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Tsunami and its Hazard in the Indian and Pacific Oceans: Introduction

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Abstract—The 2004 Indian Ocean tsunami caused an estimated 230,000 casualties, the worst tsunami disaster in history. A similar-sized tsunami in the Pacific Ocean, generated by the 1960 Chilean earthquake, commenced international collaborations on tsunami warning systems, and in the tsunami research community through the Tsunami Commission of International Union of Geodesy and Geophysics. The IUGG Tsunami Commission, established in 1960, has been holding the biannual International Tsunami Symposium (ITS). This volume contains selected papers mostly presented at the 22nd ITS, held in the summer of 2005. This introduction briefly summarizes the progress of tsunami and earthquake research as well as international cooperation on tsunami warning systems and the impact of the 2004 tsunami. Brief summaries of each paper are also presented.

Key words: Tsunami, Sumatra-Andaman earthquake, Indian Ocean, Pacific Ocean, seismology, tsunami warning system, IUGG Tsunami Commission.

1. Introduction

The 2004 Indian Ocean tsunami was the worst tsunami disaster in history. The tsunami, caused by the giant Sumatra-Andaman earthquake (M_w 9.3; Stein and Okal, 2005) on December 26, 2004, devastated the shores of the Indian Ocean. The total number of victims, dead and missing together, is estimated as 230,000 (International Federation of Red Cross and Red Crescent Societies, 2005); the largest in Indonesia (163,795), followed by Sri Lanka (35,399), India (16,389), Thailand (8,345), and Somalia (298).

In the Pacific Ocean, a similar, basin-wide tsunami occurred in 1960. This tsunami was generated by the giant Chilean earthquake, which remains the largest instrumentally-recorded earthquake on record (M_w 9.5). The tsunami caused more than 1,000 casualties along the Chilean coast, then propagated across the Pacific

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Ocean, taking 61 lives in Hawaii 15 hours later, and reaching the coast of Japan in 23 hours and claiming 142 more casualties. Following this Pacific-wide tsunami, international collaborations started on operational tsunami warning systems and scientific studies of tsunamis.

The Tsunami Commission of IUGG (International Union of Geodesy and Geophysics) was established immediately after the 1960 tsunami. The Tsunami Commission organizes the biannual International Tsunami Symposium (ITS). The 22nd ITS was held in Chania, Greece, from July 27 to 29, 2005, with approximately 90 participants from 20 countries. This volume contains selected papers presented at the meeting and a few other papers, and reflects tsunami research after the 2004 Indian Ocean tsunami.

In this introductory paper, Section 2 reviews international cooperation and progress on earthquake and tsunami research in the last half century. Section 3 describes the impacts of the 2004 Indian Ocean tsunami. Finally in Section 4 we briefly introduce the papers in the following categories; survey and research results on the 2004 and other recent tsunamis, geological studies of older tsunamis, and studies on tsunami hazard analysis.

2. Status Before the 2004 Tsunami

2.1. International Coordination on Tsunami Warning Systems

After the 1960 tsunami, which affected many countries around the Pacific Ocean, international coordination was initiated by the IOC (Intergovernmental Oceanographic Commission) under UNESCO (United Nations Educational, Scientific and Cultural Organization). In 1965, IOC set up ITIC (International Tsunami Information Center) in Hawaii with support from the USA NOAA (National Oceanic and Atmospheric Administration). With the mission of mitigating tsunami hazards around the Pacific, ITIC coordinates international activities on tsunami warning systems, helps countries to establish national warning and mitigation systems, collects publications and other materials on tsunami events, develops educational and awareness materials, and serves as an information resource on tsunamis. The ICG/ITSU (International Coordination Group for the Tsunami Warning System in the Pacific) was also established under the auspices of IOC, and first convened in 1968. The ICG/ITSU as of 2006 has 30 member countries and holds a biannual meeting to exchange information and coordinate international activities in the Pacific.

