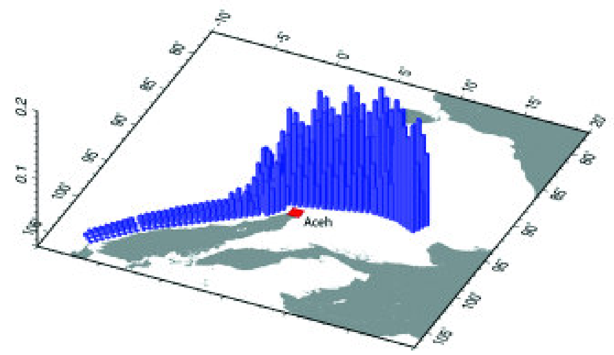
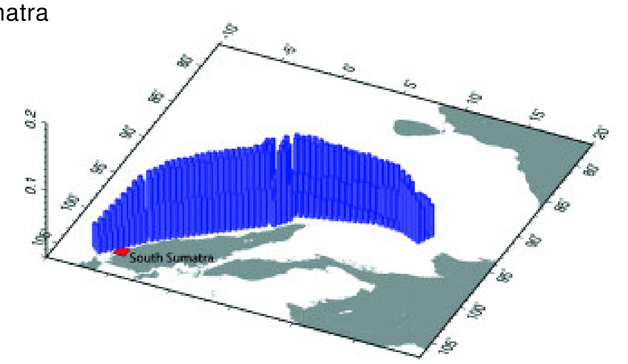
In Figure 6, we disaggregate the results with respect to the subfaults that make up the scenario earthquakes to identify which parts of the subduction zone contribute the largest part of the probabilistic hazard at the three sites. For the sites in Thailand (Kao Lak) and in Aceh, the hazard is dominated by contributions from the part of the subduction zone that ruptured during the December 26, 2004 earthquake, which is close to both sites. In contrast, for a site in southern Sumatra, the sources of hazard are evenly distributed along the entire subduction zone instead of just the parts that are near the site. The bathymetry evidently causes reflections or interference effects that lead to elevated tsunami amplitudes in southern Sumatra from more distant sources to the north.

Disaggregation of tsunami hazard for site in Aceh



Disaggregation of tsunami hazard for site in Southern Sumatra



Disaggregation of tsunami hazard for site in Thailand

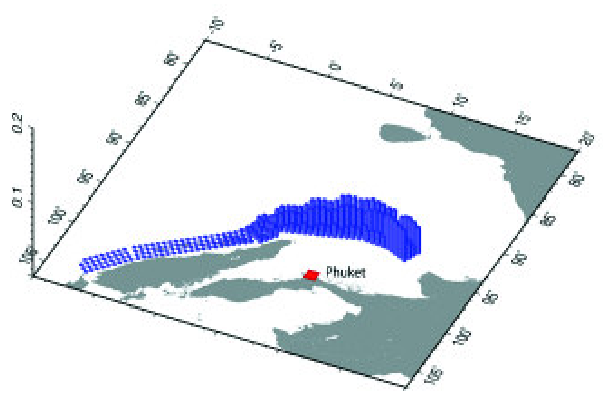


Figure 6. *Disaggregation of the tsunami hazard by subfault source location for sites in Banda Aceh, southern Sumatra, and Kao Lak (Thailand).*

Reference

Petersen, M. D, J. Dewey, S. Hartzell, C. Mueller, S. Harmsen, A.D. Frankel, and K. Rukstales (2004). Probabilistic seismic hazard analysis for Sumatra, Indonesia and across the Southern Malaysian Peninsula. *Tectonophysics* 390, 141-158.

Introducing:

Susanna Jenkins

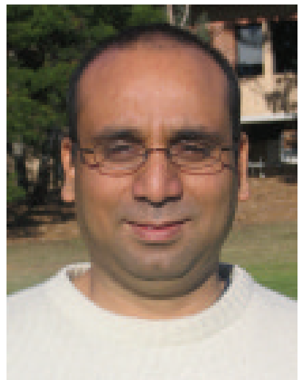
Susanna Jenkins began her PhD at Risk Frontiers in April 2005. She is interested in the hazards from explosive volcanic eruptions. It is anticipated that her project will involve physical and loss modelling, particularly in relation to multi-phase eruptions and their economic impact.

Susanna has worked on and around volcanoes in Italy, Mexico, America and New Zealand. Research projects include volcanic hazard and risk evaluation, volcano monitoring and caldera unrest.

