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Introduction to "Tsunamis: 1992–94"

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Background

Tsunamis have caused extensive human and property damage in the world. There had not been a tsunami disaster since 1983, when the Japan Sea earthquake tsunami caused 100 fatalities. In the three-year period (1992–94), however, several destructive tsunamis occurred in the world and caused more than 1,500 casualties. After each of these tsunami disasters, field survey teams consisting of scientists and engineers from various fields and countries were dispatched. They measured tsunami runup heights and estimated the velocity, direction and other local behavior. In addition to such hydrodynamic features, they searched for evidence of coseismic ground deformation and tsunami depositions and erosions. The first goal of this topical issue is to document data from these tsunamis for later use in various tsunami-related research.

The second goal is to present research results on various aspects of the recent tsunamis. During the "quiet" period of tsunami activity between 1983 and 1992, significant developments in tsunami-related research have occurred. In seismology, semi-real-time access and analysis of seismological data have become possible and tsunami data have been used to study earthquake sources. Geologists have found tsunami deposits from various geological events such as earthquakes, volcanic eruptions, submarine landslides and even a meteorite impact. On the observational side, deep ocean pressure gauges have been installed to record tsunami signals in the open ocean. Numerical modeling techniques of tsunami generation, propagation and runup processes have significantly improved, parallel to the development of computers. Three-dimensional runup processes have been modeled by theoretical, numerical, and experimental methods.

It is noteworthy that cooperation among various fields has advanced the research. For example, in order to model tsunami inundation on a particular coast, we have found that an offshore boundary condition of sinusoidal wave incidence is

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Table 1

Tsunamigenic Earthquakes in 1992–94

Year	mo	dy	hr	mn	sec	Latitude	Longitude	dep (km)	M_s	max. tsunami	Casualties	Region
1992	4	25	18	6	4.2	40.368°N	124.316°W	15	7.1	1 m	0	Cape Mendocino
1992	5	17	10	15	31.3	7.191°N	126.762°E	33	7.5	small	0	Mindanao
1992	5	27	5	13	38.8	11.122°S	165.239°E	19	7.0	small	0	Santa Cruz Is.
1992	7	18	8	36	58.7	39.419°N	143.330°E	29	6.9	0.5 m	0	Sanriku
1992	9	2	0	16	1.6	11.742°N	87.340°W	45	7.2	10 m	170	Nicaragua
1992	12	12	5	29	26.3	8.480°S	121.896°E	28	7.5	26 m	1713	Flores Is.
1993	2	7	13	27	42.0	37.634°N	137.245°E	11	6.2	0.2 m	0	Noto-oki
1993	6	8	13	3	36.4	51.218°N	157.829°E	71	7.3	0.1 m	0	Kamchatka
1993	7	12	13	17	11.9	42.851°N	139.197°E	17	7.6	30 m	239	Hokkaido
1993	8	8	8	34	24.9	12.982°N	144.801°E	59	8.0	1 m	0	Guam
1993	11	13	1	18	4.1	51.934°N	158.647°E	34	7.0	small	0	Kamchatka
1994	1	21	2	24	29.9	1.015°N	127.733°E	20	7.2	damaging	7	Halmahera
1994	4	8	1	10	40.8	40.608°N	143.683°E	13	6.3	0.2 m	0	Sanriku
1994	6	2	18	17	34.0	10.477°S	112.835°E	18	7.2	14 m	238	Java
1994	9	1	15	15	53.0	40.402°N	125.680°W	10	7.0	0.1 m	0	Cape Mendocino
1994	10	4	13	22	58.3	43.706°N	147.328°E	33	8.1	10 m	10	Kuril (Shikotan)
1994	10	8	21	44	09.1	1.222°S	127.992°E	31	6.8	damaging	1	Halmahera
1994	10	9	7	55	38.0	43.899°N	147.905°E	23	7.0	0.2 m	0	Kuril aftershock
1994	11	14	19	15	30.7	13.532°N	121.087°E	33	7.1	7 m	71	Mindoro
1994	12	28	12	19	23.6	40.451°N	143.491°E	33	7.5	1 m	0	Sanriku

According to Preliminary Determination of Epicenters (U.S.G.S). The casualties include those not due to tsunamis.

not appropriate, and tsunami generation and propagation from a geological fault model estimated from seismological analysis is necessary. The multidisciplinary nature of the tsunami phenomena has required geologists, seismologists, oceanographers and coastal engineers to interact.

