

High-frequency seismic noise: Results of investigation in Kamchatka

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Abstract

The investigation of seismic noise in Kamchatka is carried out for the control of the medium stress condition and search of the strong earthquakes precursors. The main directions of this research are modulation of high-frequency seismic noise (HFSN, frequency range of the first tens of Hz, amplitudes about 10^{-9} – 10^{-12} m) by the Earth tides and temporal variations of HFSN parameters connected with the strong earthquake preparation. For reception of the statistically significant characteristics of HFSN and tides connection it was necessary to carry out long-term HFSN observations in points free from anthropogenous influence as far as possible. The station of HFSN observation was organized in the settlement Nachiky. The sensor is a narrow-band ($Q = 100$) piezoelectric seismometer, tuned to frequency 30 Hz. Signal envelope is recorded and analyzed. The continuous HFSN registration was begun in 1990 and proceeds till now. In 2000 the second station was established in the complex geophysical observatory “Karymshina”. The HFSN sensor is set up in the borehole at the depth of 30 m. The research of HFSN structure gave the opportunity to allocate HFSN components connected with the Earth tides. Besides it was revealed that the tidal response is not stable in time: the intervals of the tidal component existence are replaced by intervals of its absence, correlation between tide and HFSN varies in time, while tides have constant parameters. We propose a hypothesis about the connection of variations of the tidal components in HFSN data with the tectonic conditions in region, and consequently, about an opportunity to use this phenomenon for the prediction of strong earthquakes. The phase of the HFSN component connected with a tidal wave O_1 ($T = 25.8$ h) was chosen as a parameter. The choice of wave O_1 is connected with its greatest hindrance-immunity. It was shown that the stabilization of this phase is observed before earthquakes with $M > 6.0$, occurred at distances up to 250 km from the HFSN registration point, within time from several weeks to several months. Since 1996 such an analysis of the HFSN response to tides is conducted in an operative mode, and only in 1 case out of 19 the large earthquake precursor was not shown in any way.

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1. Introduction

The basic direction of the investigation of seismic noise in Kamchatka is long-term observation in several points with the purpose to investigate the seismic noise characteristics and its response to external influences (seismic noise correlation with the long-period strain processes). For this

observation the high-sensitivity equipment is used. The band-pass filtration and envelope of a high-frequency signal are applied.

The high-frequency seismic noise (HFSN) is the seismic oscillations in frequency range of the first tens of Hz with amplitudes about 10^{-9} – 10^{-12} m. The seismic noise is considered as highly informative field now; it contains the unique information about a medium, its structure and stress condition.

The seismic noise investigation is used for the control of the environment stress condition and search of the strong earthquakes precursors. The main investigated effects are the modulation of HFSN by the Earth tides

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and the temporal variations of HFSN parameters connected with the strong earthquakes preparation.

The first studies of HFSN were carried out under the management of Prof. Lev Rykunov. The proof of the HFSN endogenous origin makes up greatest complexity. The discovery of the HFSN reaction on processes deforming the Earth as a whole may be this proof. The Earth tide is one of such processes. Many researchers worked on this problem (Diakonov et al., 1990; Galperin et al., 1990), but their results are ambiguous and contradictory. The hypothesis about the HFSN endogenous origin and existence of the HFSN tidal components remained nonconfirmed for a long time.

2. HFSN registration

For reception of the statistically significant characteristics of HFSN and tides connection it was necessary to install a recording station and to carry out a long-term regime HFSN observation in a point, far away from anthropogenous handicaps as far as possible. The first station of HFSN observation was organized in the settlement Nachiki (53.1°N, 157.8°E) (Fig. 1). The continuous HFSN

registration was begun in 1990 and proceeds till the present time. The continuous data recording carried out in Nachiki station is unique and has no analogue in the world practice. Type of registration was analog till 1995, but now it is digital. Primary analysis includes extraction of the HFSN envelope and calculation of its hourly mean values. An example of HFSN envelope is in Fig. 2.

In 2000 the second similar station of HFSN registration was opened on the complex geophysical observatory “Karymshyna” (52.8°N, 158.15°E). The HFSN sensor is installed in a borehole at the depth of 30 m. It is a narrow-band ($Q = 100$) piezoelectric seismometer, which is tuned to 30 Hz. Sensitivity of the seismometric channel is about 10^{-12} m. Signal envelope is recorded and analyzed.

