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Intermediate-Term Precursors of Large ($M \geq 6.6$) Kamchatka Earthquakes for the Period from 1987 to 2004: A Retrospective Assessment of Their Information Content for Prediction

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Abstract—Data from the literature were used to systematize intermediate-term (with advance times of 1 month to ~2.5 years) precursors to the $M \geq 6.6$ Kamchatka earthquakes of 1987–2004. The precursors were observed as changes in seismological, geodetic, geophysical, water-level, and hydrochemical parameters. Retrospective assessment of the information content in these intermediate-term precursors for earthquake prediction is in progress. The focus was on estimating the occurrence times of various precursors as functions of earthquake parameters (magnitude M, hypocentral distance R, and epicenter location). In the conditions of the Kamchatka observing network, precursors can be identified by a combination of methods, mostly before $M \sim 7$ earthquakes or greater south of the Kronotskii Peninsula, for which $M/\log R \geq 3$. It is shown that the relative proportion of earthquakes for which precursors have been identified in the observations considered here is 0.43–0.86.

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INTRODUCTION

Multidisciplinary geophysical observations have been conducted in Kamchatka for several decades in the search for precursors to large earthquakes. Detailed seismological observations have been conducted since 1961 and geodimeter, hydrochemical, and water-level observations have been conducted since the late 1970s. In the 1990s, the observations continued to grow in diversity, but most observation sites were concentrated in the Petropavlovsk Test Area (Fig. 1). At present the work in the test area is concerned with the search for earthquake precursors using approximately 20 methods [3]. The assessment of earthquake hazard in the form of long-term, intermediate-term, and short-term forecasts is carried out by specialized expert councils on earthquake prediction based on results from multidisciplinary geophysical monitoring [3, 6, 7]. Nevertheless, the information on the precursors that are being identified in real time is largely nonpublic, while the amount of data on the precursors of large Kamchatka earthquakes for most kinds of observation that is generally accessible is rather limited. As well, most published studies that deal with the precursors to Kamchatka earthquakes that have been identified in various fields of the Earth consider the relationships of precursors to comparatively small seismic events, with magnitudes 5–6 at the most, but the prediction of such events is mostly of academic interest, since such earthquakes do not cause catastrophic impacts on the population and the environment.

At the same time, there are several precursors that are observed over time intervals of a few years to a few tens of days before large ($M \geq 6.6$) Kamchatka earthquakes in 1987–2004, showing that the earthquakes are amenable to intermediate-term prediction, whose practical significance is in estimating the time of earthquake occurrence with advance times that allow the necessary preventive scientific and social measures to be taken. It is assumed that intermediate-term earthquake prediction can be developed by examining the precursors seen in various terrestrial fields, whose times of manifestation and amplitudes are connected through empirical relationships with the magnitude and location of a future earthquake [15]. Up to now however, such relationships for individual methods have either not been determined or are of limited use for practical earthquake prediction work.

The present study uses literature data to carry out a retrospective assessment of the information content for intermediate-term precursors contained in changes of several seismological, geodetic, geophysical, and hydrologic parameters for the prediction of large ($M \geq 6.6$) Kamchatka earthquakes that occurred during the period 1987–2004 and were accompanied by shaking in continental areas of Kamchatka with intensities of at least IV–VII on the MSK-64 scale. The choice of the precursors we consider was governed by the existence of research publications that are available to the general public and that report detailed data on the precursors identified during periods of many years, with a description of the pre-

