# How did the tsunami source of the 2004 Indian Ocean Tsunami extend to the north?

# Kenji Hirata[1]; Tsurane Kuragano[2]; Yutaka Hayashi[3]; Kenji Satake[4]; Yuichiro Tanioka[5]; Yohei Hasegawa[3]; Nobuo HAMADA[6]

[1] JAMSTEC; [2] Office of Marine Prediction, JMA; [3] MRI,JMA; [4] Active Fault Research Center, AIST, GSJ; [5] Hokkaido U; [6] JMA

The northern limit of the tsunami source of the 2004 Indian Ocean tsunami remains unresolved. From tsunami travel times, the northern limit is claimed to locate at about 9 N(Lat et al.,2005:Song et al.,2005), or up to 11 N(Neetsu et al.,2005), or farther to the north of 10-11 N(Fine et al.,2005) or so on. From tsunami waveform inversions, it seems be possible to locate at 10-11 N (Fujii & Satake,2006) or 13-14 N(Hirata et al.,2006a;Tanioka et al.,2006).

Tsunami records at the northernmost tide gauge stations at the Bay of Bengal are most sensitive to the northern limit of the tsunami source. Among such tide gauge stations whose records are open to researchers, Paradip and Vishakhapatnam are located to the northernmost. Observed tsunami travel times are 156 minutes at both stations(Department of Ocean Development, 2005). We calculated back-projecting tsunami wavefronts from these stations by using ETOPO2 bathymetry, and then compared those with tsunami source models estimated from satellite altimetry. Locations of the back-projecting tsunami wavefronts were corrected by fault rupture velocities(Hirata et al.,2006b).

Tsunami source should be outlined by such corrected, back-projecting tsunami wavefronts (black curves in Fig.1) if shallow bathymetry of ETOPO2, location of tide gauge on bathymetric grid, and tide gauge clocks are all accurate, and subfault geometry is appropriate. Since we cannot exclude these error factors, we introduce allowable range of +/-10 min in corrected travel times. If outline of a tsunami source is included in both of the allowable ranges (blue curves for Paradip and red curves for Vishakhapatnam in Fig.1), the tsunami source is considered acceptable.

Fig.1a suggests that slow propagating source models with velocities from 0.6 km/sec to 1.0 km/sec are acceptable for long-source models(1300-1400 km-long). Propagation velocities from 0.7 km/sec to 0.9 km/sec are acceptable if allowable range is set +/-5 min whereas those from 0.5 km/sec to 1.5 km/sec are acceptable if allowable range is set +/-15 min. Fig.1b suggests that no acceptable solution is obtained in velocity interval from 0.5 km/sec to 3.0 km/sec for short tsunami source models (700 km-long) when allowable range is set +/-10 min No acceptable solution is obtained in the same velocity interval when allowable range is set +/-5 min or +/-15 min. Long tsunami source with slow propagating velocity, therefore, seems to be a probable solution. Considering Fig.1 and accuracy (or arbitrary) of subfault location settings, we can conclude that the tsunami source extended up to at least about 11 N and likely farther to the north of it.

Fig.1 Comparison of various tsunami source models (model seafloor deformation patterns calculated from best-fit source models inverted from SSH data) with corrected tsunami travel times at the northernmost tide gauge stations, Paradip and Vishakhapatnam. Black curves indicate imaginary back-projecting tsunami wavefront with the corrected travel times calculated based on ETOPO2 bathymetry. Blue and red curves sandwiching the black curves represent the allowable range (+/-10 min) of corrected travel times (Black curves with the corrected tsunami travel times) for Paradip and Vishakhapatnam, respectively. Average propagation velocity Vr is shown in the bottom of each panel. (a) Comparison between corrected travel times and long tsunami sources estimated when 1400 km-long segment is allowed to generate tsunami. (b) Comparison between corrected travel times and short tsunami sources estimated when tsunami source is limited in southern 700 km-long segment.