3. Tidal components of the HFSN

The research of HFSN structure gave an opportunity to extract HFSN components connected with wind influence, with the Earth surface warming-up, with the anthropogenous factors, and also with Earth tides. The last factor is the most important, as it confirms the endogenous origin of seismic noise. It was manifested as follows (Saltykov et al., 1997):

- (1) significant changes in the HFSN average values for various phases of tide are revealed,
- (2) periodic HFSN components with the basic tidal periods are identified,
- (3) characteristic two-week tidal trains may be extracted from HFSN data.

The tidal process consists of four phases usually following one another and reflecting the growth and fall of tide. These phases are distinguished by two indications: the sign of tidal-firming potential and the sign of the time derivative of potential. If the Earth tides affect HFSN, one may expect the behavior of the noise in the various tidal phases to be different and manifested in the mean HFSN values for each of the four phases. The observed series were divided into four parts in accordance with the phase of the gravity potential, and the mean noise value was calculated in each of four intervals. The obtained values of HFSN are presented in Fig. 3.

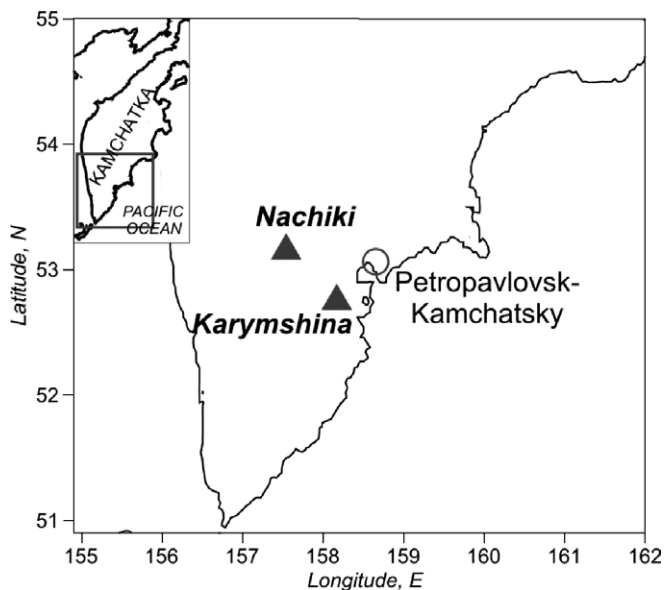


Fig. 1. The map of HFSN observation points in Kamchatka.

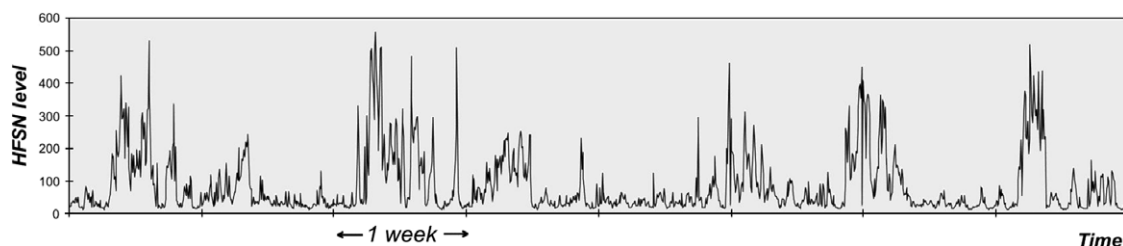


Fig. 2. Example of the HFSN envelope (hourly average) during 2 months. Unit in pm.

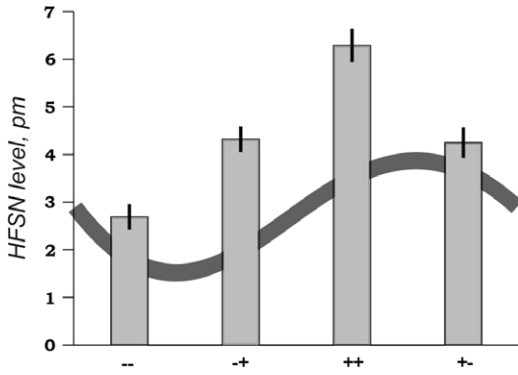


Fig. 3. Mean values of the HFSN level in the four characteristic phases of the tidal potential (registration in January–August, 1990). All data were divided into four parts in accordance with the phase of the tidal potential (increasing tide, decreasing tide, increasing ebb, decreasing ebb). The average values of the HFSN value are received for every interval. The HFSN reaches the maximum of $(6.3 \pm 0.4) \times 10^{-12}$ m in the phase of growing tide. This value is more than two times larger than the level of growing ebb – $(2.7 \pm 0.3) \times 10^{-12}$ m.