Recent developments in computer networking have also promoted the interaction of researchers across disciplines. Immediately after the 1992 Nicaragua tsunami, the Tsunami Bulletin Board (originally called the Nicaragua Tsunami Bulletin Board) was established by the Pacific Marine Environmental Laboratory of N.O.A.A., U.S.A. This system (tsunami@pmel.noaa.gov) currently has about 130 subscribers worldwide and has been used to exchange information and data on tsunamis. It has been most useful after major tsunami events. Preliminary results of seismological analyses and numerical modeling were posted within a few days; field survey plans have been posted and discussed to form international survey teams; and the survey results were also posted.

Tsunamigenic Earthquakes in 1992–94

Figure 1 shows the epicenters of large ($M_s \geq 6$) earthquakes that occurred in the three-year period (1992–94), taken from the Preliminary Determination of Epicenters (PDE) catalog published by the U.S.G.S. Most of approximately 200 events in the world occurred around the rim of the Pacific Ocean, and 20 of these events generated tsunamis. The tsunamigenic earthquakes are shown as shaded circles in Figure 1 and listed in Table 1. About half the tsunamis were smaller than 1 m in maximum height and caused no damage. The maximum tsunamis heights for 6 events exceeded 5 m, and they resulted in substantial human loss and property damage. Chronologically, the 6 largest events were: Nicaragua (Sep. '92), Flores (Dec. '92), Hokkaido (July, '93), Java (June '94), Kuril (Oct. '94) and Mindoro (Nov. '94).

The 1992 Nicaraguan earthquake generated substantially larger tsunamis than expected on the basis of the surface wave magnitude. Several similar earthquakes have occurred in the world and have been called "tsunami earthquakes," but the Nicaragua event was probably the first event documented by extensive seismological and tsunami data. This was also the first tsunami event for which international survey teams were dispatched. The survey results have been reported in ABE *et al.* (1993), BAPTISTA *et al.* (1993) and SATAKE *et al.* (1993).

Fatalities from the Flores Island earthquake were 1,700; more than half due to tsunamis. Several interesting phenomena, such as very large runup in localized regions (up to 26 m) and the total devastation on a small circular-shaped island (Babi Island), have been reported (YEH *et al.*, 1993; and TSUJI *et al.*, this topical volume).

