ISSN 1028-334X, Doklady Earth Sciences, 2008, Vol. 419, No. 2, pp. 335–338. © Pleiades Publishing, Ltd., 2008.
Original Russian Text © B.W. Levin, V.M. Kaistrenko, A.V. Rybin, M.A. Nosov, T.K. Pinegina, N.G. Razzhigaeva, E.V. Sasorova, K.S. Ganzei, T.N. Ivel'skaya, E.A. Kravchunovskaya, S.V. Kolesov, Yu.V. Evdokimov, J. Bourgeois, B. MacInnes, B. Fitzhugh, 2008, published in Doklady Akademii Nauk, 2008, Vol. 419, No. 1, pp. 118–122.

GEOPHYSICS

Manifestations of the Tsunami on November 15, 2006, on the Central Kuril Islands and Results of the Runup Heights Modeling

Corresponding Member of the RAS B. W. Levin[a], V. M. Kaistrenko[a], A. V. Rybin[a], M. A. Nosov[b], T. K. Pinegina[c], N. G. Razzhigaeva[d], E. V. Sasorova[e], K. S. Ganzei[d], T. N. Ivel'skaya[f], E. A. Kravchunovskaya[c], S. V. Kolesov[b], Yu. V. Evdokimov[e], J. Bourgeois[g], B. MacInnes[g], and B. Fitzhugh[g]

Received September 28, 2007

DOI: 10.1134/S1028334X08020335

On November 15, 2006, a strong earthquake with magnitude M_w = 8.3 occurred in the Central Kuril segment of the Kuril–Kamchatka subduction zone. The earthquake source was located in the ocean opposite to Simushir and Matua islands. The instrumental epicenter was located approximately at a distance of 85 km from the northern edge of Simushir Island. This was the first recording of such a powerful earthquake in this region in the entire history of seismic observations.

During the period from July 1 to August 14, 2007, two marine multidisciplinary expeditions were carried out in the region of the Central Kuril Islands. One of the goals of the expeditions was investigation of the coasts of the Central Kuril Islands to measure the runup heights and inundation distances of tsunami, as well as to gather data on the geological effects of the tsunami on the coasts. The first expedition was organized by the Institute of Marine Geology and Geophysics, Far East Division of the Russian Academy of Sciences (supported by the Russian Foundation for Basic Research and the Presidium of the Far East Division of the Russian Academy of Sciences). The second expedition was supported by the NSF project *Kuril Biocomplexity.* The expeditions were carried out onboard the *Iskatel-4* (registry port Korsakov). The expedition included well-known tsunami specialists from different institutes of Russia and the United States, whose joint work at the common sites provided a high level of research.

It is worth noting that many of the authors previously visited the region of the Central Kuril Islands in the summer of 2006. Thus, a unique possibility appeared to compare the coastal regions before and after the tsunami. Furthermore, in the summer of 2006, temporal GPS stations were set on Ketoi, Matua, and Kharimkotan islands, which recorded coseismic deformations caused by the November 15, 2006, and January 13, 2007 (M_w = 8.1), earthquakes. The January event was also tsunamigenous. However, we can state on the basis of a number of pressure gauge records and obtained field data that the second tsunami was much weaker than the November one.

During 45 days of work, the participants of the expeditions investigated Urup, Simushir, Ketoi, Yankicha, and Ryponkicha islands (islands of the Ushishir group), as well as the islands of Rasshua and Matua (Fig. 1).

The highest tsunami runups were found on Matua Island, where their mean height exceeded 10 m. In Ainu Bay (southwestern part of Matua Island), the tsunami changed the coastal morphology strongly and eroded a part of marine accumulation terrace 20–30 m wide. In Dushnaya Bay (northeastern part of Simushir Island), the tsunami left numerous flood gullies on the marine terrace. In addition to erosion, accumulation was observed everywhere on the investigated coasts. Tsunami deposits are presented by marine sand, pebbles, ridges, and floating material transported shoreward. Vegetation was partly destroyed on steep slopes of the coasts, and soil was also washed out by the tsunami.