For operational tsunami monitoring and warning activities in the Pacific, three tsunami warning centers have been established. The PTWC (Pacific Tsunami Warning Center), established in 1949 following the 1946 Aleutian tsunami, serves as the international warning center for the Pacific. The WC/ATWC (West Coast/Alaska

Tsunami Warning Center), established in 1967 following the 1964 Alaska earthquake tsunami, serves as a sub-regional center for the western USA and Canada. In 2006, Japan commenced operation of the Northwest Pacific Tsunami Advisory Center to provide advisories to the northwest Pacific. These centers, operated by USA NOAA and Japan Meteorological Agency, monitor seismic activity around the Pacific, and issue tsunami warnings for the Pacific countries. All the centers share information and coordinate message content before issuing advisories.

2.2. International Collaboration in Research Community

The Tsunami Commission was established at the 12th general assembly of International Union of Geodesy and Geophysics (IUGG). The Tsunami Commission is closely related to three associations of the IUGG, IASPEI (International Association of Seismology and Physics of the Earth's Interior), IAVCEI (International Association of Volcanology and Chemistry of the Earth's Interior) and IAPSO (International Association for the Physical Sciences of the Oceans). The Tsunami Commission also organizes the biannual International Tsunami Symposium and publishes Proceedings with selected papers presented at the Symposium.

Since 1992, many tsunamis have occurred in the world. The development of the internet has accelerated international collaboration through the 1990s. Immediately after the 1992 Nicaragua tsunami, an e-mail list, then called Nicaragua Bulletin Board, was set up, and has been used ever since as a forum for international collaboration and exchange of information. Now called the Tsunami Bulletin Board (TBB), this service is maintained by ITIC.

The Tsunami Commission has also performed successful international projects. The Tsunami Inundation Modeling Exchange (TIME) project distributed computer software, a support manual and conducted training programs to teach tsunami inundation modeling techniques using a numerical model developed at Tohoku University in Japan. Under the Historical Tsunami Data Base project, a repository of tsunami data has been established and is maintained through the joint efforts of the Institute of Computational Mathematics and Mathematical Geophysics, in Novosibirsk, Russia and the National Geophysical Data Center, Boulder, Colorado, USA, which also serves as the World Data Center – Solid Earth Geophysics – Tsunamis.

2.3. Scientific Developments

In 1960, when the giant Chilean earthquake generated a Pacific-wide tsunami, little was known about tsunami generation. Most of the current seismological concepts have been developed since the 1960s. Plate tectonic theory was introduced in the 1960s and now explains the mechanism of great or giant earthquakes. Mathematical models of earthquake source were developed in the 1960s to relate seismic moment and size of fault. On the observational side, the World Wide Standard Seismic Network was deployed in the 1960s.

In the 1970s, using these theories and observed data, fault parameters of many large earthquakes in the world were determined. The moment magnitude (M_w) scale, based on seismic moment, was also introduced. It took more than a decade to accurately estimate the size of the 1960 Chilean earthquake. Theoretical and computational developments made it possible to compute seafloor deformation from fault models and the tsunami propagation on actual bathymetry.

Since the 1980s, seismograms have been recorded digitally, which has improved data quality and reduced processing times. As a result, basic earthquake source parameters can be estimated quickly and almost automatically. Heterogeneous slip distributions (asperities) on the fault also have been studied. Large-scale numerical simulations of tsunamis also became popular in the 1980s.

In the 1990s, developments in computer networking have made it possible to share the results of seismic wave analysis and tsunami numerical simulations in real time through the internet. In addition to instrumental seismology, historical and geological studies of past earthquakes and tsunamis have made important discoveries around the Pacific, advancing our understanding of tsunami hazards and recurrence intervals.

At present, after a large earthquake, globally observed seismological and sea-level data, as well as initial estimation of earthquake source parameters, are available within minutes through the internet. Based on these data and information, more seismological and tsunami studies are made and the results are also shared in real time. The development of the internet thus made positive feedback and accelerated tsunami research.

