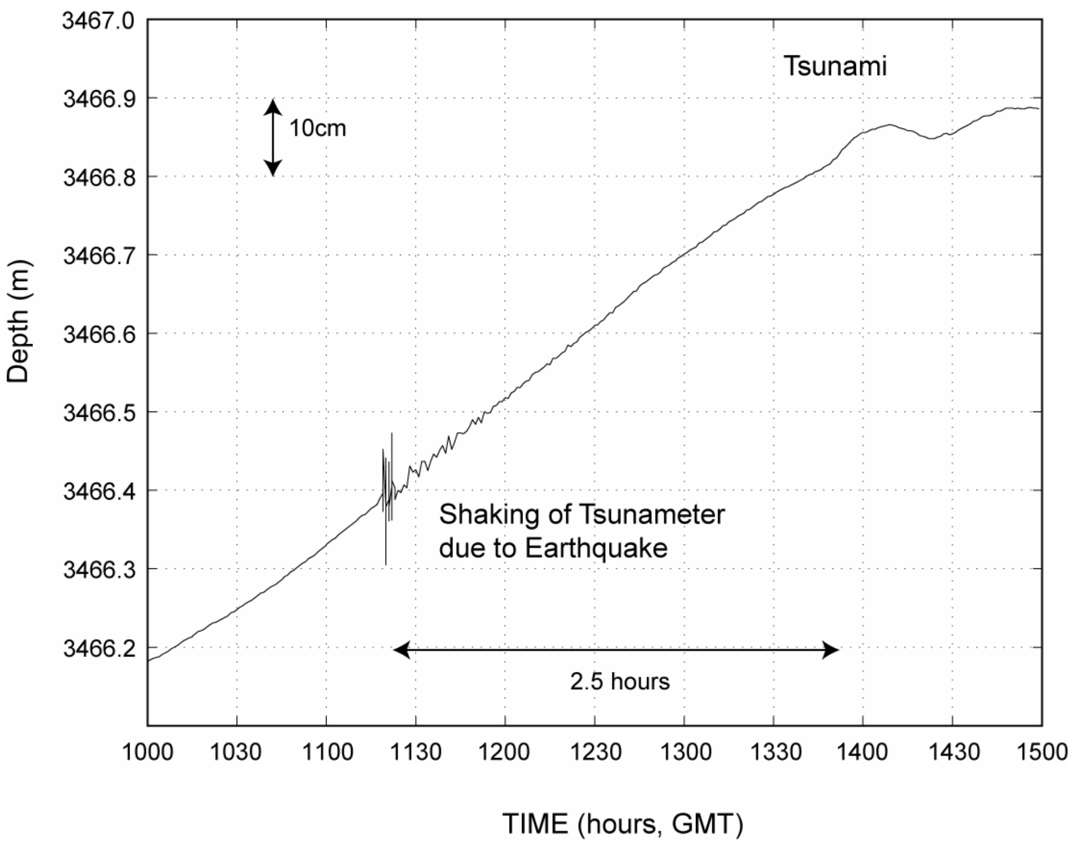

Figure 3 – Time series record from the Tsunameter showing the initial bottom disturbance and the arrival of the tsunami 2.5 hours later.

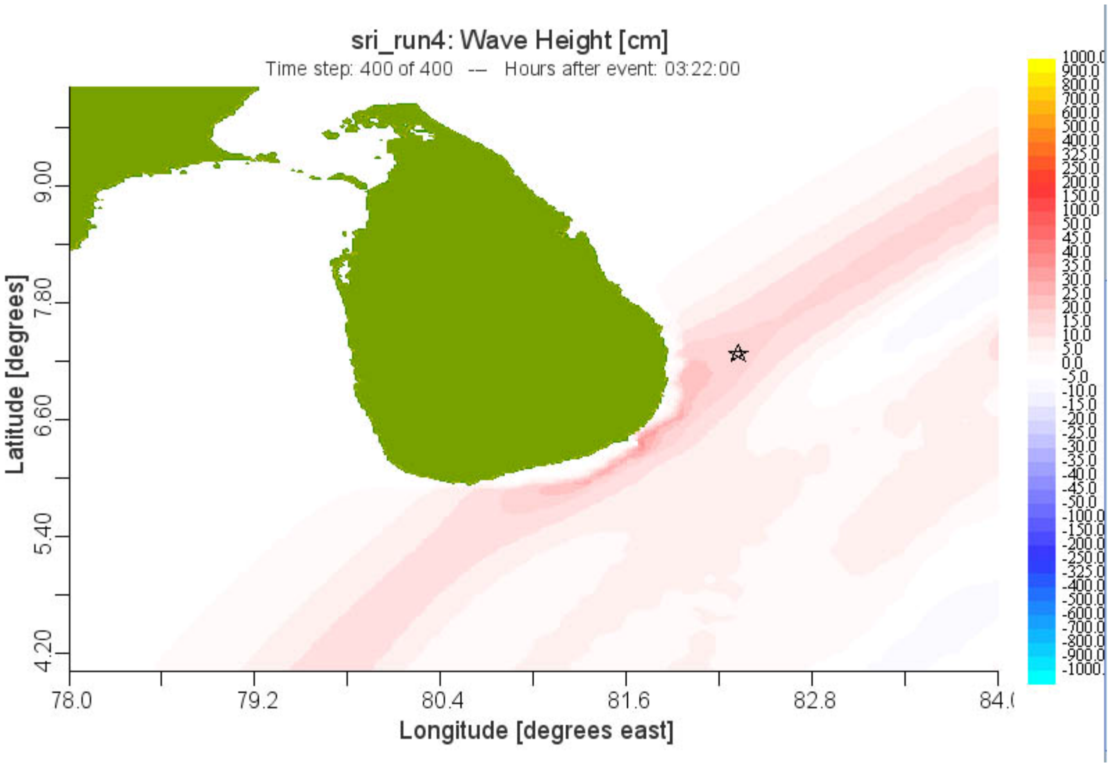

Figure 4 – Model output from ComMIT model for the region around Sri Lanka for the 12 September earthquake.