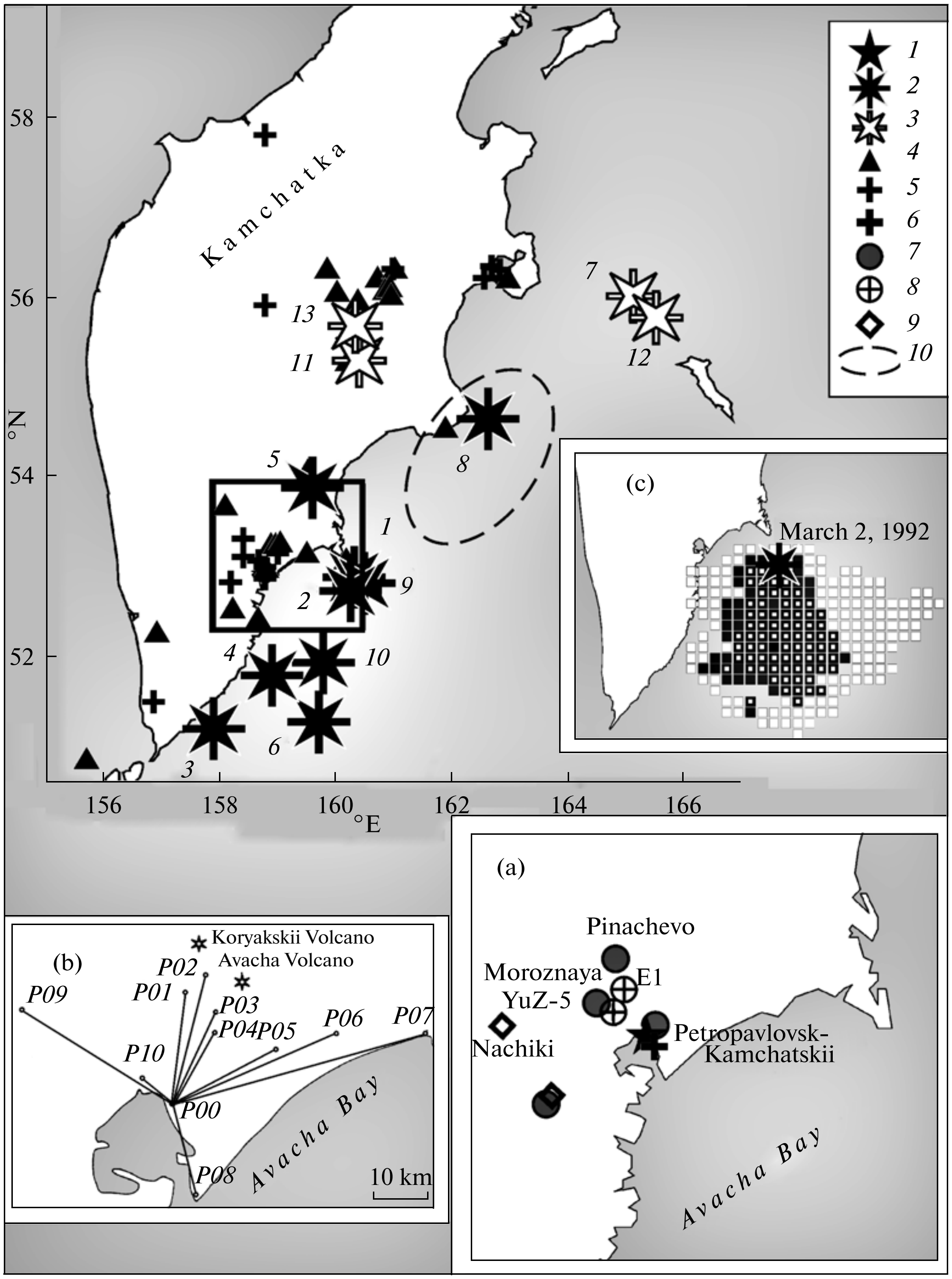

Fig. 1. Map of 1987–2004 $M \geq 6.6$ earthquake epicenters (identification numbers of the earthquakes correspond to those in Table 1) and observation sites (the square encloses the Petropavlovsk Test Area). Insets: (a) the Petropavlovsk Test Area and observation sites, (b) geodimeter lines measured from the Mishennaya Observatory [1], (c) map position of the RTL anomaly preceding the March 2, 1992 earthquake [9].

(*1*) data acquisition and processing center in the town of Petropavlovsk-Kamchatskii (a), (*2*) earthquakes with $M/\log R \geq 3$, (*3*) earthquakes with $M/\log R < 3$, (*4*) radio telemetry seismic stations, (*5*) GPS sites, (*6*) Mishennaya Observatory (a), (*7*) observation sites for monitoring groundwater chemical composition (a), (*8*) observation wells where water-level variations are measured (a), (*9*) sites where HFSN is observed (a), (*10*) rupture zone of the Kronotskii earthquake (December 5, 1997, M_W 7.8).

cursors and estimates of the times the precursors were observed before specific earthquakes. In order to estimate the information content of precursors, we systematized the precursor data and analyzed the relationship between the number of precursors, the time of precursor appearance, and earthquake parameters: magnitude M and the $M/\log R$ ratio, where R is the hypocentral distance to the town of Petropavlovsk-Kamchatskii (km) situated at the

Table 1. Data on $M \geq 6.6$ earthquakes occurring in 1987–2004 (as reported by the KB GS RAS, GS RAS, and NEIC)

Row #	Date	Time, h:min:s	Latitude, deg. N	Longitude, deg. E	Depth, km	Class K_S	R, km	M_W NEIC	$M/\log R$	Intensity on MSK-64 scale
1	1987.10.06	20:11:36	52.86	160.23	33	14.1	120	6.6**	3.17	4–5 PET
2	1992.03.02	12:29:39	52.76	160.20	20	14.6	110	6.9	3.38	5–6 PET
3	1993.06.08	13:03:37	51.20	157.80	40	15.0	210	7.5	3.23	5 PET
4	1993.11.13	01:18:07	51.79	158.83	40	14.6	140	7.0**	3.27	5–6 PET
5	1996.01.01	09:57:46	53.88	159.44	0	14.3	110	6.9**	3.38	4–5 PET
6	1996.06.21	13:57:06	51.27	159.63	2	13.9	210	7.0	3.01	3–5 PET
7	1996.07.16	03:48:25	56.00	165.05	40	13.4	540	6.6	2.42	
8	1997.12.05	11:26:51	54.64	162.55	10	15.5	200*	7.8	3.39	5–6 PET
9	1998.06.01	05:34:03	52.81	160.37	31	13.8	120	6.9	3.32	4–5 PET
10	1999.03.08	12:25:43	51.93	159.72	7	14.3	140	7.0	3.26	4–6 PET
11	2003.06.16	22:08:02	55.30	160.34	190	14.7	340	6.9	2.73	3–4 PET
12	2003.12.05	21:26:14	55.78	165.43	29	14.8	540	6.7	2.45	2–3 PET
13	2004.06.10	15:19:55	55.68	160.25	208	14.9	380	6.9	2.68	3–4 PET

Notes: * Distance to the center of the earthquake source zone, ** M_S magnitude as reported by GS RAS, Obninsk, PET stands for the town of Petropavlovsk-Kamchatskii.

center of the Petropavlovsk Test Area. The quantity $M/\log R$ is used as a parameter that characterizes the intensity of precursory processes, with due account of the distance between the epicenter and the center of the test area.

