Releasing the strain

Forecasting tsunamis is quite a challenge. **John McCloskey** reveals how one ambitious study could help Sumatra prepare for a future earthquake.

The great 2004 Indian Ocean earthquake, measuring 9.2 on the Richter scale, raised the seafloor by as much as five metres in the deep water north-west of Sumatra and simultaneously lowered the Sumatran coast by up to two metres. The seismic shock sent a wave travelling outwards from the earthquake zone. When it hit the shallows of Sumatra's western Aceh province, the wall of water in places towered 30 metres high. The town of Banda Aceh, broadside to the worst part of the earthquake, was devastated by the tsunami – 80,000 of its 90,000 inhabitants were killed in minutes. Over the next ten hours, the wave flooded coasts throughout the Indian Ocean killing over 250,000 thousand people.

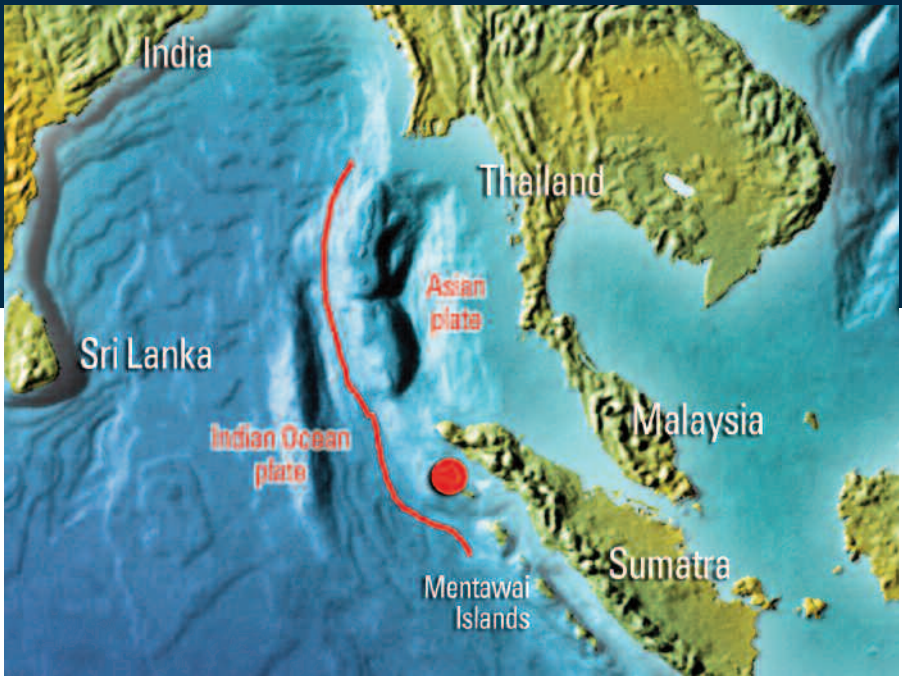
Now, we have all heard that lightning does not strike twice, but not so for earthquakes. The occurrence of one, actually makes the occurrence of another more likely – probably because they transfer stress to the surrounding crust, pushing nearby faults closer to failure. So it was in March 2005, only three months later, the neighbouring section of the crust failed in another great earthquake measuring 8.7 on the Richter scale. Remarkably, this second earthquake did not generate another large tsunami. The highest recorded waves barely reached four metres and the death-toll was mercifully low.

This chain reaction, with one earthquake triggering another, may not be over. The next section of the subduction zone, under the Mentawai Islands, has not experienced a large earthquake since 1797 and is clearly ready for another. The cities of Padang and Bengkulu, with a combined population of over one million, lie on Sumatra's low coastal plains facing directly into the worst earthquake threat. A future Mentawai earthquake has the potential to be even more devastating than 2004. All of this assumes another large tsunami but is that really likely? And why did two similar Indonesian earthquakes in 2004 and 2005 influence the seas so differently?