The most important criterion for the noise-tide relation may be given by the presence of harmonics, typical for tides, in the noise envelope spectrum, as is shown in Fig. 4. This makes it possible to reveal the fine structure of the HFSN tidal component. The spectrum of the tidal potential has a few maxima of different amplitude, depending on the geographic position of the observation point, that are corresponding to a fixed set of frequencies.

The periodical components with periods of the main tidal waves of diurnal (23.93 h – K_1 , 24.07 h – P_1 , 25.82 h – O_1 , 26.87 h – Q_1) and semidiurnal (12.00 h – S_2 , 12.42 h – M_2 , 12.66 h – N_2) groups are presented here. Extraction was made by synchronous stacking (Buj-Ballot scheme). Note that the whole set of the diurnal HFSN waves has

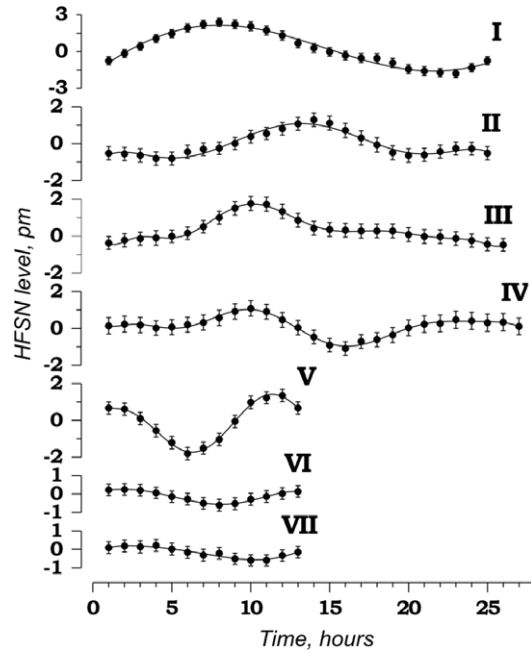


Fig. 4. Components with periods 23.93 (I), 24.07 (II), 25.82 (III), 26.87 (IV), 12.00 (V), 12.42 (VI), 12.66 (VII) hours, extracted from the 7 month HFSN data.

large amplitudes and is determined with a relative deviation smaller than that of the semidiurnal waves. This corresponds to the ratio of diurnal and semidiurnal waves in the tidal potential.

Typical two-weekly tide trains, which are due to the interference of O_1 - and K_1 -waves (periods 25.8 and 23.9 h), are extracted from the HFSN level, as is illustrated in Fig. 5. All maxima of the envelope of the interference between diurnal HFSN harmonics correlate with the max-