DATA SET AND METHODS OF STUDY

We consider the precursors of 13 $M = 6.6$–7.8 earthquakes that occurred in 1987–2004. The epicenters and the basic data can be found in Fig. 1 and in Table 1. Twelve of the thirteen are interplate events that occurred in the crust and upper mantle during interaction between the Pacific plate and the continental Sea-of-Okhotsk and Bering Sea microplates. Such earthquakes are confined to the volume of the dipping seismic zone that plunges under the continent. Earthquake 5 (Table 1) occurred in the continental volcanic area and was accompanied by an eruption on Karymskii Volcano and an underwater eruption in the Akademii Nauk caldera.

This study is based on publications dealing with five kinds of observation (geodimeter measurements [4, 11], hydrogeochemical [8, 18, 19], water-level observations [5], the RTL method [9, 16, 17], and the HFSN (high-frequency seismic noise) method [10, 12, 13, 14]).

Our chosen quantitative parameter for precursory anomalies was the time (duration) of their appearance T; this was estimated as the length of time between the start of an anomaly and the earthquake occurrence time.

Based on geodimeter measurements of the lengths of lines conducted from the Mishennaya Observatory in 1979–1998 (Figs. 1a, 1b), the precursory anomaly was taken to be a baylike shortening, which indicates the horizontal contraction of the test area [1]. Such contraction bays are related by the authors of [4, 11] to the precursory periods of earthquakes 1, 2, and 8 (Table 1). The duration of this precursor varied between 8–9 and 24 months.

Based on hydrogeochemical observations, the characteristic precursor was taken to be a decreased concentration of chlorine ions in the water of well GK-1 at the Pinachevo station (Fig. 1a). The authors of [8, 18, 19] estimate that the duration of this precursor before six large Kamchatka earthquakes of 1987–2003 was 1.5–9 months.

Based on observations of water level in well E1 (Fig. 1a) from 1987 to March 1998, the precursor was taken to be a water-level drop at a rate of at least 0.06 cm/day during a few weeks to a few months [5]. The duration of this precursor before six large earthquakes of the seven that occurred during the period of continuous observation varied between 5 and 36 weeks.

Based on the variations of the RTL predictive parameter, the precursor is taken to be its baylike change [9, 16, 17]. The RTL parameter is calculated from data of the Kamchatka regional earthquake catalog, which is routinely produced by the Kamchatka Branch of the Geophysical Service (KB GS) of the Russian Academy of Sciences (RAS). Calculations of the RTL parameter are based on data for earthquakes with energy classes $13 \geq K \geq 9$ at depths of 30–100 km in areas with a radius as great as 100 km from the epicenters of earthquakes 1 through 13 (Table 1). A decrease and a subsequent increase in the RTL parameter indicate the successive alternation of qui-

Table 2. Composition and time of appearance of precursors before $M \geq 6.6$ earthquakes (Table 1)

Row #	Earthquake date	Precursor duration by methods considered T					
		RTL method, months		Water-level drop in well E1 [5], weeks	HFSN method, Nachiki station [10, 12–14], days	Variation in concentration of chlorine ions in well GK-1 at Pinachevo station [8, 18, 19], in months	Geodimeter observations [3, 10], in months
		after [16, 17]	after [9]				
1	1987.10.06		5	5		6.5–7	8–9
2	1992.03.02	~5	6	9.5	?	9	8–9
3	1993.06.08	~13	10	36	34	1.5	
4	1993.11.13	~12	15	12	?	1.5	
5	1996.01.01		14	n.d.	28	3	
6	1996.06.21		11	14	23		
7	1996.07.16		6				
8	1997.12.05	~31	24	?	~35	5–6	~24
9	1998.06.01				25		
10	1999.03.08		27				
11	2003.06.16				41		
12	2003.12.05						
13	2004.06.10			~7	48		

Note: ? precursor has been identified, but there are no data on its duration; n.d. means "no data."

escences and foreshock activations in the source area of the future earthquake.

The duration of precursor occurrence based on the RTL parameter was estimated from the data of two sources. Sobolev [16, 17] gives calculations of the RTL parameter until the 1990s. The anomalies that were identified are only compared with the larger earthquakes (2–4 and 8 in Table 1). Sobolev's estimates [16, 17] give $M \geq 7.0$ for these earthquakes.

Kravchenko [9] gives maps of the spatial positions and estimated durations of the RTL anomalies for the depth range 30–100 km prior to the $M \geq 6.0$ Kamchatka earthquakes of 1980–2003. The present study estimates the duration of that precursor (5–31 months) from the time that the RTL parameter reaches its minimum until the occurrence time of the earthquake [9, 16, 17]. The relationship between the time of precursor appearance T and earthquake parameters was estimated for each of the two options separately. When estimating the number of precursors N before earthquakes (Table 1) with the RTL parameter taken into account, we used data from both sources, i.e., the method was considered as a single one. Since both options for calculating the RTL parameter yield consistent results, this approach is justified.

The HFSN method is based on the study of variations in the phase of the high- frequency seismic noise component related to the action of the O_1 tidal wave [10, 12–14]. A characteristic feature for the precursory process of a large earthquake is phase stabilization at some level during at least 3 weeks. For the earthquakes we considered here (Table 1) the precursor duration is 23 to 48 days.

For each earthquake we determined the content and time of precursor appearance (T) using the five methods considered here (Table 2). Figures 1c and 2 give one example of precursory anomaly appearance before the March 2, 1992, $M_W = 6.9$ earthquake. Before that event the duration of precursory variations by the methods under consideration varied between 1 and 9 months. As the occurrence time of the earthquake approached, the number of methods that revealed precursors did so too; as well, the number of observation sites where the anomalies were recorded was gradually increasing and reached the maximum approximately a month before the event. The best-pronounced anomalies were seen in variations of the concentrations of components in the chemical composition of underground water and gases in the flowing well GK-1 at the Pinachevo station and well 1 at the Moroznaya station (Fig. 1a) [8].

