leach out the soil of the affected areas to improve EC and apply gypsum based on soil sample test to bring pH to normal value. This can be achieved by developing suitable sub-surface drainage systems at select locations, (ii) Alternatively, if the salinity of groundwater increases with depth, construct structures for skimming sweet water in such areas, (iii) Raise community nursery of saline-tolerant crop varieties of varying duration from the national collection and make it available to farmers by July/August 2005. Ten rice varieties have been chosen in this regard and (iv) To launch educational programmes on management of problem soils.

1. DOA, *Soil Atlas – Nagapattinam district*, Department of Agriculture, Tamil Nadu, 1998, p. 195.

ACKNOWLEDGEMENTS. We thank Prof. S. Nagarajan, Director, IARI and Prof. C. Ramasamy, Vice Chancellor, Tamil Nadu Agricultural University (TNAU), Coimbatore for providing facilities for the survey team. Help rendered by the staff of TNAU at Coimbatore and IARI at New Delhi is acknowledged.

Received 12 May 2005; revised accepted 2 June 2005

H. CHANDRASEKHARAN[1,*]
V. P. SINGH[1]
D. U. M. RAO[1]
M. NAGARAJAN[1]
B. CHANDRASEKARAN[2]

[1]*Indian Agricultural Research Institute, New Delhi 110 012, India*
[2]*Tamil Nadu Rice Research Institute, Aduthurai 612 101, India*
**e-mail: hcsekaran@iari.res.in*

Was there active tsunami generation during 28 March 2005 Sumatra earthquake?

When the 8.7 magnitude (March 2005) earthquake (epicentre, 2.074°N, 97.013°E) occurred in the Indian Ocean (near the position of 26 December 2004 giant earthquake, epicentre: 3.316°N, 95.854°E) in northern Sumatra, the world anxiously awaited word of yet another devastating tsunami similar to the earlier one. There was, however, a vast difference. The tsunami warnings were issued in India by India Meteorological Department, quickly in anticipation and were as quickly withdrawn officially. The question arises whether there was a tsunami generation on this occasion? This correspondence looks into some of the differences and the conclusions based on a computer simulation using the TOAST model[1].

There are four major factors determining tsunami generation, its propagation and its build-up near the coastal regions[1]. They are:

(i) The magnitude of ocean surface displacement and its direction (essentially the amount of kinetic energy released from the shaking into the ocean water).

(ii) Amplification of the kinetic energy release at the bottom in terms of tsunami generation at the water surface.

(iii) The tsunami 'focusing' aspect (i.e. the primary direction of the tsunami wave propagation).

(iv) The bathymetry at the coastal regions for tsunami amplification.

The TOAST model is not fully geared for the calculation of tsunami amplification near the coast, as the model is presently limited due to poor bathymetry information. However, tsunami generation at source and its propagation up to the near-coastal regions can be tracked quite successfully. The tsunami height generation at the source is quite preliminary in both cases, since there is no direct measurement of the kinetic energy release at the ocean floor. Kinetic energy estimates are approximated using elastic plate calculations, which are gross.

As a comparison, the magnitude of the earlier earthquake (Sumatra90) was 9.0 (revised to 9.3)[2] and the latest one (Sumatra87) was 8.7 on moment magnitudes M_w and might not mean serious difference from the point of view of available total kinetic energy. However, the effective bulk modulus of rock in the two cases means a large difference due to large difference in the depth of occurrence below the mantle. While Sumatra90 was at the depth of 17 km, Sumatra87 was at the depth of 30 km (as reported in preliminary report from USGS[3]). This means that the efficiency of kinetic energy transmission to the ocean water due to rock resistance is far lower in the latter case. Tsunami generation is affected by dip-slip changes and therefore, the position of the epicentre zone with respect to the subduction zone is important. In the case of Sumatra90, it occurred near the subduc-

Figure 1. Location of Sumatra90 and Sumatra87 earthquakes and general layout of the rupture region. Sumatra87 occurred in an area which was already ruptured during 1861 earthquake.