She holds an MSc in Geophysical Hazards from University College London and a BSc in Geology from the University of Leeds, UK.

Susanna's homepage provides more detail on current research.

Rahul Nakhasi



Rahul Nakhasi began his PhD degree at Risk Frontiers in 2005. Rahul's thesis will be administered under a programme of cotutelle by which he is jointly enrolled at both Macquarie University and the Ecole Nationale Supèieure des Mines de St-Etienne, France. His research focuses on community vulnerability and resilience to climate change with particular application to the Indian province of Orissa on the Bay of Bengal. This low-lying, density populated coastal strip is prone to tropical cyclones and flooding. Rahul is also interested in the possible role of insurance as one means of accelerating disaster recovery in developing countries.

Rahul holds Bachelors and Masters degrees in Architecture, Urban Planning and Environmental Risk Management from engineering faculties in India and France. Recent projects include disaster risk management and community vulnerability to industrial hazards undertaken at research institutions in France, Austria and India.

Thursday 25th August, 2005
2.30pm to 4.40pm
Museum of Sydney
(cnr Phillip & Bridge Sts, Sydney)

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Risk Frontiers

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Probabilistic Tsunami Hazard Analysis

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Introduction

The recent tsunami disaster caused by the 2004 Sumatra-Andaman earthquake has focused attention on the hazard posed by large subduction zone earthquakes and the tsunamis that they generate. Even though events like this are rare, the very large loss of life (over 200,000 dead or missing) and tremendous material destruction indicate the need for careful quantification of the hazards posed by tsunamis, and the development of capabilities that can mitigate tsunami hazards. We have capabilities that can contribute towards both of these goals.

- On a short time scale, we use rapid waveform inversion techniques to provide near real-time source characterization as well as rapid near real time tsunami simulation. These capabilities are aimed at enhancing tsunami warning systems.
- On a longer time scale, we perform probabilistic analysis of tsunami hazard.

The focus of this document is on the second of these goals, Probabilistic Tsunami Hazard Analysis (PTHA). Probabilistic Seismic Hazard Analysis (PSHA) has become standard practice in the evaluation and mitigation of seismic hazards to structures, infrastructure and lifelines. Its ability to condense the complexities and variability of seismic activity into a manageable set of parameters greatly facilitates the design of effective seismic resistant buildings and infrastructure.

Although Probabilistic Seismic Hazard Analysis usually treats the ground shaking hazard from earthquakes, the same approach can be used to estimate other seismic hazards, such as fault displacement, surface folding due to subsurface faulting, soil liquefaction, lateral spreading of soil, and landslides. We have extended the capability of PSHA to include tsunami wave height at the shoreline.

The method that we have developed for Probabilistic Tsunami Hazard Analysis (PTHA) is based on standard PSHA and is therefore completely consistent with standard seismic practice. This provides a means of evaluating the total risk (seismic and tsunami) to coastal infrastructure. As described below in Section 3, our technique provides a synopsis of the tsunami hazard along entire coastlines (Figure 4), and identifies the specific tsunami source regions that most strongly influence the tsunami hazard at each site on the coastline (Figure 5).

Our Probabilistic Tsunami Hazard Analysis can be used to identify whether a significant tsunami hazard may exist at a particular coastal location or over a stretch of coastline. If the hazard is found to be significant, then we can perform further analyses:

- Probabilistic tsunami runup and inundation calculations at the site based on the probabilistic tsunami wave height at the shoreline
- Probabilistic tsunami loss calculations based on the probabilistic runup and inundation

The Sumatra Earthquakes of 2004 and 2005

We developed slip maps of the Mw 9.15 December 26, 2004 and Mw 8.7 March 28, 2005 Sumatra earthquakes, and used the slip maps to calculate the tsunamis generated by each earthquake. The slip maps describe the amount and direction of slip that occurred on the subduction plate interface during the earthquakes. Figure 1 shows the projection of the slip maps of the two earthquakes onto the sea floor. The shallow edge of the fault rupture zone lies on the west side, and the deep edge lies on the east side adjacent to the west coast of Sumatra and the Nicobar and Andaman Islands. The amount of slip is shown by vectors and color shading. The March 28 earthquake had a much smaller rupture area (shown by dashed pale blue lines) than the 2004 December 26 earthquake. Most of the slip in the March event was deep while in the December event there was a lot of shallow slip as well as deep slip. Shallow slip produces the largest movements of the sea floor, and it is these movements that generate the tsunami.