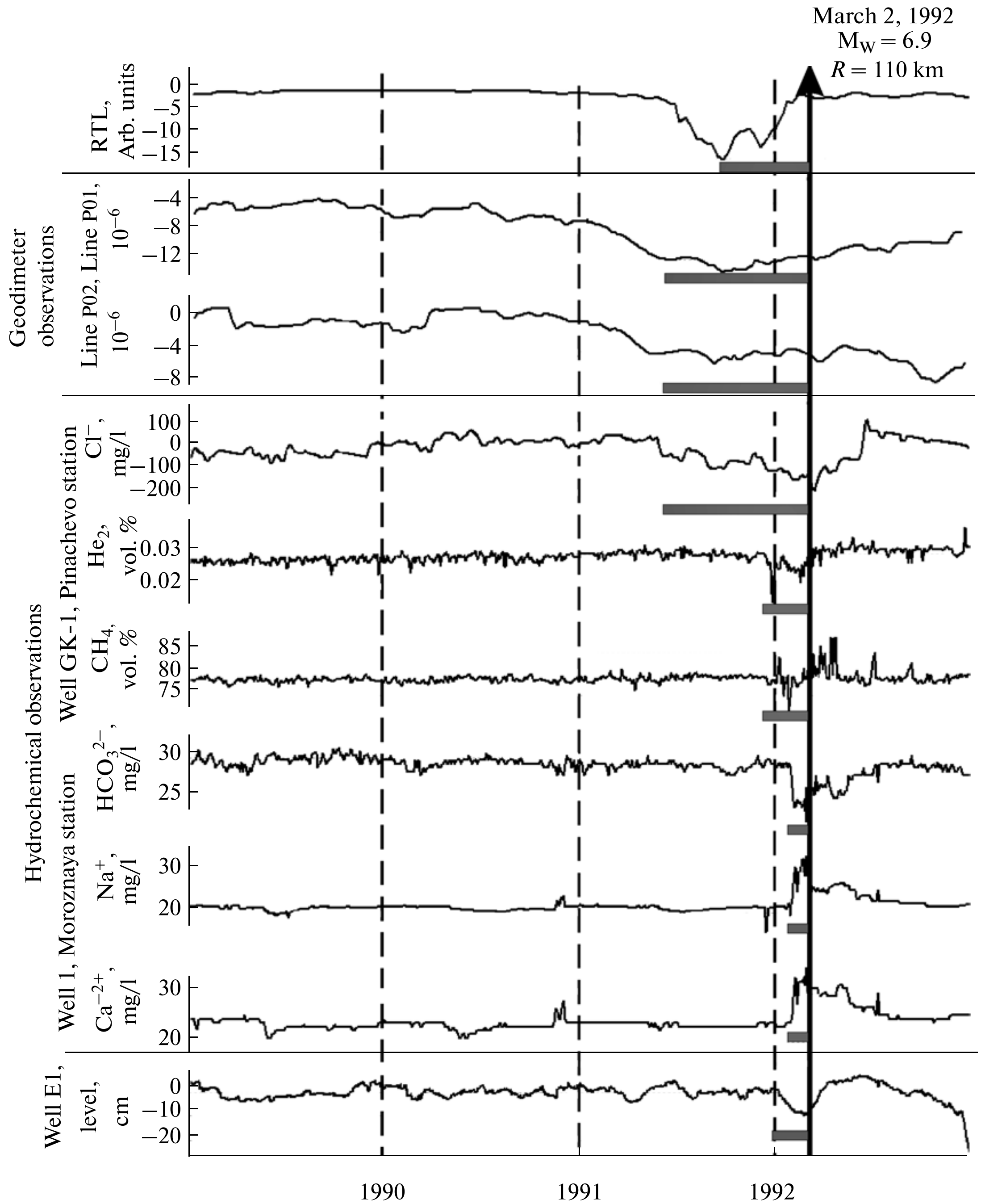

Fig. 2. Observed precursors before the March 2, 1992 M_W = 6.9 earthquake; R is the distance to the Test Area center. Grey horizontal bars mark the intervals of precursor observation.

For earthquakes with a parameter measuring the intensity of seismic excitation $M/\log R \geq 3$, the number of methods for which precursors were seen varies between three and five. The only exceptions are two events, June 1, 1998 and March 8, 1999 (Table 1). The first of these was preceded by a precursor based on HFSN data only and the second by that identified by the RTL parameter (Table 2). These two events occurred 6 and 15 months after the great Kronotskii earthquake of December 5, 1997. For this reason it may be supposed that the precursory processes occurred upon the background of postseismic variation.

