

Preseismic anomaly of LF signal on the wave path Japan–Kamchatka during November–December 2004

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Abstract

The variations of phase and amplitude of LF signal propagating from the transmitter JJY (40 kHz, Fukushima prefecture, Japan) are analyzed. The receiver is situated in Petropavlovsk-Kamchatski (Russia). The time interval from July 1, 2004 till January 24, 2005 is included in the examination. This interval is characterized by quiet seismic conditions up to the beginning of November, but rather strong seismic activity occurs in November and December not far from Hokkaido (Japan) and in the region of northern Kuril Islands. Seismic activity in a zone of sensitivity of our wave paths is determined by three series of earthquakes with $M = 5.6$ – 7.1 . Nighttime “bay-like” phase and amplitude anomalies of the LF signal begin some days before the first earthquake and continue till the last earthquake of this series ($M = 6.2$, November 11, 2004). Most strong and obvious anomalies appear in the amplitude of the LF signal. After that, during about one fortnight a period of seismic calm is observed. Then there is a following anomaly of the LF signal before two earthquakes ($M = 7.1$, 28.11.04 and $M = 6.8$, 6.12.04). The next LF anomaly is observed before the earthquakes on December, 18 and 21 ($M = 5.8$ and $M = 5.6$). During the whole period of seismic activity a significant shift in terminator times is also evident. The spectrum of LF seismo-induced anomalies shows a clear increase for the periods of 10–25 min.

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1. Introduction

Subionospheric VLF/LF signal monitoring has been widely used in the last 15 years for the search of possible short-time precursors of earthquakes. The observed VLF/LF signal parameters are mainly dependent on the ionospheric condition at the reflection height (typically 80–85 km), which depends on the value and gradient of the electron density near the atmosphere–ionosphere boundary. Perturbations in these parameters of the boundary

layer lead to corresponding disturbances in subionospheric VLF/LF signals.

Analyzing the famous Kobe earthquake ($M = 7.2$), Hayakawa et al. (1996) proposed a terminator time (TT) method. The TT is determined by the position of a characteristic minimum in the phase and/or amplitude of the signal during sunset and sunrise. This method was applied for processing the VLF signal received at Inubo observatory and transmitted by the Omega station in Tsushima (Japan). The authors found that the evening TT deviated significantly from the monthly averaged value 3 days before the main shock. Using TT method for 11 events with $M > 6$ Molchanov and Hayakawa (1998) had found that an anomalous shift in TT fluctuations appears in a 3

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to 10-days period before crust earthquakes and continues a few days after it. Terminator time shift was lately found a few days before two earthquakes in Japan with $M > 6$ in 2004 (Yamauchi et al., 2005).

Another method to study VLF/LF phenomena associated with seismic activity is based on the analysis of night-time phase and amplitude fluctuations. Anomalies in phase and amplitude of VLF/LF signals before earthquakes with $M > 5.5$ have been reported recently (Rozhnoi et al., 2004; Shvets et al., 2004).

Observations in Petropavlovsk-Kamchatski have been carried out since June, 2000. The wave path location was determined by strong seismicity of the Kurile–Kamchatka region and Japan. The area of wave path sensitivity covers almost the whole high activity in the Idzu–Bonin and Kurile–Kamchatka arcs. During 4.5 years of monitoring in the third Fresnel zone of our wave path 73 earthquakes with $M > 5.5$ and five earthquakes with $M \geq 7.0$ have been registered (according to the USGS catalog).

Several cases of nighttime anomalies of the LF signal a few days before enough strong isolated earthquakes have been revealed. We consider anomalies of the LF signal connected with seismic events if they do not continue less than 3 days at quiet heliogeomagnetic condition and if there are no deviations of the LF signal in other wave paths at the same time.

2. Description of measurements

For the registration of VLF/LF signals the OMNIPAL receiver is used. It is located in Petropavlovsk-Kamchatski (Geographic coordinates: 53.15°N, 158.92°E) in Russia and registers signals from several transmitters: Australia (19.8 kHz), China (22.2 kHz), Hawaii (21.4 kHz) and JG2AS (JJY) (40 kHz) in Fukushima prefecture, Japan

(37.37°N, 140.85°E). In this work we only analyze the signal from the last transmitter. The signals from the other transmitters are regarded as a control. The 20-s digital data of amplitude and phase of the LF signal are used for our analysis.

Several strong earthquakes with $M \sim 6$ –7 occurred in November and December 2004 not far from Hokkaido (Japan) and in the region of northern Kuril Islands. In this paper we report some results of LF signal monitoring on the wave path Japan–Kamchatka during this period.