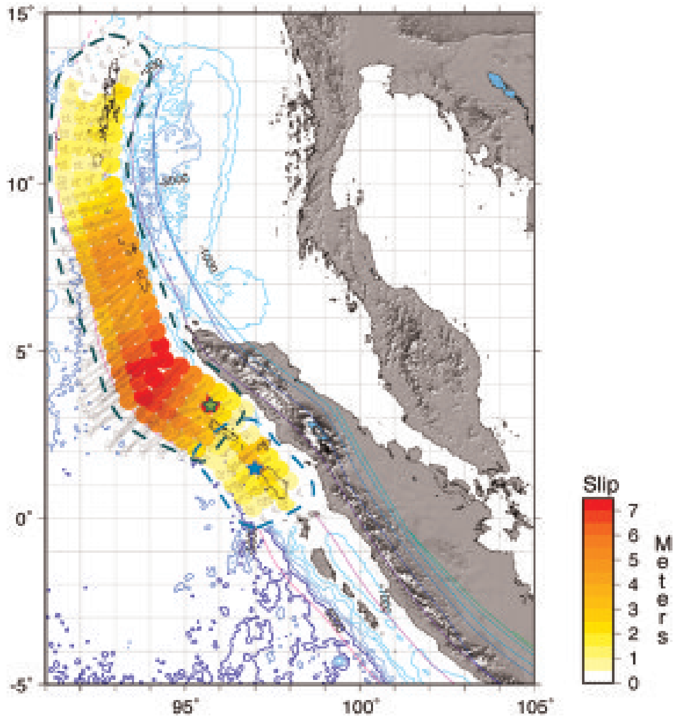

Figure 1. *Slip maps of the December 2004 and March 2005 Sumatra earthquakes*

The peak wave heights of the tsunamis throughout the ocean, calculated from the slip maps (Figure 1), are compared in Figure 2, and the maximum wave height along the coastline (without runup effects due to shallow bathymetry) are compared in Figure 3. These figures show that the small amount of shallow slip of the March earthquake resulted in reduced potential for an ocean-wide destructive tsunami. Since the rupture area and shallow slip for the March earthquake were much smaller than for the December event, only a small tsunami was generated whose height was significant only locally, not regionally. Also, more coastline was exposed to the December earthquake than for the March earthquake because of its location adjacent to India and Thailand.