For earthquakes where the parameter of intensity of seismic excitation $M/\log R < 3$ the number of methods that revealed precursors varied between zero and two. It should be noted that all these earthquakes occurred north

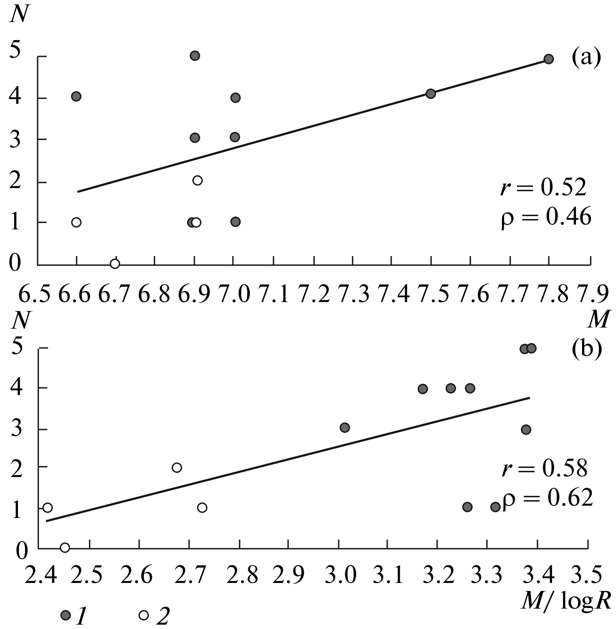

Fig. 3. The number of precursors N detected by the methods considered here as a function of earthquake parameters M (a) and $M/\log R$ (b): (*1*) earthquakes with $M/\log R \geq 3$, (*2*) earthquakes with $M/\log R < 3$. r is sampling correlation coefficient and ρ Spearman rank correlation coefficient.

of 55.0° N (Fig. 1). Consequently, the decrease in the intensity of seismic excitation $M/\log R$ was largely caused by the comparatively great epicentral distances of these earthquakes ($R = 340$–540 km).

Figures 3–5 show diagrams that characterize the relationship between precursor parameters (the number of methods N that revealed precursory anomalies and precursor time T) and earthquake parameters (magnitude M and the quantity $M/\log R$). The diagrams in Figs. 3–5 are based on data from Table 2.

The correlation analyses of the T–M and T–$M/\log R$ relations for four methods are given in Table 3. The geodimeter method was not considered because of the few precursors identified (k = 3). The quantities that were used to characterize the statistical relationship between precursor time and earthquake parameters were chosen to be the sampling correlation coefficient r (whenever its value was equal to or greater than $\geq|\pm 0.5|$) and the Spearman rank correlation coefficient ρ with statistical significance $P \leq 0.05$ for sample sizes $k \geq 4$ [2].

Considering that some kinds of observation have data for a limited time interval that is shorter than the period 1987–2004, we also used the ratio $s = n/m$ to characterize the relationship between earthquakes and precursors, where n is the number of earthquakes with precursors observed prior to it and m is the number of earthquakes that occurred during the period of observation considered here (Table 4).

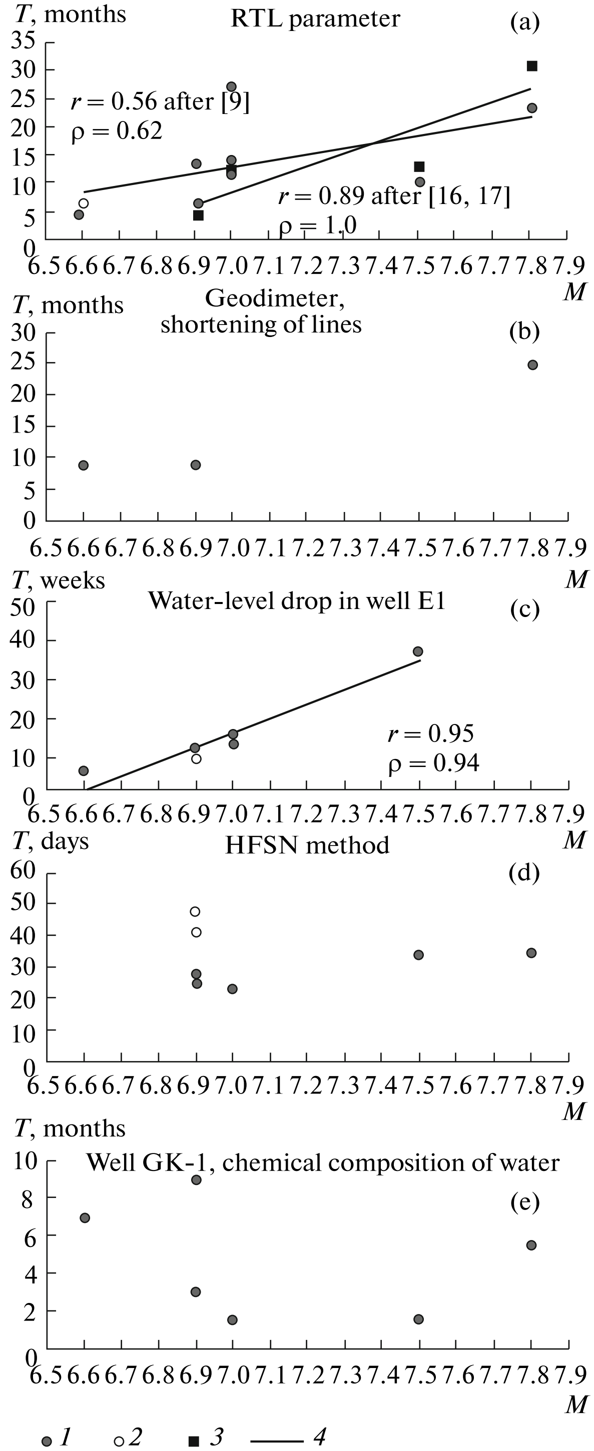

Fig. 4. Precursor time T as a function of earthquake magnitude M: (a) the RTL parameter based on low-magnitude events, (b) shortening of geodimeter lines, (c) water-level drop in well E1, (d) O_1 phase stabilization in HFSN changes, (e) drop in chlorine concentration in well GK-1. (*1*) earthquakes with $M/\log R \geq 3$, (*2*) earthquakes with $M/\log R < 3$ (a, c, d), (*3*) $M \geq 7$ earthquakes (after [16, 17], (*4*) relationship trend for sampling correlation coefficient $r \geq 0.5$ and the Spearman rank correlation coefficient ρ at significance levels $P \leq 0.05$ (a, c).