3. Results of the LF signal processing

The interval from July 1, 2004 till January 24, 2005 is included in the examination. This interval is characterized by quiet seismic conditions up to the beginning of November and rather strong seismic activity in November and December near Hokkaido (Japan) and in the region of northern Kuril Islands. The seismic activity in the zone of sensitivity of our wave path is determined by three series of earthquakes with $M = 5.6$ –7.1. Within almost 3 months (until the first earthquake ($M = 5.6$) in November) there were no strong earthquakes with $M > 5.0$ in this region. In Fig. 1 the third Fresnel zone for our propagation path and positions of the epicenters of the earthquakes with $M > 5.5$ for November–December are shown. Fig. 2 presents the running average (within 1 h) of the residual signal of phase dP and amplitude dA (defined as the difference between the hourly-mean signal and the average signal for the quiet days of the month) for the period from October 1, 2004 till January 15, 2005. Only night-time measurements are taken into account.

Anomalies in amplitude and phase of LF signal begin 1–2 days before the first set of earthquakes, continue 13–14 days and finish on the day of the last earthquakes of this

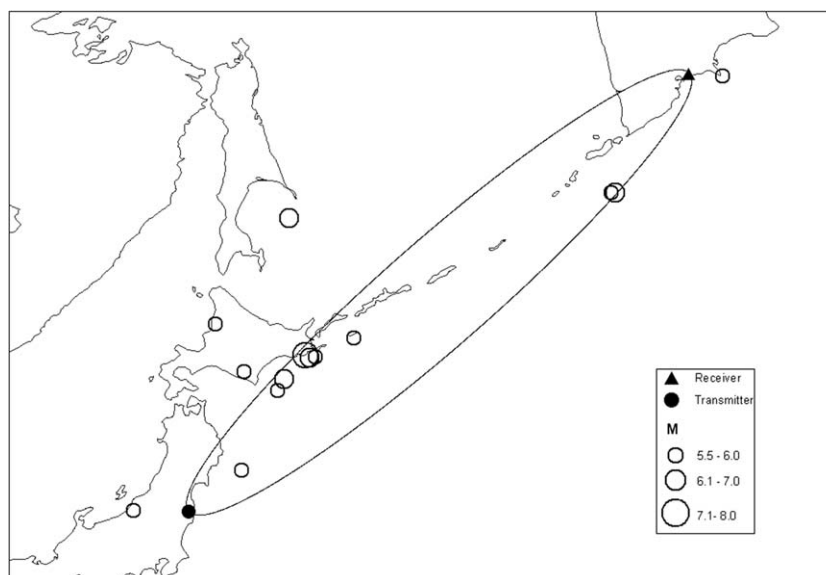


Fig. 1. A map of epicenters of earthquakes in November–December 2004 with $M > 5.5$ and LF wave path.