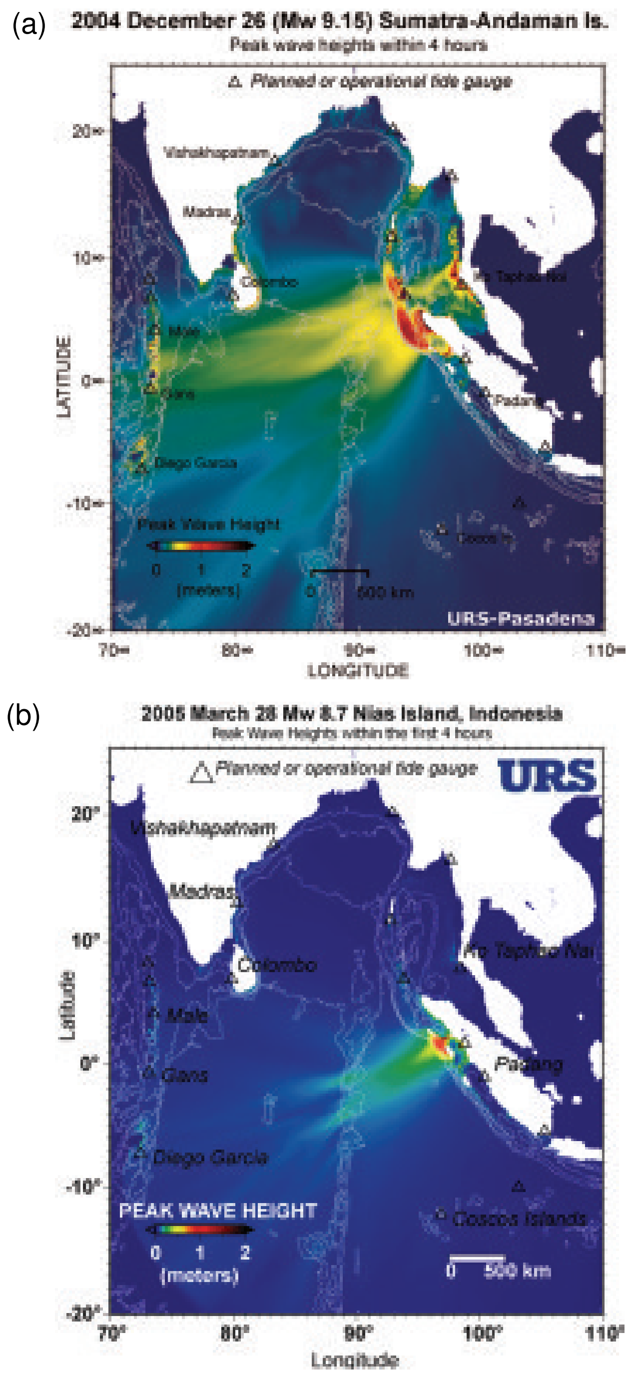

Figure 2. *Peak tsunami wave height for the December 26, 2004 (a) and March 28, 2005 (b) Sumatra earthquakes.*

Probabilistic Tsunami Hazard Analysis

In probabilistic ground motion hazard analysis, the estimation of ground shaking level for a specified magnitude and distance is based on ground motion attenuation relations. This kind of approach is not feasible for tsunamis, because fault orientation and ocean bathymetry cause large variability in the height of the tsunami, which is not a simple function of distance, as shown in Figures 2 and 3. To estimate the tsunami height at a particular location on the coast for a given earthquake, we have adopted a waveform excitation and propagation approach instead of trying to develop tsunami attenuation relations. We compute the complete tsunami wave field for each scenario earthquake, like the examples shown in Figure 2.

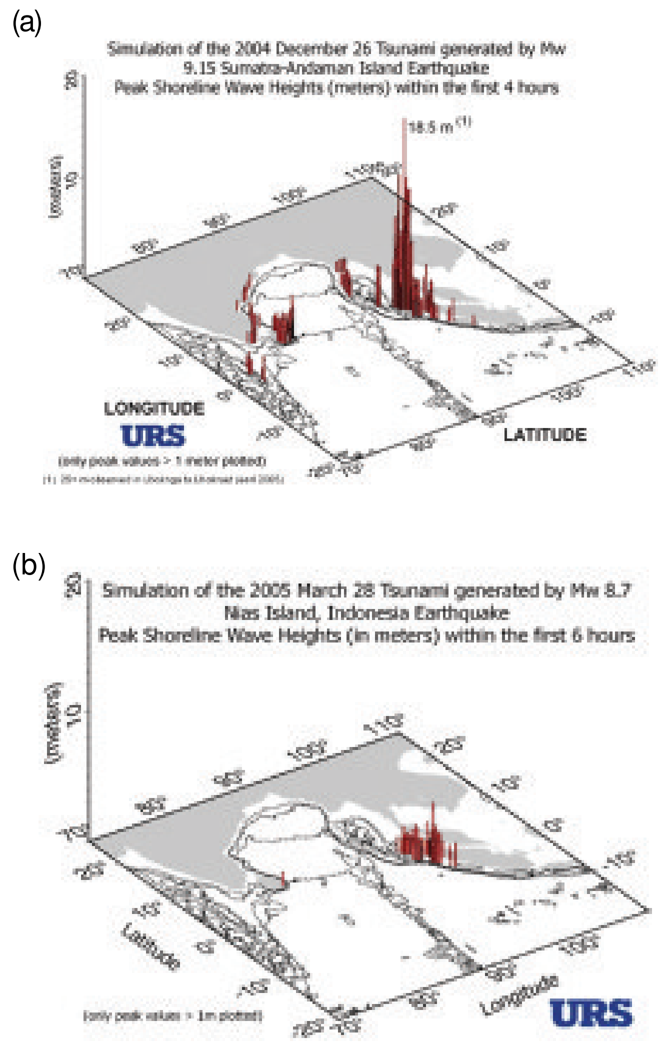

Figure 3. *Peak tsunami shoreline wave height for the December 26, 2004 (a) and March 28, 2005 (b) Sumatra earthquakes*

We have carried out preliminary tsunami hazard calculations for the Sumatra-Andaman subduction zone based on the earthquake recurrence model of Petersen et al. (2004), who performed a PSHA for the island of Sumatra and surrounding regions. The calculations use a set of 2,000 scenario earthquakes to provide a probabilistic description of earthquake occurrence in the region. In Figure 4, we show probabilistic tsunami wave heights for return periods of 72, 475 and 975 years, corresponding to probabilities of exceedance of 50%, 10% and 5% in 50 years. The vertical scale for the 72 year case is different from those of the 475 and 975 cases.