RESULTS AND DISCUSSION

Figure 3 shows diagrams that characterize the relationship between the number of precursors N and earthquake parameters: magnitude M and the quantity $M/\log R$. Comparison of Figs. 3a and 3b shows that the use of the $M/\log R$ parameter, which incorporates the distance between earthquakes and the center of the Petropavlovsk Test Area, somewhat enhances the relationship and increases the correlation coefficient r from 0.52 to 0.68, with the Spearman rank correlation coefficient ρ increasing from 0.46 to 0.62. The tendency towards a direct statistical relationship between the number of precursors N and the earthquake parameters M and $M/\log R$ indicates that the number of precursors N carries sufficient information in intermediate-term terms for predicting earthquakes that are larger and relatively "closer" to the Petropavlovsk Test Area.

An analysis of the T–M relations for individual methods indicates a direct relationship between precursor time T and the magnitude of the subsequent earthquake, as predicted by the RTL parameter, which is based on low seismicity data (Fig. 4a), as well as for water-level drops in well E1 (Fig. 4c). At the same time, there is no relationship between the times of phase stabilization for the O_1 component in HFSN changes and in decreases of chlorine concentration in well GK-1 and the magnitudes of subsequent earthquakes (Figs. 4d, 4e). This shows that the precursor time for most of the precursors considered here is not informative for estimating the magnitude of the subsequent earthquake.

The use of the $M/\log R$ parameter, which incorporates the distance of the earthquakes to the center of the Petropavlovsk Test Area and to the relevant observation sites, does not produce any significant improvement in the statistical relationship between the precursor times for individual methods and the parameter in question. Its use reveals an inverse relationship between the duration of O_1 phase stabilization in HFSN changes and the $M/\log R$ parameter (Fig. 5c); no relationships between the precursor times for the three other kinds of observation and the parameter in question were detected (Figs. 5a, 5b, and 5d). This result indicates that the use of the precursor duration parameter based on individual methods T cannot furnish a simultaneous prediction of earthquake magnitude and distance to the center of the Petropavlovsk Test Area at present.

The relationship of precursors in the variation of observable parameters and the Kamchatka earthquakes (Table 1) that occurred during the observation time is characterized by values of $s = 0.38$–0.75 (Table 4), that is, precursors appeared before 38–75% of the large seismic events.

If we consider only the larger earthquakes that occurred comparatively close to the Petropavlovsk Test Area ($M/\log R \geq 3$, $R = 110$–210 km) (Fig. 1), we find that the relationship between precursors and earthquakes is somewhat improved ($s' = 0.43$–0.86). This indicates that the observing network in the Petropavlovsk Test Area is mostly oriented toward detecting the precursors of large earthquakes within that fragment of the Kamchatka Benioff zone, which includes the southern Kronotskii Bay, the Avacha Bay, and southern Kamchatka (about 51°–54°N).

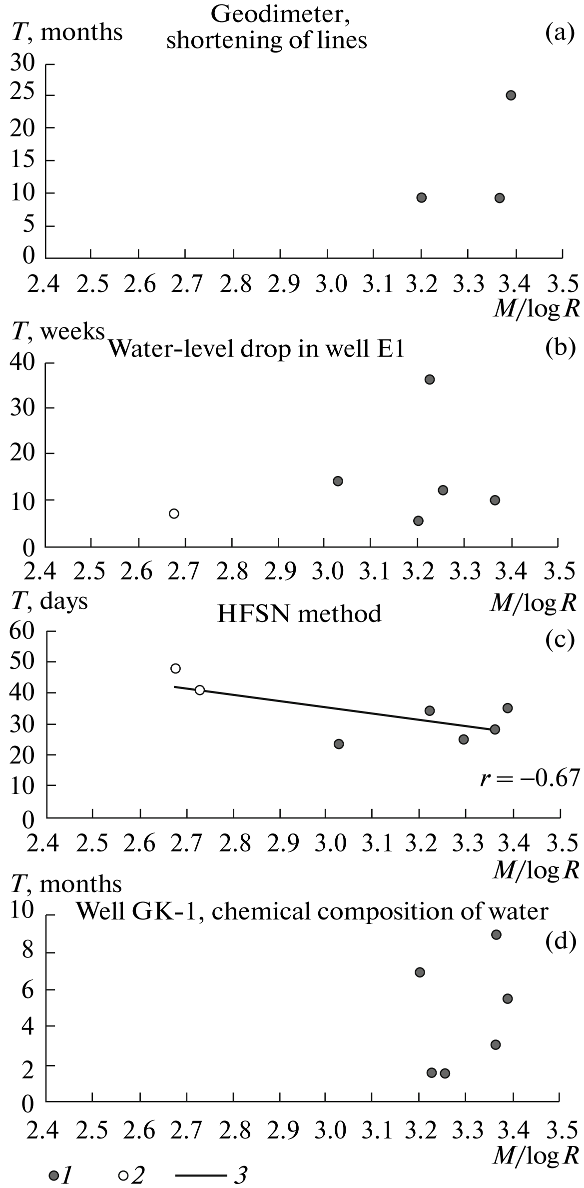

Fig. 5. Precursor time T as a function of the parameter $M/\log R$: (a) shortening of geodimeter lines, (b) water-level drop in well E1, (c) O_1 phase stabilization in HFSN changes, (d) drop in chlorine concentration in well GK-1. (*1*) earthquakes with $M/\log R \geq 3$, (*2*) earthquakes with $M/\log R < 3$ (b, c), (*3*) relationship trend for sampling correlation coefficient $r \geq 0.5$ and Spearman rank correlation coefficient ρ at significance level $p \leq 0.05$ (c).

