Research on Sumatran Earthquakes Uncovers New Mysteries about Workings of Earth

The Sumatra-Andaman earthquake of December 26 was an unmitigated human disaster. But three new papers by an international group of experts show that the huge data return could help scientists better understand extremely large earthquakes and the disastrous tsunamis that can be associated with them.

Appearing in a themed issue of this week's journal Science, the three papers are all co-authored by California Institute of Technology seismologists. The papers describe in unprecedented detail the rupture process of the magnitude-9 earthquake, the nature of the faulting, and the global oscillations that resulted when the earthquake "delivered a hammer blow to our planet. " The work also shows evidence that the odd sequence of ground motions in the Andaman Islands will motivate geophysicists to further investigate the physical processes involved in earthquakes.

"For the first time it is possible to do a thorough seismological study of a magnitude-9 earthquake, " says Hiroo Kanamori, who is the Smits Professor of Geophysics at Caltech and a co-author of all three papers. "Since the occurrence of similar great earthquakes in the 1960s, seismology has made good progress in instrumentation, theory, and computational methods, all of which allowed us to embark on a thorough study of this event. "

"The analyses show that the Global Seismic Network, which was specifically designed to record such large earthquakes, performed exactly according to design standards, " adds Jeroen Tromp, who is McMillan Professor of Geophysics and director of the Caltech Seismology Lab. "The network enables a broadband analysis of the rupture process, which means that there is considerable information over a broad range of wave frequencies, allowing us to study the earthquake in great detail. "

In fact, Kanamori points out, the data have already motivated tsunami experts to investigate how tsunamis are generated by seismic deformation. In the past, seismic deformation was treated as instantaneous uplift of the sea floor, but because of the extremely long rupture length (1200 km), slow deformation, and the large horizontal displacements as well as vertical deformation, the Sumatra-Andaman earthquake forced tsunami experts to rethink their traditional approach. Experts and public officials are now incorporating these details into modeling so that they can more effectively mitigate the human disaster of future tsunamis.

Another oddity contained in the data is the rate at which the ground moved in the Andaman Islands. Following the rapid seismic rupture, significant slip even larger than the co-seismic slip (in other words, the slip that occurred during the actual earthquake) continued beneath the islands over the next few days.

"We have never seen this kind of behavior, " says Kanamori. "If slip can happen over a few days following the rapid co-seismic slip, then important hitherto unknown deformational processes in the Earth's crust must have been involved; this will be the subject of future investigations. "

As for the "ringing " of Earth for literally weeks after the initial shock, the scientists say that the information will provide new insights into the planet's interior composition, mineralogy, and dynamics. In addition, the long-period free oscillations of such a large earthquake provide information on the earthquake itself.

The first of the papers is "The Great Sumatra-Andaman Earthquake of 26 December 2004. " In addition to Kanamori, the other authors are Thorne Lay (the lead author) and Steven Ward of UC Santa Cruz; Charles Ammon of Penn State; Meredith Nettles and Goan Estrom of Harvard; Richard Aster and Susan Bilek of the New Mexico Institute of Mining and Technology; Susan Beck of the University of Arizona; Michael Brudzinski of the University of Wisconsin and Miami University; Rhett Butler of the IRIS Consortium; Heather DeShon of the University of Wisconsin; Kenji Satake of the Geological Survey of Japan; and Stuart Sipkin of the US Geological Survey's National Earthquake Information Center.

The second paper is "Rupture Process of the 2004 Sumatra-Andaman Earthquake." The Caltech co-authors are Ji Chen, Sidao Ni, Vala Hjorleifsdottir, Hiroo Kanamori, and Donald Helmberger, the Smits Family Professor of Geological and Planetary Sciences.

The other authors are Charles Ammon (the lead author) of Penn State; David Robinson and Shamita Das of the University of Oxford; Thorne Lay of UC Santa Cruz; Hong-Kie Thio and Gene Ichinose of URS Corporation; Jascha Polet of the Institute for Crustal Studies; and David Wald of the National Earthquake Information Center.

The third paper is "Earth's Free Oscillations Excited by the 26 December 2004 Sumatra-Andaman Earthquake," of which Jeffrey Park of Yale University is lead author. The Caltech coauthors are Teh-Ruh Alex Song, Jeroen Tromp, and Hiroo Kanamori. The other authors are Emile Okal and Seth Stein of Northwestern University; Genevieve Roult and Eric Clevede of the Institute de Physique du Globe, Paris; Gabi Laske, Peter Davis, and Jon Berger of the Scripps Institute of Oceanography; Carla Braitenberg of the University of Trieste; Michel Van Camp of the Royal Observatory of Belgium; Xiang'e Lei, Heping Sun, and Houze Xu of the Chinese Academy of Sciences' Institute of Geodesy and Geophysics; and Severine Rosat of the National Astronomical Observatory of Japan.

The second paper contains web references to three animations that help to illustrate various aspects of this great earthquake:

http://www.gps.caltech.edu/~vala/sumatra_velocity_global.mpeg

Global movie of the vertical velocity wave field. The computation includes periods of 20 seconds and longer and shows a total duration of 3 hours. The largest amplitudes seen in this movie are the Rayleigh waves traveling around the globe. Global seismic stations are shown as yellow triangles.

http://www.gps.caltech.edu/~vala/sumatra_velocity_local.mpeg

Animation of the vertical velocity wave field in the source region. The computation includes periods of 12 seconds and longer with a total duration of about 13 minutes. As the rupture front propagates northward the wave-field gets compressed and amplified in the north and drawn out to the south. The radiation from patches of large slip shows up as circles that are offset from each other due to the rupture propagation (a Doppler-like effect).

http://www.gps.caltech.edu/~vala/sumatra_displacement_local.mpeg

Evolution of uplift and subsidence above the megathrust with time. The duration of the rupture is 550 seconds. This movie shows the history of the uplift at each point around the fault and, as a result, the dynamic part of the motion is visible (as wiggling contour lines). The simulation includes periods of 12 s and longer. The final frame of the movie shows the static field.

All animations were produced by Seismo Lab graduate student Vala Hjorleifsdottir with the assistance of Santiago Lombeyda at Caltech's Center for Advanced Computing Research. The simulations were performed on 150 nodes of Caltech's Division of Geological & Planetary Sciences' Dell cluster.

Source: California Institute of Technology