To address these questions, the geophysics group at the University of Ulster teamed up with scientists from the National Institute for Geophysics and Vulcanology (INGV) in Rome and Caltech in California, to simulate thousands of possible Mentawai earthquakes using the best knowledge of the geology and geophysics of the region. The aim was to explore the range of possible tsunamis which would result

Devastation in Banda Aceh, Sumatra, five days after a tsunami destroyed the city.

Map showing the epicentre (marked by the red dot) of the Sumatra-Andaman earthquake, 26 December, 2004. The red line marks the plate boundaries.



from all likely events. The project was ambitious and multidisciplinary, involving modelling of complex earthquake sources and the seafloor displacements they would produce. We then used these displacements as input into sophisticated tsunami simulations which exploit accurate digital models of the seafloor and the best numerical simulation codes to predict the tsunami over the entire Indian Ocean.

Here's how we did it. The Ulster University geophysicists sent a large number of simulated complex Mentawai Islands earthquakes to the Caltech group who selected the hundred or so they thought were most likely to happen. We then plugged these selected earthquakes into a seafloor displacement simulation, fed the results into the tsunami model and sat back while INGV's super-computer spent a couple of months crunching the numbers.

Our results show that a tsunami generated by a Mentawai Islands earthquake will have a much smaller impact around the Indian Ocean than the 2004 earthquake. Sri Lanka, India and Thailand will experience smaller waves and, while the coasts of Africa will be harder hit, the wave energies will still be relatively small. The situation on western Sumatra is more disturbing, but even here, none of the simulations reproduce the 30-metre waves of 2004. The maximum wave heights for Padang are about ten metres, whilst at the more exposed province of Bengkulu, they reach 15 metres. Even these figures are extreme. Only 20 percent of the simulated waves for Padang and Bengkulu exceed five and six metres respectively. The smaller waves, compared to those experienced in 2004, are mainly due to the presence of the islands which shield much of the threatened coast from energy generated by large seafloor movements.

These results are, of course, no cause for complacency. At its highest, Padang is just ten metres above sea level; this means that 20 percent of the likely earthquakes will inundate a great area of the city and would result in tens, or even hundreds, of thousands of casualties. But can we predict how much time people will have to escape when the ground stops shaking? Surely the answer depends on the earthquake? Well, surprisingly, it doesn't. Despite the complexity of these earthquake simulations and the range of predicted wave heights and magnitudes, the timing of the waves is more or less the same for any point on the Sumatran coast – about 33 minutes for Padang. And there's more. Our results show that the amount of vertical movement experienced at Padang (and for other places) is directly proportional to the height of the biggest wave that will reach there. This means, remarkably, that if you measured the ground movement with a GPS, like in your car's SatNav, you would in principle be able to predict the height of the largest wave which would arrive about 30 minutes later.

The reason is simple – and sort of obvious. All the earthquakes we are simulating are big so the general shape of the seafloor movement is always the same; the offshore islands go up and the coast goes down. Now for the magnitude 9 earthquakes, the offshore islands go up a lot and the coast goes down a lot. While for the 8s, the offshore islands go up a little and the coast goes down a little. The amount of vertical movement at a point on the coast tells us not only how far the coast goes down, but also the amount the islands will go up, which determines the height of the tsunami. So we can predict the wave height when we know the vertical movement. Secondly, no matter their size, the maximum uplift will always be under the islands so the wave will always travel from there, no matter what the earthquake was like. We also know that the wave speed is independent of the earthquake. All the complexity in the earthquake source, which we took so much trouble to include, is simply filtered out and the basic geometry of the problem eventually dominates. Stunning!

It is up to others to decide how these results can help prepare the people of western Sumatra for an inevitable and essentially unpredictable earthquake, but it is clear that studies of this type, based on the best current science, are vital. While we can't predict exactly where, when or what size the next earthquake will be, we can help planners to make well informed decisions and to target resources for the probable, rather than simply the possible. ❖

John McCloskey is Professor of Geophysics at the School of Environmental Sciences, University of Ulster. Email: j.mccloskey@ulster.ac.uk

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