Table 3. Correlation analysis of how precursor duration T depends on earthquake parameters M and $M/\log R$

		RTL method after [9]	RTL method after [16, 17]	HFSN method after [10, 12–14]	Hydrochemical observations after [8, 18, 19]	Water-level observations after [5]	Geodimeter observations after [4, 11]
M	r	0.56	0.89			0.95	
	ρ	0.62	1.0			0.94	
	n	9	4	7	6	6	3
$M/\log R$	r			–0.67			
	ρ						
	n			7	6	6	3

Note: r is the sampling correlation coefficient (values presented here are not below $|\pm0.5|$) and ρ is the Spearman rank correlation coefficient (with statistical significance $p \le 0.05$) for sample sizes $k \ge 4$ [2], n is the number of earthquakes preceded by precursors with identified advance time.

Table 4. Estimates of the relationship between intermediate-term precursors detected by individual methods and the large Kamchatka earthquakes of 1987–2004

	RTL method after [9]	RTL method after [16, 17]	HFSN method after [10, 12–14]	Hydrochemical observations after [8, 18, 19]	Water-level observations after [5]	Geodimeter observations after [4, 11]
Period of observation, years	1987–2003	1987–1999	1992–2005	1987–2003	1987–1997	1987–1998
n	9	4	9	6	5	3
m	12	10	12	12	7	8
$s = n/m$	0.75	0.40	0.75	0.50	0.71	0.38
n'		4*	7	6	5	3
m'		6*	8	9	6	7
$s' = n'/m'$		0.67	0.86	0.67	0.83	0.43

Note: n is the number of earthquakes preceded by a precursor, m the number of earthquakes (Table 1) recorded during the time period under consideration, n' the number of earthquakes with $M/\log R \ge 3$ preceded by a precursor, m' the number of earthquakes with $M/\log R \ge 3$ during the time period under consideration, * the number of $M \ge 7.0$ earthquakes after [16].

CONCLUSIONS

(1) We have systematized the precursors identified by five observation methods for the M 6.6–7.8 Kamchatka earthquakes occurring in 1987–2004, determined their content and time of appearance.

(2) Analysis of the relationships between precursor duration T and the magnitudes of subsequent earthquakes indicates a direct statistical relationship between these for the RTL parameter based on low-magnitude events and for water-level drops in well E1. Looking at the relationship between the time of contraction of geodimeter lines and the magnitudes of subsequent earthquakes, one is merely entitled to say that a tendency toward such a relationship exists (Fig. 4b). At the same time, no relationship has been detected between the time of O_1 phase stabilization in HFSN changes and drops in the concentration of chlorine in the water of well GK-1 on the one hand and the magnitudes of subsequent earthquakes on the other.

(3) In the conditions that prevail for the Kamchatka observing network, precursors can be detected by a combination of methods, mostly before magnitude 7 or greater earthquakes in areas south of the Kronotskii Peninsula ($M/\log R \ge 3$). For such events we found a closer relationship between the precursors identified by several methods and earthquakes, with s' reaching 0.43–0.86. At the same time, the duration of these precursors, as well as the very fact of their being identified, are not at present sufficient to estimate the magnitude of a subsequent large earthquake in and around the Petropavlovsk Test Area (in the magnitude range 6.6–7.8).

(4) One important requirement for further development of intermediate-term prediction of Kamchatka earthquakes is to set up a publicly-accessible database on intermediate-term precursors with detailed descriptions of these involving all observation methods that have been used.

REFERENCES

1. Bakhtiarov, V.F. and Levin, V.E., Ground Deformation Based on Continuous Geodimeter Observations from the Mishennaya Observatory, Kamchatka between 1979

and 1985, *Vulkanol. Seismol.*, 1989, no. 2, pp. 94–101 [*Volc. Seismol.*, 1990, vol. 11(2), pp. 258–270].

2. Bol'shev, L.N. and Smirnov, N.V., *Tablitsy matematicheskoi statistiki* (Tables of Mathematical Statistics), Moscow: Nauka, 1965.

3. Gordeev, E.I., Saltykov, V.A., and Serafimova, Yu.K., Precursors of Kamchatka Earthquakes (Based on Materials Supplied by the Kamchatka Branch of the Federal Earthquake Prediction Center, 1998–2004), *Vulkanol. Seismol.*, 2006, no. 4, pp. 3–13.

4. Zobin, V.M., Gordeev, E.I., Levina, V.I., et al., The Kamchatka Earthquake of March 2, 1992 (magnitude MLH 7.1) in the Avacha Bay and Associated Phenomena, *Vulkanol. Seismol.*, 1996, no. 6, pp. 48–61 [*Volc. Seismol.*, 1997, vol. 18(6), pp. 687–702].

5. Kopylova, G.N., Water-Level Changes in Well Elizovskaya-1, Kamchatka Due to Large Earthquakes: The 1987–1998 Observations, *Vulkanol. Seismol.*, 2001, no. 2, pp. 39–52.