3. *Impacts of the 2004 Tsunami*

3.1. *International Activities*

The lack of a tsunami warning system in the Indian Ocean contributed to the severity of the 2004 Indian Ocean tsunami. At the 2005 IOC general assembly, it was proposed and adopted to organize ICGs (Intergovernmental Coordination Groups) in oceans and basins other than the Pacific. They are ICG/IOTWS (ICG for the Indian Ocean Tsunami Warning and Mitigation System), ICG/NEAMTWC (ICG for the Tsunami Early Warning and Mitigation System in the northeastern Atlantic, the Mediterranean and connected seas), and ICG/CARIBE-EWS (ICG for Tsunami and Coastal Hazards Warning System for the Caribbean and Adjacent Regions). The ICG/ITSU for the Pacific has been renamed as ICG/PTWS (ICG for the Pacific Tsunami Warning and Mitigation System). ICG/PTWC performed the first international tsunami drill for issuing and transmitting tsunami warning messages in May 2006.

Among the scientific community, information on tsunami damage, survey plans and obtained data or research results have been exchanged and discussed through Tsunami Bulletin Board (TBB). Within a month after December 26, about 500 mails were posted to the TBB. Through such coordination, hundreds of tsunami scientists around the world participated in tsunami surveys, most of them consisting of international teams, to document the 2004 tsunami. The survey data were also shared through the Tsunami Bulletin Board and individual websites. The surveys showed that tsunami heights were very large around Band Aceh (maximum 30 m) on Sumatra Island. They were 5 to 15 m along Thailand and Sri Lanka coast, but much smaller in Myanmar (< 3 m) or the Andaman Islands (< 5 m).

At the business meeting held during the 22nd ITS, the Tsunami Commission decided to publish collections of selected papers presented at the Symposium. The Commission also organized Working Groups to collect field data, survey results, tide gauges and satellite data on the 2004 Indian Ocean tsunami.

3.2. Scientific Impacts

There are several new lines of scientific progress resulting from the 2004 Indian Ocean tsunami. Numerical simulations were made immediately; with several groups performing the numerical simulations within hours after the event and posting the results on websites.

Sea-level monitoring stations, namely GLOSS (Global Sea Level Observation System) stations and stations in Australia, the Pacific and Atlantic Oceans recorded the 2004 tsunami (RABINOVICH and THOMSON, 2007). For tsunami recording, higher sampling interval (1 min) than ordinary tide (typically 6 min) is required. Such digital data were provided to researchers through websites in real- or semi-real-time.

High-resolution satellite images, taken before and after the tsunami, made it possible to estimate the tsunami damage in the hardest-hit areas such as Banda Aceh (e.g., BORRERO, 2005). Snapshots of nearshore tsunamis (e.g., on Sri Lanka coasts) were recorded in high-resolution satellite images. Tsunami propagation across the Indian Ocean was also captured by satellite altimeter (JASON-1) data (e.g., FUJII and SATAKE, 2007).

Numerous reports and papers have been published regarding the 2004 earthquake and tsunami, and it is almost impossible to list all of them. Here we only refer to special issues of other scientific journals. A special section in *Science* on May 20, 2005 (BILHAM, 2005) contains papers mostly on the seismological aspects. The special issue of *Earth, Planets and Space* (vol. 58, no. 2) contains 20 papers on various aspects such as GPS measurements or tsunami surveys (TANIOKA *et al.*, 2006). The June 2006 issue of *Earthquake Spectra* contains 44 reports, mostly on tsunami field surveys and societal responses (IWAN, 2006). A special issue of *Bulletin* *of Seismological Society of America* contains 22 papers on seismological and tsunami analysis (BILEK *et al.*, 2007).