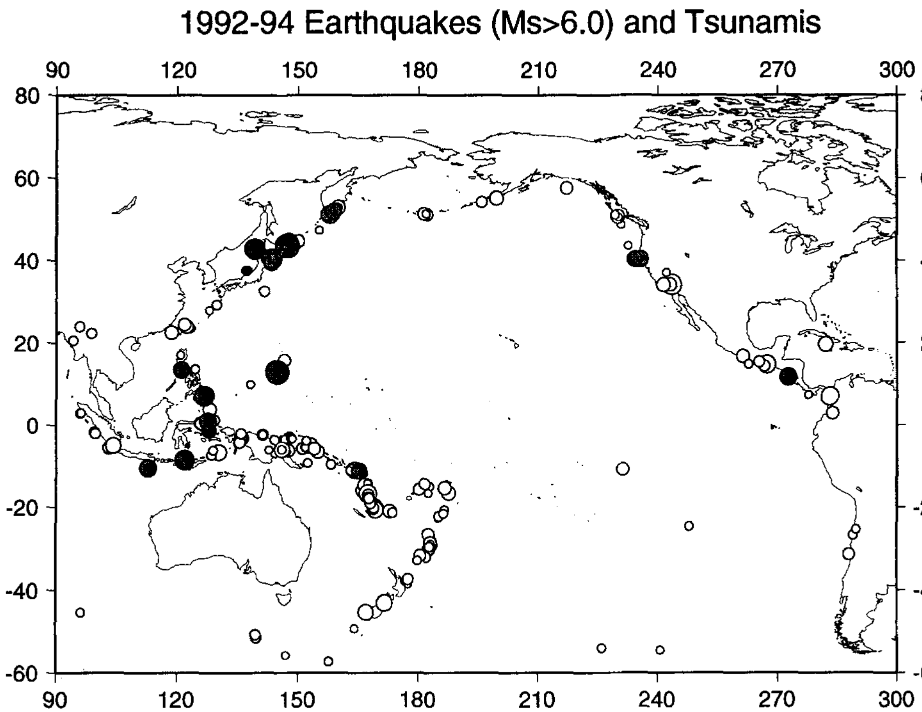

Figure 1
Epicenters of large shallow earthquakes (surface wave magnitude M_s equal or larger than 6.0) for the three-year period (1992–94) according to National Earthquake Information Center, the U.S.G.S. The size of the symbols is proportional to M_s. Tsunamigenic earthquakes are shown by shaded circles and listed in Table 1.

The Hokkaido earthquake of July 1993 produced a maximum runup height of 30 m on Okushiri Island, making it the largest tsunami in the three-year period. The fatalities which ensued from this earthquake and tsunami numbered about 230. This tsunami has been more extensively studied than any previous events. An initial report was made by the Hokkaido Tsunami Survey Group (1993). Eight follow-up papers appear in this volume.

In 1994, three hazardous tsunami events took place. The Java earthquake in June was another example of a "tsunami earthquake"; there was no damage due to ground shaking, while the maximum tsunami height was 14 m and over 200 people died. The largest earthquake in terms of surface wave magnitude (M_s 8.1) during the three-year period was the Kuril earthquake in October, 1994, although the tsunami caused little damage. The Mindoro, Philippines, earthquake in November was a strike-slip faulting, which is usually not effective in generating tsunamis. However, the runup height was as large as 7 m and about 70 people died.

Brief Summary of each Paper

This topical issue contains 26 papers treating various aspects of recent tsunamis (Table 2). They are arranged by earthquake in chronological order. SCHINDELE *et al.* report their seismological analysis of eight tsunamigenic earthquakes based on single station data at Papeete. They show that a "tsunami earthquake" can be detected in real time through their analysis. They further simulated the single station method for the eight earthquakes, and demonstrated the effectiveness of this method for real-time tsunami warning.

GONZÁLEZ *et al.* analyzed tsunami waveforms from the 1992 Cape Mendocino, California, earthquake. They demonstrated, through numerical and analytical modeling, that the maximum amplitude recorded about 3 hours after the initial onset of the tsunami was due to edge waves. THOMSON *et al.* report a rather unusual observation of the tsunami; they detected signals on the ocean cable connecting California and Hawaii and interpret them as tsunami-related signals induced by seawater movement.

Table 2

List of papers in this issue

Author(s)	Event(s)	Topic(s)
SCHINDELE *et al.*	8 tsunamis in '92–'94	Seismological Analysis
GONZÁLEZ *et al.*	'92/4 Cape Mendocino	Observation/Modeling
THOMSON *et al.*	'92/4 Cape Mendocino	Observation
KIKUCHI and KANAMORI	'92/9 Nicaragua	Seismological Analysis
SATAKE	'92/9 Nicaragua	Numerical Modeling
HATORI	central American tsunamis	Tsunami Magnitude Scale
TSUJI *et al.*	'92/12 Flores	Field Survey
SHI *et al.*	'92/12 Flores	Tsunami Deposits
HIDAYAT *et al.*	'92/12 Flores	Seismology/Modeling
IMAMURA *et al.*	'92/12 Flores	Numerical Modeling
BRIGGS *et al.*	circular island	Physical Modeling
TINTI and VANNINI	circular island	Theoretical Modeling
ABE and OKADA	'93/2 Noto-oki	Numerical Modeling
JOHNSON *et al.*	'93/6 & 11 Kamchatka	Seismological Analysis
SHUTO and MATSUTOMI	'93/7 Hokkaido	Field Survey
SHIMAMOTO *et al.*	'93/7 Hokkaido	Field Survey
SATO *et al.*	'93/7 Hokkaido	Tsunami Deposits
NISHIMURA and MIYAJI	'93/7 Hokkaido	Tsunami Deposits
ABE	'93/7 Hokkaido	Tsunami Magnitude Scale
TAKAHASHI *et al.*	'93/7 Hokkaido	Numerical Modeling
MYERS and BAPTISTA	'93/7 Hokkaido	Numerical Modeling
SATAKE and TANIOKA	'93/7 Hokkaido	Numerical Modeling
TANIOKA *et al.*	'93/8 Gaum	Seismological Analysis
TSUJI *et al.*	'94/6 Java	Field Survey
YEH *et al.*	'94/10 Shikotan	Field Survey
IMAMURA *et al.*	'94/11 Mindoro	Field Survey