At return periods of 475 and 975 years, tsunami heights reach more than 20 m along the entire subduction zone. Away from the subduction zone, the amplitudes are significantly lower, but there is strong variability along the coastline of Thailand. In particular, the highest calculated tsunami amplitudes are at Kao Lak and Phuket, which were hardest hit during the December 26, 2004 earthquake. The high waves along this stretch of shoreline are evidently caused by local bathymetry. This illustrates the usefulness of this method in identifying stretches of coastline that are particularly vulnerable to tsunami damage.

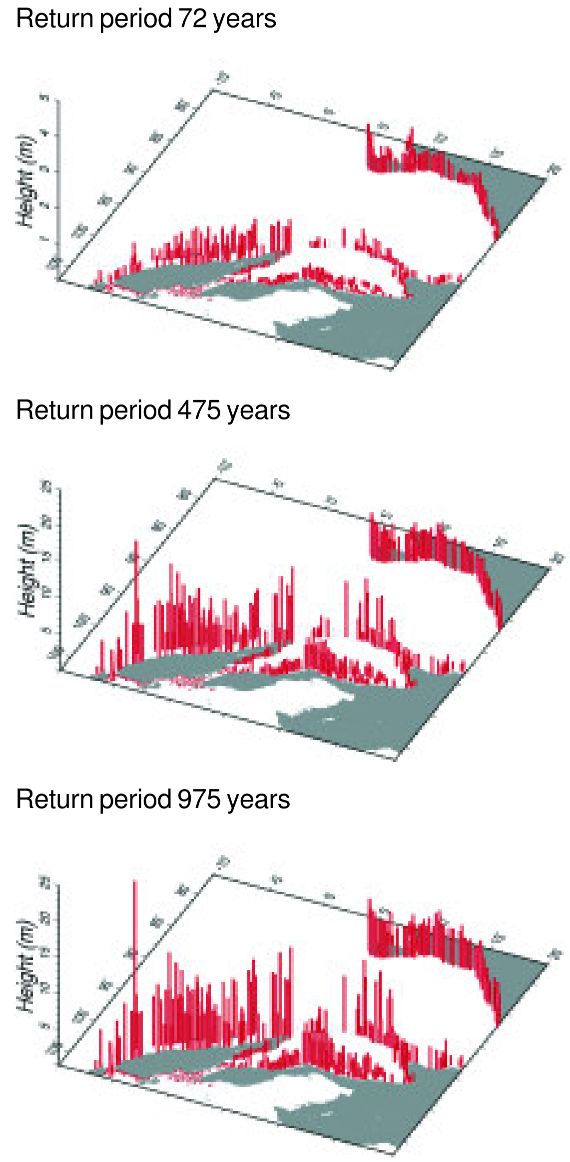

Figure 4. *Probabilistic tsunami hazard for the northeastern Indian Ocean for three return periods.*

In Figure 5, we show tsunami wave height hazard curves at four locations in the northeast Indian Ocean region. These curves indicate that the December 26, 2004 tsunami was an approximately 500 to 1,000 year event.

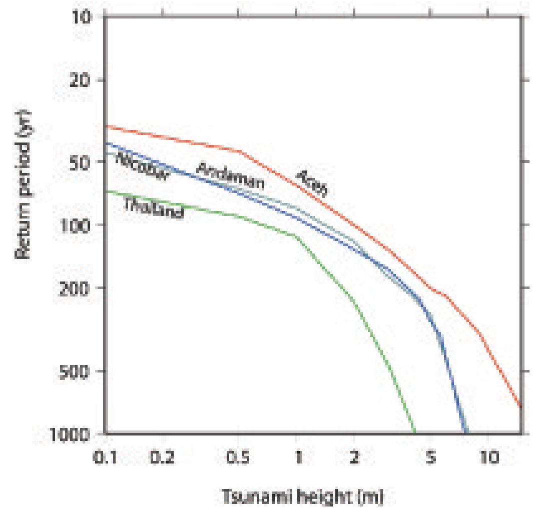

Figure 5. *Tsunami wave height hazard curves at four locations in the northeast Indian Ocean region.*