3.3. Future Improvements

Despite the advances mentioned in the previous subsection, we still need to improve our scientific understanding of tsunamis. We are still unable to accurately forecast coastal tsunami heights in real time. Initial numerical simulations made after the Sumatra earthquakes in December 2004 and March 2005 assumed a generalized source mechanism and computed tsunami propagation over the relatively coarse ETOPO2, 2 min gridded bathymetry data (SMITH and SANDWELL, 1997). Although these data are accurate for deep oceans, shallow bathymetry is not accurate enough to be used for reliable tsunami forecasting. Hence the numerical simulations reproduce the overall features of tsunami propagation but cannot predict accurate arrival times and amplitudes. Nearshore tsunami effects can be accurately reproduced using available numerical codes for tsunami generation, propagation and inundation, however the results depend heavily on detailed information on the source mechanism as well as on local bathymetric and topographic features.

Since it is unlikely that the detailed analysis of the seismic signals will accelerate significantly nor will there ever be established a comprehensive database of detailed bathymetry for every coast in the world, it is important that we develop the technology to continuously monitor the tsunamigenic regions of the world and directly observe tsunami generation and propagation. Offshore tsunameters (buoys) capable of relaying real-time information to warning centers are essential for determining whether or not a tsunami has been generated and how big the wave will be when it reaches the coast. Dense networks of costal sea-level gauges in tsunami-prone areas provide important confirmation of a tsunami's generation, so that more distant communities can be warned. All of these will enable more informed evacuation decisions, as well as eliminate costly and potentially dangerous false evacuations. Satellite technology should also be improved to allow for targeted tsunami observation and rapid damage assessment for remote or inaccessible locations. Of course, the real-time availability and exchange of these data are essential to improving our understanding of a tsunami event as it unfolds and for saving lives and property. It is also important to urge port and harbor officials to install or upgrade tide measuring stations to record water levels at a higher sampling rate (1-minute or shorter) on a continuous or event-triggerred basis.

For long-term forecast of future tsunamis, probabilistic estimation can be made based on the study of past tsunamis, using historical and geological data. Paleoseismological work in the Nicobar and Andaman Islands would help us to understand the occurrence and recurrence of great earthquakes in the Indian Ocean since prehistoric time.

4. *Contents of this Issue*

4.1. On the 2004 Indian Ocean Tsunami

As a part of the Tsunami Commission Working Group on tide gauge data, RABINOVICH and THOMSON (2007) collected and compiled about 50 tide gauge records around the Indian Ocean and provided analysis such as arrival times, maximum amplitude and spectral components.

Tsunami was also recorded on hydrophones or seismometers. OKAL *et al.* (2007) analyzed the hydrophone records at Diego Garcia and showed that the tsunami signal is detected in a very wide period range (about 90 s to 3000 s), beyond the shallow-water approximation. The dispersion character was modeled by normal mode theory. OKAL (2007) shows that the 2004 Indian Ocean tsunami and other recent tsunamis are recorded on horizontal components of seismometers. The seismic detection of a tsunami can be modeled by using normal mode theory of the Earth including the tsunami mode, thus leading to estimate the seismic moment of parent earthquake from tsunami records.

OKAL and TITOV (2007) proposed a new magnitude scale, M_{TSU}, from spectral amplitude of tsunami. Similar to the mantle magnitude, M_m, the method is based on normal-mode theory and uses variable frequency, hence it is free from saturation. They demonstrate that the new magnitude scale recovers the seismic moment within a factor of two (0.2 in magnitude scale) from DART tsunameter records, and from satellite sea-surface data obtained for the 2004 tsunami in the Indian Ocean.

The 2004 tsunami was also detected in the Atlantic and Pacific Oceans. KOWALIK *et al.* (2007) carried out a tsunami simulation on the global ocean while monitoring energy flux. They found many important features of the tsunami. Reflection from the coasts of Sri Lanka and Maldives were larger than the direct wave; the tsunami entered the Pacific Ocean through various routes; the amplified tsunami energy arrived much later than the first arrival.