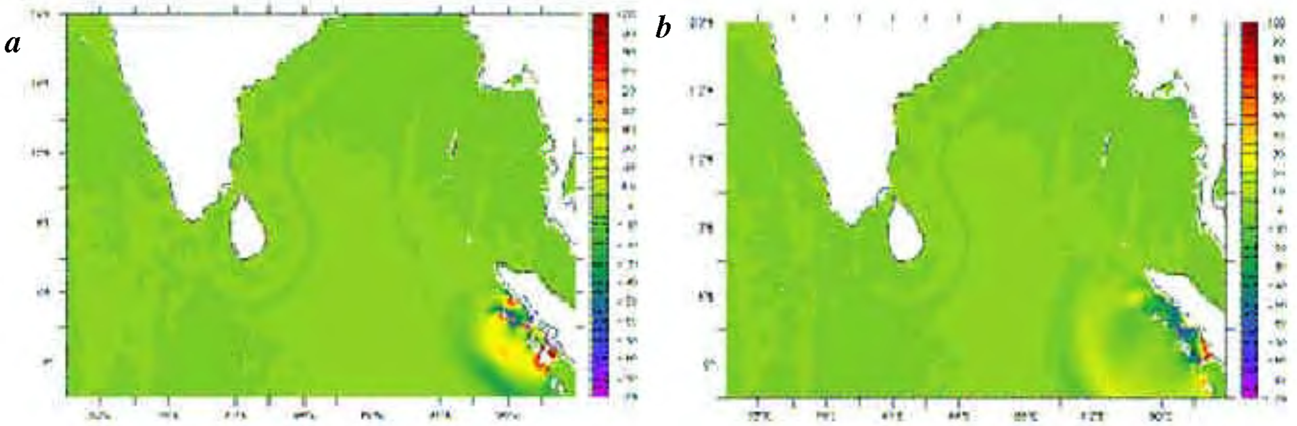

Figure 2. TOAST simulation of 28 March 2005 tsunami generation off Sumatra coast (***a***) 30 min and (***b***) 60 min after main-wave generation. There is a build-up of surge in the eastern side, while the wave on western side is ebbing out faster.

tion zone, while Sumatra87 was near the coastal region. Another contrasting factor is that Sumatra90 occurred in a near-virgin area, while Sumatra87 in an area already ruptured during the 1861 earthquake. This would have limited the actual extent of rupture compared to model simulations. During Sumatra90, the dip-slip, though initially low, increased to a large extent with mean 5 m elevation of sea floor (a peak movement around 10 m)[4]. On the other hand, in the case of Sumatra87, the dip-slip might have been less than 1 m and most of the movement was horizontal (strike angles are different, based on finite fault simulation model)[3]. Sumatra90 stayed for larger duration (main oscillation time 190 s), while Sumatra87 was for shorter duration (main oscillation time 110 s). The elastic plate calculations led to an estimate of the effective vertical kinetic energy release during Sumatra90 as 250 HPa (on the average side) in pressure terms, while for Sumatra87, it is 80–100 HPa (on the upper side).

During Sumatra90, the water column depth was between 2 and 2.5 km, while for Sumatra87 the water column depth was about 1.0 km. This means that the released kinetic energy had lesser volume of water to displace for generation of initial wave (since the tsunami generation mainly depends upon the column integrated velocity component of kinetic energy). Therefore, tsunami generation for Sumatra87 case is expected to be far lower than Sumatra90, both due to reduced vertical component of kinetic energy (larger slip than dip) as well as availability of less water volume for displacement. (The source point tsunami generation using TOAST is estimated as 275 cm for Sumatra90 and 75 cm for Sumatra87). The size and direction of rupture of the sea floor due to the earthquake mainly determines the propagation of tsunami waves, as has been observed in simulations for Sumatra90 and Sumatra87. During Sumatra90, the rupture plane had an orientation almost facing west and therefore, the major wave trains propagated in the direction of India and Sri Lanka shores. Since there was no obstacle on the eastern side, its impact was felt in deeper regions like Thailand. During Sumatra87, the rupture direction was roughly southwest and therefore, taking account of the epicentre, the tsunami waves have travelled into the open Indian Ocean regions (see Figure 1) in the west, losing their energy quite fast. On the eastern side, there is a short-term build-up of waves going as much as 2–3 m (Figure 2). Another interesting feature of the Sumatra87 event is that it happened near the land mass (sea being shallow), and the major chunk of kinetic energy was lost to the landmass, preventing intensification of the tsunami[5].

We observe that as anticipated, there was generation of tsunami during 28 March 2005 earthquake, though relatively quite weak compared to the 26 December 2004 event. However, it propagated mostly towards the southwest direction, and since there are no shallow regions around, the tsunami did not get amplified. It had amplification in the eastern side in the smaller regions in close proximity to the epicentre and the build-up might have reached to 2–3 m. There were no significant sea level changes in satellite altimeter data during the period (the passes were on western side of the event) and little later.

1. Agarwal, V. K., Agarwal, N. and Rajkumar, *Curr. Sci.*, 2005, **88**, 439–444.
2. Stein, S. and Okal, E., *Nature*, 2005, **34**, 581–582.
3. USGS website: http://earthquake.usgs.gov/neis/eq_depot/2005/; http://earthquake.usgs.gov/neis/eq_depot/2004/
4. Kerr, R. A., *Science*, 2005, **308**, 341.
5. Bilham, R., *Science*, 2005, **308**, 1126–1127.

ACKNOWLEDGEMENTS. We are grateful to Dr G. Madhavan Nair, Chairman, ISRO/Secretary, DOS and Dr K. N. Shankara, Director, SAC (ISRO) for encouragement. We also thank Dr B. Manikiam, ISRO-HQ, for useful suggestions. We are grateful to GFDL, NOAA (USA) for making their modular ocean model available to us, and TOPEX mission team for availability of bathymetry data. Data from altimeter used in this study came from the JASON team. We thank the Computer Facility team at the Meteorology and Oceanography Group, SAC (ISRO) for computer support. We also thank the referee for valuable suggestions to improve the manuscript.

Received 16 May 2005; revised accepted 3 June 2005

VIJAY K. AGARWAL*
NEERAJ AGARWAL
RAJKUMAR

Ocean Sciences Division,
Space Applications Centre,
(Indian Space Research Organization),
Ahmedabad 380 015, India
**e-mail: vijay-agarwal@sac.isro.gov.in*