[a] *Institute of Marine Geology and Geophysics, Far Eastern Division, Russian Academy of Sciences, ul. Nauki 1b, Yuzhno-Sakhalinsk, 693022 Russia*
[b] *Moscow State University, Leninskie gory, Moscow, 119991 Russia; e-mail: rybin@imgg.ru*
[c] *Institute of Volcanology and Seismology, Far East Division, Russian Academy of Sciences, bulv. Piipa 9, 683006 Petropavlovsk-Kamchatskii, Russia*
[d] *Pacific Institute of Geography, Far East Division, Russian Academy of Sciences, ul. Radio 7, Vladivostok, 690041 Russia*
[e] *Shirshov Institute of Oceanology, Russian Academy of Sciences, Nakhimovskii pr. 36, Moscow, 117997 Russia*
[f] *Tsunami Center of the Sakhalin Hydrometeorological Service, ul. Zapadnaya 78, Yuzhno-Sakhalinsk, 693000 Russia*
[g] *University of Washington, Department of Earth and Space Sciences, Box 351310, Seattle, WA 98195 USA*

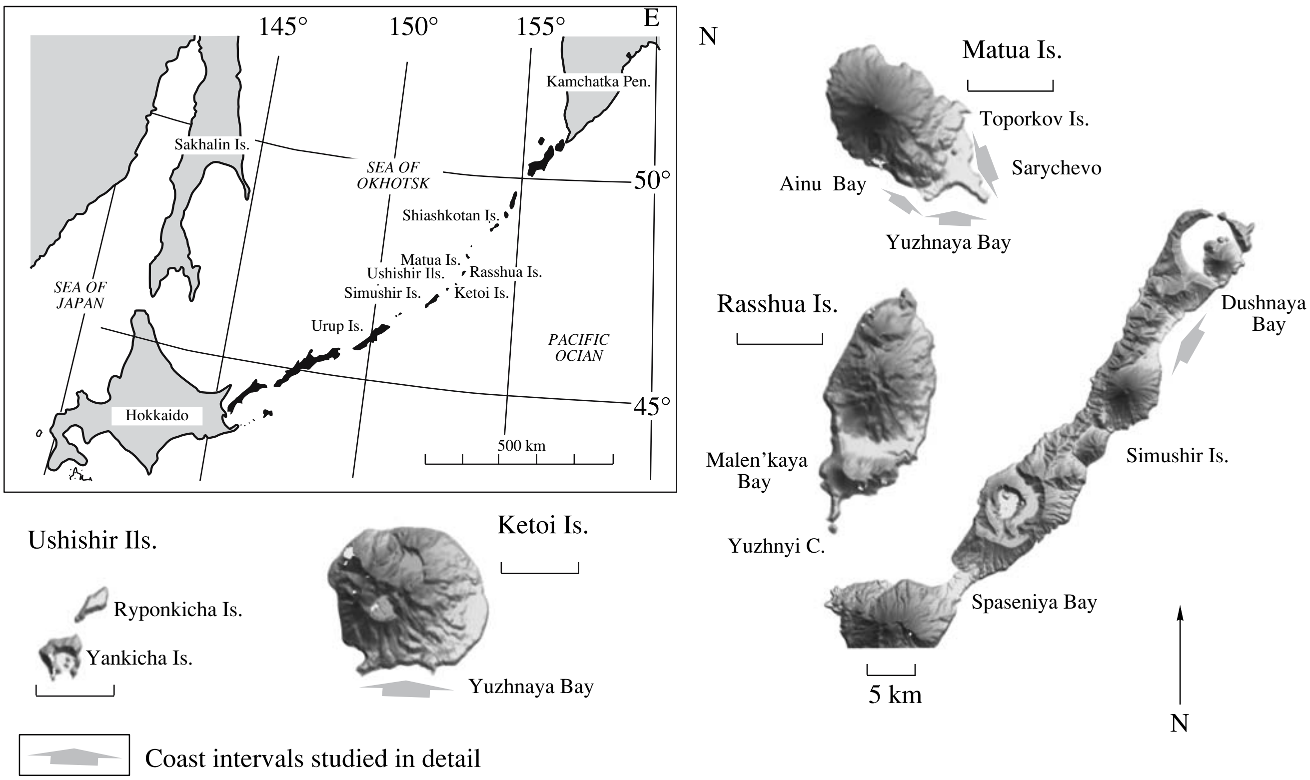

Fig. 1. Region of fieldwork and sites of studied coasts. All islands are shown in different scales; the bar length is 5 km in each case.

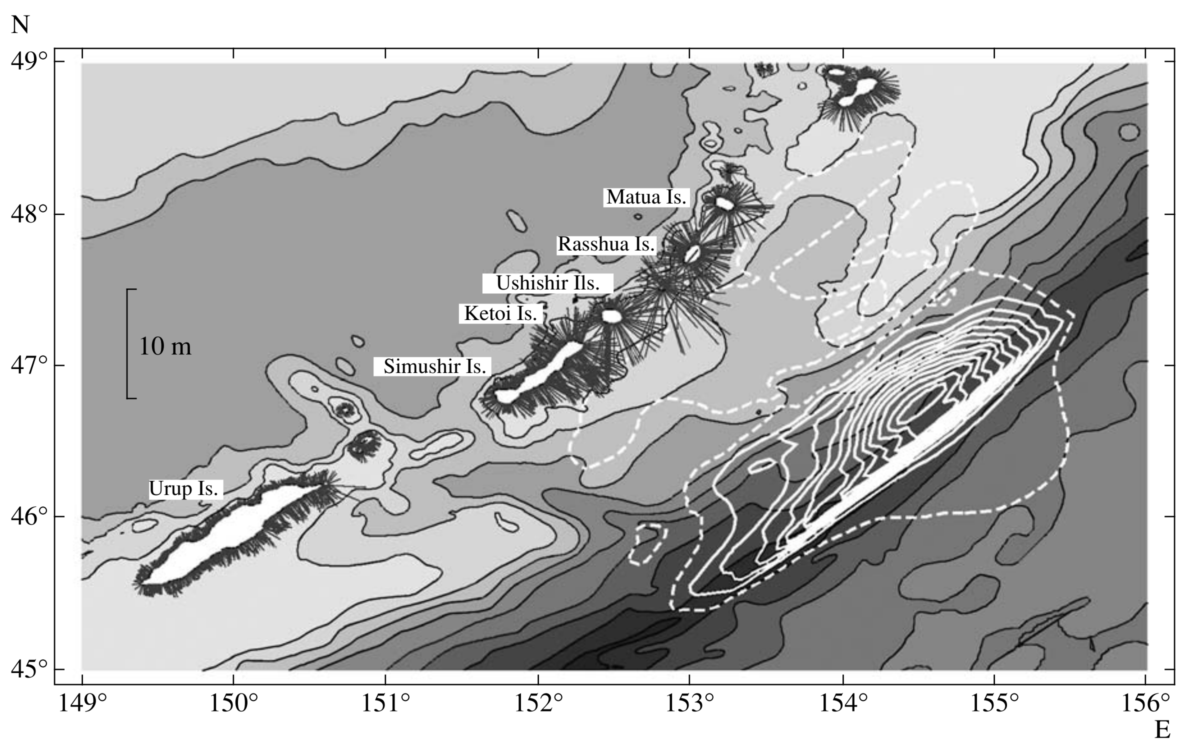

Fig. 2. Calculation area and tsunami source on November 15, 2006. The isobaths are shown with a step of 1000 m. White contour lines show vertical deformation of the bottom (solid line denotes uplift; dashed line, subsidence; contour lines are shown with a step of 0.2 m). Calculated runup heights are shown with segments oriented normal to the coastline. The segment length is proportional to the runup height. (10 m) Scale of runup height.