INOUE *et al.* (2007) reports tsunami heights, arrival times and damage along the Sri Lankan coast. A damaging tsunami had never been observed on this island country, and then the 2004 tsunami resulted in about 36,000 victims. KELLETAT *et al.* (2007) examined the geological effects of the 2004 tsunami on the Thai coast. They found minimal geomorphological changes and tsunami traces in their survey immediately after the tsunami. Based on their observations, they concluded that the 2004 tsunami was considerably smaller than the paleo-tsunami events in the Atlantic Ocean or Caribbean Sea that transported boulders.

4.2. Analysis and Simulations for other Tsunamis

The last disastrous tsunami prior to the 2004 tsunami was the 1998 tsunami in Papua New Guinea. This event generated tsunami waves as large as 15 m around

Sissano Lagoon near the epicenter and casualties estimated at 2,200. JOKU *et al.* (2007) report on their follow-up surveys of eyewitness accounts of this tsunami on the coast west of the tsunami source region. They also summarize the experiences of coastal residents from historical tsunamis since 1940.

Large tsunamis, including the 2004 event, demonstrate strong directivity; the largest tsunami heights were in directions perpendicular to the source, e.g., Sumatra, Thai and Sri Lankan coasts. ABE (2007) found that in the direction of the long axis of the tsunami source, or in the direction where the smallest tsunami amplitudes are observed, the source length is represented well by the period of the initial tsunami wave. Through examinations of tide gauge records from four large Japanese earthquakes in the last few decades, he measured the periods of the initial tsunami wave, estimated the source length assuming that the observed period is equal to the tsunami travel time across the source, and found that they are well correlated with the earthquake magnitudes.

CHERNIAWSKY *et al.* (2007) carried out numerical simulations of tsunamis in the southern Vancouver Islands from possible scenario earthquakes in the Cascadia region of the Pacific Northwest. A very fine bathymetry grid, as small as 10 m, is used in their simulation, and tsunami run-up on land is considered. The computed coastal tsunami heights are mostly 5–8 m, with the maximum of 16 m, and larger than those inferred from paleoseismological studies. The simulation also predicts very fast current velocity up to 17 m/s (33 knots).

4.3. Geological Studies of old Tsunamis

Geological records or tsunami deposits have been studied around the Pacific Ocean for the last two decades. KOMATSUBARA and FUJIWARA (2007) provide an overview of such studies carried out in southwestern Japan along Nankai, Suruga and Sagami troughs. Many studies of tsunami deposits have been carried out in the last 15 years but most of them were reported in Japanese language and not known to the international community. The geological records cover a much longer time range than the historical records. The inferred recurrence interval is variable; the shortest ones are similar to those estimated from historical records.

In the Cascadia subduction zone, off the Pacific Northwest of the USA and Canada, the recurrence of giant earthquakes similar in size to the 2004 event has been inferred from geological and historical records. KILFEATHER *et al.* (2007) extended such studies on tsunami deposits by examining micro-structures in thin sections. They found millimeter-scale stratigraphic features indicating multiple waves of tsunamis, that are not visible on a macro-scale in the field.

FREUNDT *et al.* (2007) examined geological traces of past tsunamis around two lakes in Nicaragua, Lake Nicaragua and Lake Managua. These tsunamis were of volcanic origin, generated by pyroclastic flows or debris avalanches from flank collapse of nearby volcanoes. They emphasize that the tsunamis in shallow lakes can be highly disastrous, not only in Nicaragua but also in other countries.

4.4. Tsunami Hazard Analysis

Probabilistic models have been developed to estimate coastal tsunami heights from future earthquakes. Such methods have been widely used for seismic hazard (Probabilistic Seismic Hazard Analysis), but only recently applied to tsunamis. POWER *et al.* (2007) developed a Probabilistic Tsunami Hazard Analysis (PTHA) method and applied it for estimating probabilistic tsunami heights from distant earthquakes. The end result is a map showing expected maximum tsunami heights in the next 500 years around New Zealand from earthquakes off South America.