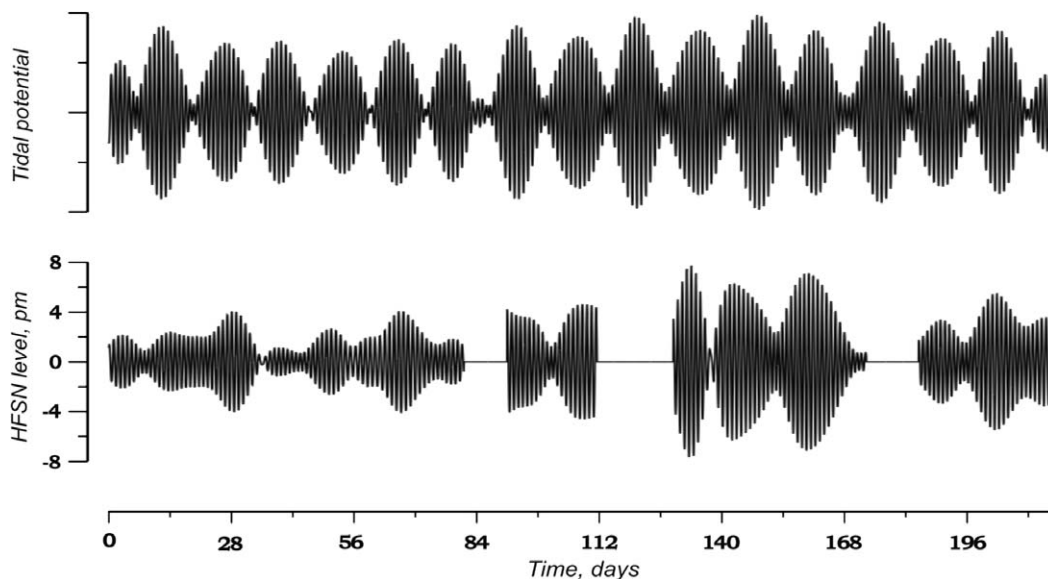


Fig. 5. Filtered “diurnal” oscillations of the tidal potential (top) and the HFSN level (bottom).

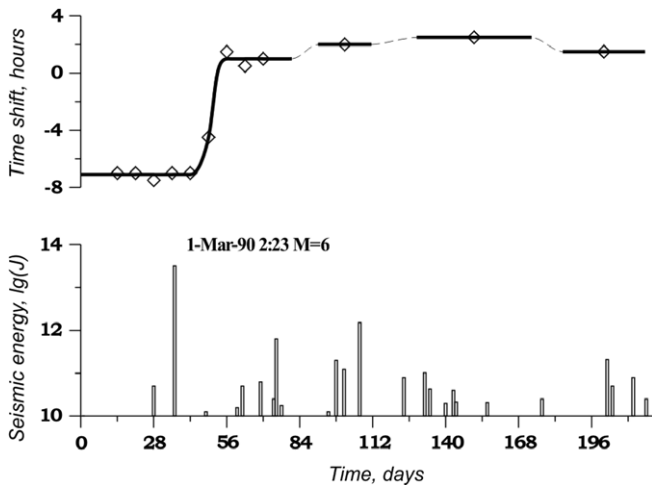


Fig. 6. Comparison of change in time-shift of maximum of correlation function between real HFSN and the model of tidal noise (top) and energy of South-Kamchatka earthquakes (bottom).

ima of the tidal trains. Tendencies in variations of the HFSN and tidal potential amplitudes are the same: amplitude maximum – third group, amplitude minimum – first group. The gaps between the oscillations correspond to the absence of HFSN data due to technical reasons.

For the first part of uninterrupted registration the time shift of the maximum of the correlation function was calculated in a sliding window of 28 days with steps of 7 days (see Fig. 6). Earthquakes with epicentral distance less than 250 km from the registration point were considered. Time of the abrupt change of time shift corresponds to the strongest earthquake during the period of the HFSN observation – March 1, 1990, $M = 6.0$, epicentral distance 150 km (when we say about correspondence, we take into account the value of sliding window).

Besides it was revealed that the tidal response is not stable in time: intervals of the tide components existence are replaced by intervals of absence, the amplitude-phase relation between tide and HFSN varies, though tides have constant-in-time parameters. The authors put forward a hypothesis on the connection of variations of the tidal components in HFSN data with the tectonic conditions in region, and consequently on the opportunity to use this phenomenon for the forecast of strong earthquakes.

4. Monitoring of tidal component parameters

The phase of the HFSN component connected with a tidal wave O_1 ($T = 25.8$ h) was chosen as a parameter (Rykunov et al., 1998; Saltykov et al., 1998). The choice of wave O_1 is connected with its greatest hindrance-immunity. It was shown in Fig. 8 that the stabilization of this phase is observed before earthquakes with $M > 6.0$, that occurred at distances up to 250 km from the HFSN registration point (Fig. 7, and Table 1), within several weeks. For 1992–1995 the medium state control by the HFSN