Runup and inundation distances of the tsunami on November 15, 2006, on the studied coasts of the Central Kuril Islands

Date of investigations (2007)	Island	Region of observations	Runup height, m	Accuracy of measurements, ±m	Inundation distance, m	Method of measurements	Number of profiles	Number of measurements of runups	Notes to measurements
August 8	Toporkov (east of Matua)	Western coast of the island	9–10	1.0	30–40	HRR	6	14	In the strait between Toporkov Island and Matua Island
August 2–3	Matua	Sarychev Coast, north	11–17	<0.5	50–60	LR, HRR	9	16	Excluding the lowest and highest runups
August 2–4	″	Sarychev Coast, central part	13–16	<0.5	50–65	LR, HRR	8	12	The same
August 7	″	Sarychev Coast, southern part	6–10	0.5	60–100	HR	9	9	The same
August 6	″	Yuzhnaya Bay, eastern part	6–8	0.5	100–140	HR	6	6	With account for the height of coastal ridges between the coast and line of maximal runup
August 6–7	″	Yuzhnaya Bay, western part	6–8	<0.5	180–220	LR + 2006	4	5	The same
August 2–5	″	Ainu Bay, south-eastern part	12–14	0.5	100–120	HR	2	2	
August 4–6	″	Ainu Bay, central part	17–20	0.5	200–400	HR, LR, HRR + 2006	8	16	
August 2–5	″	Ainu Bay, north-western part	13–14	0.5	70–120	HR	2	2	Inundation distances based on GPS measurements
August 11	Rasshua	Cape Yuzhnyi, Okhotsk side	4.2, 5	0.5	65	HR	2	2	
August 11	″	Malen'kaya Bay	9.7	0.5	50	HRS	1	1	Determination based on the final ridge of floating material and plastic
August 9	Ryponkicha	Northern edge	5.7	0.5	54	HR	1	1	
August 9	Ryponkicha	SE coast	10–11	<0.5	45–55	LR	6	19	Excluding lowest and highest runups
August 10	Yankicha	Northern edge	12.8	<0.5	50	LR	1	1	Determination based on the large amount of floating material and plastic on the coastal ridge
July 8	Ketoi	Yuzhnaya Bay, eastern part	6.5–7.5	0.5	50–60	HRR	5	34	Excluding lowest and highest runups
July 8–11	″	Yuzhnaya Bay, western part	6–9	0.5	35–65	HR	17	17	The same
July 10–27	Simushir	Dushnaya Bay, northern part	9–14	<0.5	50–90	LR	10	100	The lowest and highest runups are excluded for short and steep profiles
July 10–27	″	Dushnaya Bay, central part	7–9	<0.5	100–150	LR + 2006	13	30	The lowest and highest runups are excluded for long and flat profiles
July 10–27	″	Dushnaya Bay, southern part	12–19	<0.5	80	LR, HR	3	3	Very steep profiles
July 12–19	″	Spaseniya Bay	4.5–7	0.5	80–140	HR	7	8	Excluding lowest and highest runups

Note: (1) Part of the data has not been corrected based on the tide tables; variations in sea level in the studied regions are usually less than ±0.5 m. (2) Errors of runup and inundation distances obtained from topographic profiles are usually less than 10%; the error (sometimes correction) was estimated using the GPS along the straight line between the water edge and the point of the maximal tsunami runup. (3) Methods of measurements: (LR) level instrument and height rod; (HRR) hand level instrument, height rod, and roulette; (HRS) hand level instrument, height rod, and step measuring survey; (HR) hand level instrument and rod for measuring heights and distance; (+2006) topographic profiles of 2006 were used. (4) The number of runup heights measured between topographic profiles.

In the southeastern part of Simushir Island, the intensity of the tsunami was much smaller, while the runup heights did not exceed the elevation of storm waves in the southern part of Urup Island. They were not greater than 4–6 m and could be even smaller. The obtained results on runup and inundation of the tsunami are presented in Table 1.