A method for evaluating tsunami risk at nuclear power facilities in Japan is proposed by YANAGISAWA *et al.* (2007). Their method is based on a parametric study, in which numerical simulations are repeated for element tsunamis with various fault parameters, and the element tsunami with the greatest influence is selected as the design tsunami. The design tsunami is further compared with the historical data to ensure that it produces tsunami heights larger than those historically recorded. ANNAKA *et al.* (2007) proposed a logic-tree approach for PTHA. Their end product is a hazard curve, a relationship between coastal tsunami heights and the probability of exceedance at a particular site. The hazard curve is obtained by integration over the aleatory uncertainties, whereas a large number of hazard curves are obtained for different branches of logic-trees representing epistemic uncertainty, such as tsunami sources, size and frequency of tsunamigenic earthquakes, standard errors of estimated tsunami heights.

ORFANOGIANNAKI and PAPADOPOULOS (2007) examined the stochastic methods to compute the probability of tsunami generation from historical data of tsunami and earthquakes. Two methods, based on the conditional probability of tsunami occurrence and the total probability theorem, are compared to estimate the probabilities in three regions around the Pacific: South America, Kuril-Kamchatka and Japan.

FARRERAS *et al.* (2007) reports developments of the Mexican national program for tsunami hazard reduction. It consists of a sea-level monitoring system with real-time data access, deployment of a numerical simulation to construct tsunami inundation maps for coastal communities, and publication and distribution of educational material on tsunamis. These efforts cover the three important areas, warning guidance, hazard assessment and mitigation of tsunami hazard reduction on both national and international levels.

The coastal behavior of tsunamis, such as wave fission or wave breaking, can be studied by laboratory experiments. MATSUYAMA *et al.* (2007) report their experiments on tsunami wave fission and wave-breaking in large-scale undistorted experiments.

REFERENCES

ABE, K. (2007), *Phases representing source lengths of tsunamis in tide gauge records*, Pure Appl. Geophys. *164*, 453–463.

ANNAKA, T., SATAKE, K., SAKAKIYAMA, T., YANAGISAWA, K., and SHUTO, N. (2007), *Logic-tree approach for probabilistic tsunami hazard analysis and its applications to the Japanese coasts*, Pure Appl. Geophys. *164*, 577–592.

BILHAM, R. (2005), *A flying start, then a slow slip*, Science *308*, 1126–7.

BILEK, S.L., SATAKE. K., and SIEH, K. (2007), *Preface to the issue dedicated to the 2004 Sumatra-Andaman earthquake*, Bull. Seismol. Soc. Am. *97*, 1–5.

BORRERO, J.C. (2005), *Field data and satellite imagery of tsunami effects in Banda Aceh*, Science *308*, 1596.

CHERNIAWSKY, J.Y., TITOV, V.V., WANG, K., and LI, J.-Y. (2007), *Numerical simulations of tsunami waves and currents for southern Vancouver Island from a Cascadia megathrust earthquake*, Pure Appl. Geophys. *164*, 465–492.

FUJII, Y. and SATAKE, K. (2007), *Tsunami source of the 2004 Sumatra-Andaman earthquake inferred from tide gauge and satellite data*, Bull. Seismol. Soc. Am. *97*, 192–207.

FARRERAS, S., ORTIZ, M., and GONZALEZ, J.I. (2007), *Steps towards the implementation of a tsunami detection, warning, mitigation and preparedness program for southwestern coastal areas of Mexico*, Pure Appl. Geophys. *164*, 605–616.

FREUNDT, A., STRAUCH, W., KUTTEROLF, S., and SCHMINCKE, H.-U. (2007), *Volcanogenic tsunamis in lakes: examples from Nicaragua and general implications*, Pure Appl. Geophys. *164*, 527–545.

INOUE, S., WIJEYEWICKREMA, A.C., MATSUMOTO, H., MIURA, H., GUNARATNA, P., MADURAPPERUMA, M., and SEKIGUCHI, T. (2007), *Field survey of tsunami effects in Sri Lanka due to the Sumatra-Andaman earthquake of December 26, 2004*, Pure Appl. Geophys. *164*, 395–411.