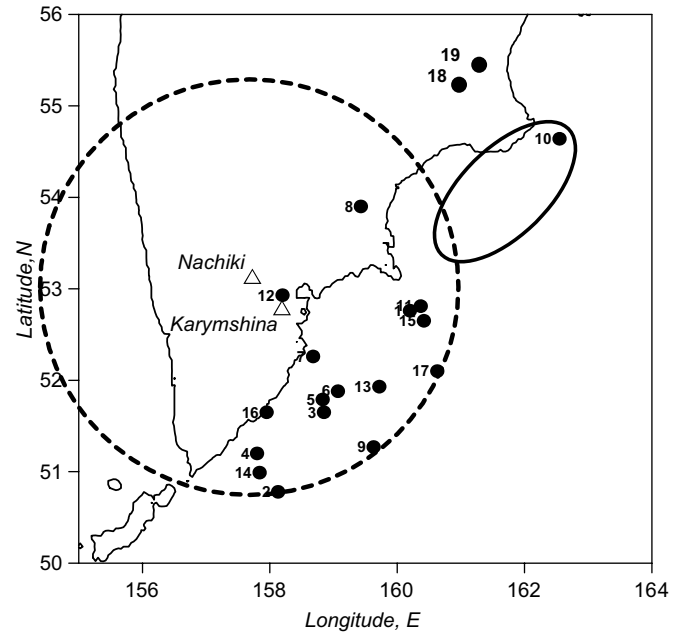


Fig. 7. Map of the Southern Kamchatka with marked epicenters of large earthquakes 1992–2004 (magnitude $M \geq 6.0$, epicentral distance $D < 250$ km). Earthquake numbering is the same as in the table. The ellipse marks the source of Kronotsky earthquake December 5, 1997. 250-km zone is limited by the dotted line.

use was carried out as a retrospective analysis. Since 1996 such analysis of the HFSN response to tides is conducted in an operative mode, and only in 1 case out of 19 the strong earthquake precursor was not shown in any way. The estimations of the seismic environment in Kamchatka region obtained by the analysis of HFSN data from Nachiky and Karymshyna stations, are weekly communicated to the Kamchatkan Branch of the Federal Center of Earthquakes Forecasting.

The phase is calculated in the following way: periodical component with O_1 -wave period is extracted from the HFSN data in the sliding 28-day window by the least-squares method. Theoretical value of tidal phase is calculated by means of known equations of the static theory of the Earth tides. The obtained value of the phase shift corresponds to the end of temporal window.

5. Conclusion

Long-term registration of the HFSN is carried out in Kamchatka for the control of the large earthquakes preparation process.

On the basis of long-term investigation of the HFSN the present method seems to be sufficiently promising for the control of the medium stress conditions and for intermediate prediction of large earthquakes.

Now parameters of the HFSN are used for large earthquakes prediction in near real time by Kamchatkan Center of Earthquakes Forecasting.