6. Kopylova, G.N. and Zhalyaeva, Yu.K., On the 1995–1996 Activities of the Expert Team in the Earthquake Prediction Section, Interdepartmental Science and Technology Expert Council Affiliated with the Kamchatka Center for Monitoring of Seismic and Volcanic Hazard, in *Opyt prognozirovaniya seismicheskoi opasnosti na Kamchatke v 1995–1996 gg. (po materialam raboty Mezhvedomstvennogo nauchno-tekhnicheskogo ekspertnogo soveta pri Kamchatskom tsentre monitoringa seismicheskoi i vulkanicheskoi aktivnosti)* (Experience in the Prediction of Earthquake Hazard in Kamchatka during 1995–1996: Using Materials from the Work of the Interdepartmental Science and Technology Expert Council Affiliated with the Kamchatka Center for Monitoring of Seismic and Volcanic Activity), Petropavlovsk–Kamchatskii: KOMSP GS RAN, 1999, pp. 4–21.

7. Kopylova, G.N. and Zhalyaeva, Yu.K., Forecasts and Precursors of the December 5, 1997, Kronotskii Earthquake (Based on Materials from the Work of the Interdepartmental Science and Technology Expert Council Affiliated with the Kamchatka Center for Monitoring of Seismic and Volcanic Activity), in *Problemy seismichnosti Dal'nego Vostoka* (Problems in the Russian Far East Seismicity), Petropavlovsk-Kamchatskii: KOMSP GS RAN, 2000, pp. 146–154.

8. Kopylova, G.N., Sugrobov, V.M., and Khatkevich, Yu.M., The Discharge Variation of Springs and Hydrogeological Wells in the Petropavlovsk Test Site, Kamchatka Induced by Earthquakes, *Vulkanol. Seismol.*, 1994, no. 2, pp. 53–70 [*Volc. Seismol.*, 1994, vol. 16(2), pp. 145–163].

9. Kravchenko, N.M., Estimating the Efficiency of the RTL Prediction Parameter, *Vestnik KRAUNTS, Ser. Nauki o Zemle*, 2005, no. 6, pp. 99–107.

10. Kugaenko, Yu.A. and Saltykov, V.A., Comparing the Responses of Seismic Noise to Tides Based on Data from the Shikotan, Nachiki, and Karymshina Stations, in *Geofizicheskii monitoring Kamchatki* (Geophysical Monitoring of Kamchatka), Petropavlovsk-Kamchatskii: Ottisk, 2006, pp. 114–121.

11. Levin, V.E., Magus'kin, M.A., Bakhtiarov, V.F., et al., The Multisystems Geodetic Monitoring of Recent Crustal Movements in Kamchatka and the Commander Is., *Vulkanol. Seismol.*, 2006, no. 3, pp. 54–67.

12. Saltykov, V.A., Precursory Variations of High Frequency Seismic Noise Prior to Large Kamchatka Earthquakes of 1992–2004, in *Solnechno-zemnye svyazi i elektromagnitnye predvestniki zemletryasenii* (Solar–Terrestrial Relationships and Electromagnetic Precursors of Earthquakes), Petropavlovsk-Kamchatskii: IKIR DVO RAN, 2004, pp. 116–120.

13. Saltykov, V.A., Sinitsyn, V.I., and Chebrov, V.N., Variations of the Tidal Component of High Frequency Seismic Noise Due to Changes in the Earth Stresses, *Vulkanol. Seismol.*, 1997, no. 4, pp. 73–83 [*Volc. Seismol.*, 1998, vol. 19(4), pp. 471–483].

14. Saltykov, V.A., Sinitsyn, V.I., and Chebrov, V.N., Using High Frequency Seismic Noise for Intermediate-Term Prediction of Large Earthquakes, in *Kronotskoe zemletryasenie na Kamchatke 5 dekabrya 1997 goda: predvestniki, osobennosti, posledstviya* (The Kronotskii, Kamchatka Earthquake of December 5, 1997: Precursors, Features, Impact), Petropavlovsk-Kamchatskii: KGARF, 1998, pp. 99–105.

15. Sobolev, G.A., *Osnovy prognoza zemletryasenii* (Principles of Earthquake Prediction), Moscow: Nauka, 1993.

16. Sobolev, G.A., Precursory Periods of Large Kamchatka Earthquakes, *Vulkanol. Seismol.*, 1999, no. 4–5, pp. 63–72 [*Volc. Seismol.*, 2000, vol. 21(4–5), pp. 497–509].

17. Sobolev, G.A., The Seismic Properties of the Outer and Inner Zones of an Earthquake Rupture Volume, *Vulkanol. Seismol.,* 2003, no. 2, pp. 3–12.

18. Khatkevich, Yu.M. and Ryabinin, G.V., Water-Level Changes and Gas Chemical Variations in Ground Water Behavior during the Precursory Period and Occurrence of the December 5, 1997 Kronotskii Earthquake, in *Kronotskoe zemletryasenie na Kamchatke 5 dekabrya 1997 g. Predvestniki, osobennosti, posledstviya* (The Kronotskii Earthquake of December 5, 1997 in Kamchatka: Precursors, Features, Impact), Petropavlovsk–Kamchatskii: KGARF, 1998, pp. 134–147.

19. Khatkevich, Yu.M. and Ryabinin, G.V., Hydrogeochemical Studies in Kamchatka, in *Kompleksnye seismologicheskie i geofizicheskie issledovaniya Kamchatki* (Multidisciplinary Seismological and Geophysical Studies of Kamchatka), Petropavlovsk-Kamchatskii: Kamchatskii Pechatnyi Dvor, 2004, pp. 96–112.