INTERNATIONAL FEDERATION of RED CROSS and RED CRESCENT SOCIETIES, *World Disasters Report*. (Kumarian Press, 2005), 246 p.

IWAN, W.D. (2006), *Preface to the Issue dedicated to the 2004 Sumatra-Andaman earthquake*, Earthq. Spectra *22*, S3, xi.

JOKU, G.N., DAVIES, J.M., and DAVIES, H.L. (2007), *Eye-witness accounts of the impact of the 1998 Aitape tsunami, and of other tsunamis in living memory, in the region from Jayapura, Indonesia, to Vanimo, Papua New Guinea*, Pure Appl. Geophys. *164*, 433–452.

KELLETAT, D., SCHEFFERS, S., and SCHEFFERS, A. (2007), *Field signatures of the SE-Asian mega-tsunami along the West Coast of Thailand compared to holocene paleo-tsunami from the atlantic region*, Pure Appl. Geophys. *164*, 413–431.

KILFEATHER, A.A., BLACKFORD, J.J., and VAN DER MEER, J.J.M. (2007), *Micromorphological analysis of coastal sediments from Willapa Bay, Washington, USA: A technique for analysing inferred tsunami deposits*, Pure Appl. Geophys. *164*, 509–525.

KOMATSUBARA, J. and FUJIWARA, O. (2007), *Overview of Holocene tsunami deposits along the nankai, Suruga, and Sagami Troughs, southwest Japan*, Pure Appl. Geophys. *164*, 493–507.

KOWALIK, Z., KNIGHT, W., LOGAN, T., and WHITMORE, P. (2007), *The tsunami of 26 December 2004: Numerical modeling and energy considerations*, Pure Appl. Geophys. *164*, 379–393.

MATSUYAMA, M., IKENO, M., SAKAKIYAMA, T., and TAKEDA, T. (2007), *A study on tsunami wave fission in an undistorted experiment*, Pure Appl. Geophys. *164*, 617–631.

OKAL, E.A. (2007), *Seismic records of the 2004 Sumatra and other tsunamis: A quantitative study*, Pure Appl. Geophys. *164*, 325–353.

OKAL, E.A., TALANDIER, J., and REYMOND, D. (2007), *Quantification of Hydrophone records of the 2004 Sumatra tsunami*, Pure Appl. Geophys. *164*, 309–323.

OKAL, E.A. and TITOV, V.V. (2007), *M_{TSU}: Recovering seismic moments from tsunameter records*, Pure Appl. Geophys. *164*, 355–378.

ORFANOGIANNAKI, K. and PAPADOPOULOS, G.A. (2007), *Conditional probability approach of the assessment of tsunami potential: application in three tsunamigenic regions of the Pacific Ocean*, Pure Appl. Geophys. *164*, 593–603.

POWER, P., DOWNES, G., and STIRLING, M. (2007), *Estimation of tsunami hazard in New Zealand due to South American earthquakes*, Pure Appl. Geophys. *164*, 547–564.

RABINOVICH, A.B. and THOMSON, R.E. (2007), *The 26 December 2004 Sumatra tsunami: analysis of tide gauge data from the World Ocean: Part 1. Indian Ocean and South Africa*, Pure Appl. Geophys. *164*, 261–308.

SMITH, W.H.F. and SANDWELL, D.T. (1997), *Global sea floor topography from satellite altimetry and ship depth soundings*, Science *277*, 1956–1962.

STEIN, S. and OKAL, E.A. (2005), *Speed and size of the Sumatra earthquake*, Nature *434*, 581–582.

TANIOKA, Y., GEIST, E.L., and PUSPITO, N.T. (2006), *Preface to special issue* "The 2004 great Sumatra earthquake and tsunami", Earth, Planet Space *58*, 111.

YANAGISAWA, K., IMAMURA, F., SAKAKIYAMA, T., ANNAKA, T., TAKEDA, T., and SHUTO, N. (2007), *Tsunami assessment for risk management at nuclear power facilities in Japan*, Pure Appl. Geophys *164*, 565–576.

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