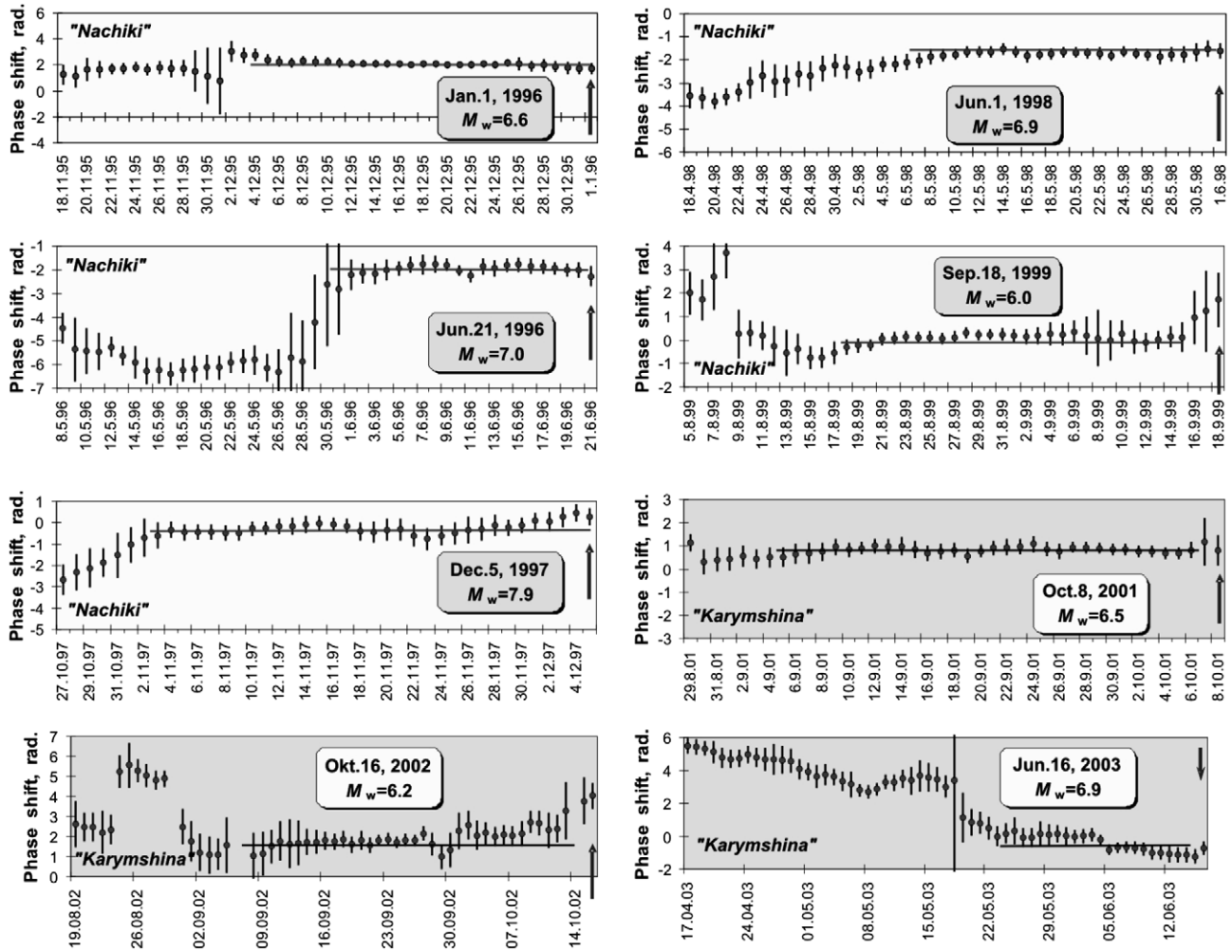


Fig. 8. Variations of the phase of the HFSN component connected with tidal wave O_1 action before strong Kamchatkan earthquakes ($M \geq 6.0$, $D < 250$ km). Horizontal lines show the stabilization of this phase. Arrows point the large earthquakes time.

Table 1
Catalogue of strong earthquakes on Southern Kamchatka in 1992–2004

N	Date	Time	Latitude, °N	Longitude, °E	H , km	M_w	M_{psp}	M_s
1	1992-03-02	12:29	52.76	160.20	20		6.8	7.1
2	1992-07-13	15:34	50.78	158.13	20		5.8	5.9
3	1992-12-19	12:14	51.65	158.85	40		6.1	5.6
4	1993-06-08	13:03	51.20	157.80	40	7.1	6.5	7.4
5	1993-11-13	01:18	51.79	158.83	40	7.0	6.5	7.1
6	1994-02-14	11:14	51.88	159.07	25	5.9	6.4	
7	1994-08-02	14:17	52.26	158.68	140	5.9	6.2	
8	1996-01-01	09:57	53.90	159.43	0	6.6	6.5	7.0
9	1996-06-21	13:57	51.27	159.63	3	7.0		
10	1997-12-05	11:26	54.64	162.55	10	7.9		
11	1998-06-01	05:34	52.81	160.37	31	6.9		
12	1998-10-31	14:03	52.93	158.20	167	5.5		
13	1999-03-08	12:25	51.93	159.72	7	7.0		
14	1999-09-18	21:28	50.99	157.84	40	6.0		
15	2001-10-08	18:14	52.65	160.42	26	6.5		
16	2002-10-16	10:12	51.65	157.95	113	6.2		
17	2003-03-15	19:41	52.10	160.63	5	6.0		
18	2003-06-16	22:08	55.30	160.33	190	6.9		
19	2004-06-10	15:19	55.55	160.67	198	6.9		

Earthquake coordinates from the Kamchatkan Branch of Geophysical Survey, RAS (Petropavlovsk-Kamchatsky, Russia), magnitudes – from Geophysical Service, RAS (Obninsk, Russia) and National Earthquake Information Center (USA). Strong aftershocks were removed from this table.

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