After final processing, all the data gathered during the expeditions will be included in the Russian and World databases. The collected material will allow us to test and refine the numerical models used to estimate the tsunami hazard on the coasts.

Numerical modeling of the November 15, 2006, tsunami was carried out within the linear theory of long waves [1]. Linearized equations of shallow water written in the spherical coordinate system without account of the Coriolis force were reduced to a wave equation with respect to the displacement of the free sea surface. The boundary condition of full reflection was specified near the coastline at the 10 m isobath. The condition of free flow was specified at the external boundaries of the calculation area. The deviation of the free water surface from the equilibrium position was used as the initial condition, which was assumed identical to the vertical residual deformations of the bottom. The wave equation was approximated by the traditional explicit finite-difference scheme on a rectangular grid.

The displacement of the free water surface from the equilibrium position, which was assumed identical to the vertical deformations of the ocean bottom, was considered as the initial condition. Vertical deformations were calculated from the Okada formulas according to the earthquake source model developed at the U.S. Geological Survey (http://earthquake.usgs.gov/). Vertical deformations of the bottom are shown in Fig. 2 with white contour lines. The time step (0.75 s) was determined by the Courant instability condition. The calculation area extended from 149° to 156° E and from 45° to 49° N. The spatial step was 0.004° (1751 × 1001 nodes).

Reliable data on the bottom topography (bathymetry) are required to model the tsunami wave propagation, especially in shallow regions. In our calculations, we used combined bathymetry based on a 1-min digital GEBCO atlas (British Oceanographic Data Center, http://www.ngdc.noaa.gov/mgg/gebco/) and a digital model of the bottom topography with a resolution of 0.25 angular minutes based on unclassified marine navigation charts presented by the Main Administration on Navigation and Oceanography of the Russian Ministry of Defense (GUNIO).

During the expedition, an echo sounder survey was performed on the shelf of the Kuril Islands to test the quality of the information on ocean depths. The data of measurements were compared with the information from the GEBCO atlas and GUNIO digital model of bottom topography. It was found that the GEBCO atlas frequently overestimates the depths in the study region (the error reaches 100% of the actual depth and even more). The GUNIO digital model demonstrated a good correlation with the data of measurements. Since the digital model of the bottom topography does not cover the entire region needed for the calculations and only covers areas corresponding to the sheets of marine navigation charts (scale 1 : 250 000), it was necessary to create combined bathymetry.

The distribution of calculated maximum wave heights is shown in Fig. 2 with gray segments oriented normal to the coastline. The segment length is proportional to the runup height. The maximum calculated runups (up to 7.5 m) correspond to the Pacific coast of Simushir, Ketoi, Ushishir, Rasshua, and Matua islands. The Okhotsk coast of the islands is influenced by waves of notably smaller amplitude. Runup heights in the southern part of Simushir Island (Spaseniya Bay) appear much smaller as compared to its northern part (Dushnaya Bay). The wave heights on the coasts of Urup Island appear comparatively small.

We recall that the numerical model used in our work is a linear one. In addition, it calculates the runup height not at the real coast but at a hypothetical vertical wall set along the 10-m isobath. It is known that the account for nonlinearity increases the runup height but by not more than a factor of 2. The runup height also increases strongly in the case of the tsunami wave incident on a flat beach. Therefore, the calculated wave heights are 2–3 times smaller than the measured values. Taking into account this correction, we can conclude that the calculated runup heights generally correspond well to the measured values.

ACKNOWLEDGMENTS

This work was supported by the Russian Foundation for Basic Research (project nos. 07-05-10070k, 06-05-08098, 07-05-00363, 07-05-00414, and 05-05-64733), the Presidium of the Far East Division of the Russian Academy of Sciences, and the National Science Foundation (project no. ARC-0508109). The authors thank I.V. Fine for the data on the vertical deformation of the bottom in the tsunami source region.

REFERENCES

1. B. W. Levin and M. A. Nosov, *Physics of Tsunami and Similar Phenomena in the Ocean* (Yanus–K, Moscow, 2005) [in Russian].