The next three papers report the Nicaragua tsunami, as well as other tsunamis in central America. KIKUCHI and KANAMORI carried out detailed seismological analyses and showed that this tsunami earthquake was characterized by a slow and smooth rupture. SATAKE conducted numerical modeling of this tsunami and compared the results with the observations. He also examined the effects of various parameters on the computed tsunami waveforms and heights. HATORI examined the regional characteristics of the tsunami magnitude scale for the Nicaragua and other central American tsunamis.

The Flores earthquake generated the most fatalities in the three-year period. TSUJI *et al.* presented very detailed results of their field survey. SHI *et al.* analyzed the sand deposits from this tsunami. A detailed analysis of modern tsunami deposits is obviously very important and critical for paleotsunami studies. HIDAYAT *et al.* made seismological analyses and numerical computations of tsunamis to construct a source model of this earthquake. They illustrate that a fault model cannot explain the largest tsunami heights; an additional local source, presumably local slumping, is needed. IMAMURA *et al.* obtained similar results from their numerical modeling and also demonstrated that the extensive damage on Babi Island, a circular island, was due to reflected waves. More general research on tsunami behavior around a circular island is provided by BRIGGS *et al.*, who measured tsunami runup heights around a circular island in a physical model and TINTI and VANNINI, who studied trapping of tsunamis around circular islands through theoretical computations.

Two smaller tsunamigenic earthquakes occurred in 1993, and small amplitude tsunamis were recorded on tide gauges. ABE and OKADA modeled the source of the 1993 Noto-Hanto-oki earthquake, the smallest earthquake included in this issue (M_s 6.3), through comparisons of computed waveforms with those recorded on tide gauges. JOHNSON *et al.* compared two earthquakes that occurred in June and November, 1993 off Kamchatka. Although the surface wave magnitudes are similar, they have different characteristics and only the June event generated observable tsunamis.

The tsunami from the 1993 Hokkaido earthquake has been the most extensively studied of all the recent tsunami events. SHUTO and MATSUTOMI report their field surveys of tsunami heights along Okushiri, Hokkaido and Tohoku coasts. SHIMAMOTO *et al.* provided a very detailed survey on Okushiri Island of tsunami behavior such as flow directions, velocity, and the wave heights above ground level. SATO *et al.* examined tsunami deposits from this and a previous earthquake, and discuss the difficulties of paleotsunami studies. NISHIMURA and MIYAJI also studied tsunami deposits from the Hokkaido event and compared features with those from 1640 tsunami generated by a volcanic eruption.

ABE used his tsunami magnitude scale, which was originally developed to estimate the earthquake size from tsunami heights, to predict tsunami runup heights for 1993 earthquake; he demonstrated that a quick prediction of tsunami heights is possible. Three papers present numerical modeling results of the 1993 tsunami.

TAKAHASHI *et al.* computed tsunamis from 24 different source models and compared the calculated heights with observed runup heights and the tide gauge records. MYERS and BAPTISTA made similar computations of tsunami generation and propagation and compared their results with the observations. They employed the finite-element method, while other modelers used finite-difference methods. SATAKE and TANIOKA combined tsunami waveforms recorded on tide gauges with seismic analysis and geodetic data to estimate the slip distribution on the fault. They also discussed the free oscillation of the Japan Sea excited by the earthquake.

TANIOKA *et al.* analyzed seismic and tsunami data from the 1993 Guam earthquake, the largest earthquake ever recorded in the Mariana trench. They point out that the tide gauge record would have been beneficial to study this unique seismic event if the sampling rate were smaller.

After the above papers were submitted to this topical issue, three large tsunami events occurred and survey teams were dispatched. We include field survey reports for these "late-breaking" tsunamis. TSUJI *et al.* report on the field survey of the June 1994 Java earthquake. YEH *et al.* report on their survey on the Kuril Island following the October 1994 earthquake. Finally, IMAMURA *et al.* report on their field survey conducted after the Mindoro Island, Philippines, earthquake in November 1994.

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