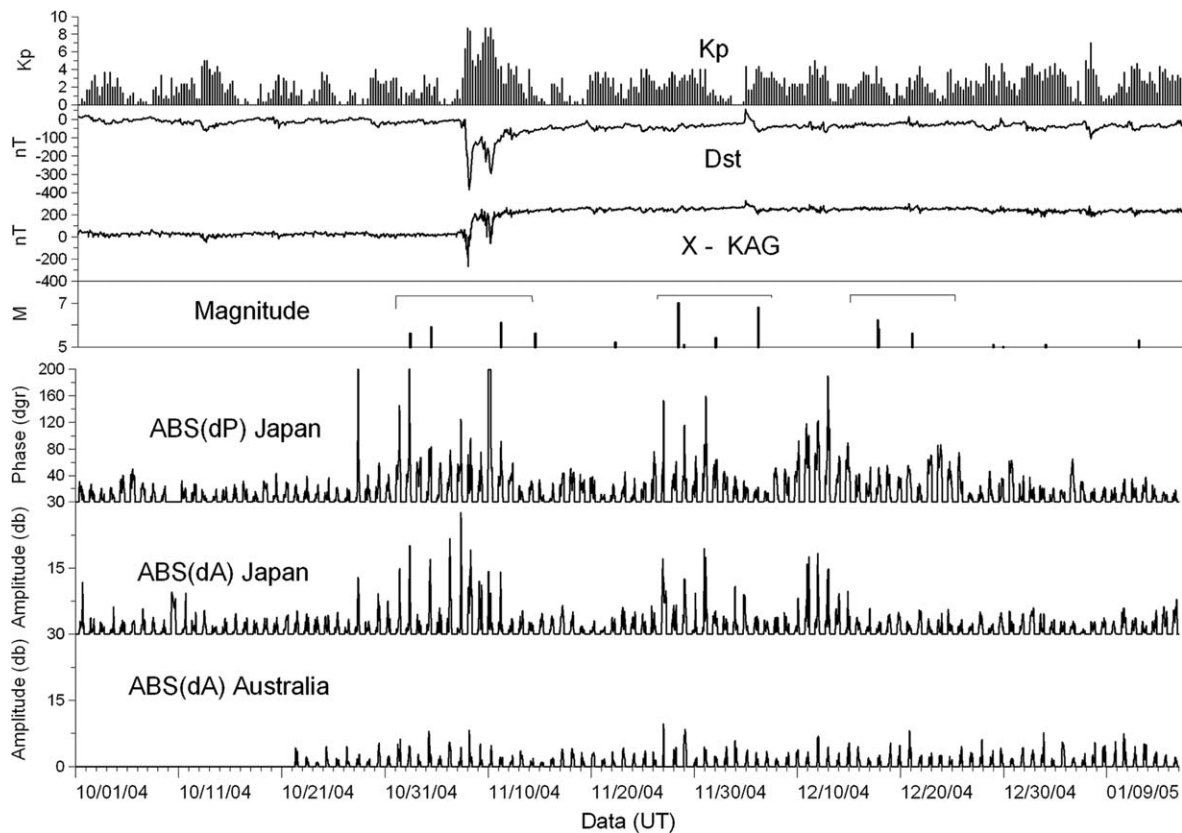


Fig. 2. Residual signal of phase dP and amplitude dA of nighttime for Japanese propagation path and dA for Australian path, magnitudes of earthquakes, magnetogram of observatory Kagashima, K_p and Dst indices during the period from October 1, 2004 till January 15, 2005.

set ($M = 6.2$, 11.11.04). Afterward, a quiet period in seismicity and in LF signal is observed during about one fortnight. Then 2–3 days before two earthquakes ($M = 7.1$, 28.11.04 and $M = 6.8$, 6.12.04), the next anomalies in phase and amplitude appear and they continue 8 days. The next anomalies after the small quiet period (4 days) are observed before two earthquakes in the 18 and 21 of December ($M = 5.8$, $M = 5.6$) and last 17 days. Most strong anomalies are shown in the amplitude of LF signal. After December, 21 seismic activity decay may be observed.

It is necessary to note that, in accordance with the registration of the magnetic observatory Kagashima located in the nearest magnetic meridian to our wave path in the period under consideration, a strong magnetic storm took place on November, 8–10 with Dst ~ 400 nT. The examinations of the influence of magnetic storms and substorms on the behavior of the LF signal carried out previously in the network of VLF/LF receiving stations have shown that anomalies in the signal are observed during the main phase of storms or substorms only if the sudden commencement (SC) happens in the night time. It was found that during the maximum of the bursts of Pi3 geomagnetic pulsations at nighttime there are (sometimes with the delay of a few tens of minutes) “bay-like” LF phase and amplitude anomalies. At the same time sometimes during magnetic storm or substorm, anomalies of the LF signal can be observed simultaneously only in some of the receiving

stations while in the rest ones the signal is not perturbed. It may be connected with the characteristic features of receiving station positions with regard to the transmitter (Rozhnoi et al., 2006). In this case the magnetic storm had two stages. The sudden commencement of the first stage took place in the daytime and it had no effect on the LF signal. Besides it, anomalies in the signal are observed within a week before the magnetic storm. The second maximum of the storm happened in the nighttime and a strong anomaly in amplitude and phase of the signal observed on that day can be caused by the magnetic storm.

In the control wave path Australia–Kamchatka (19.8 kHz) anomalies in the VLF signal during the whole period under review are not found. Taking into account that earthquakes in the region of northern Kuril Islands fall within the zones of sensitivity of both Japanese and Australian wave paths, it is probable that anomalies in LF signal are resulting from the earthquakes of Hokkaido region.

Fig. 3 illustrates the anomalies of the LF signal phase and amplitude and their wavelets for one of the disturbed days (November 4, 2004). Only nighttime signal, filtered in a frequency band of 0.4–15 mHz (as shown in the middle panels), is used for wavelet analysis. The signal maximum with the period of about 0.7–0.8 mHz (20–25 min) is clearly observed in the bottom panels. The second maximum has a

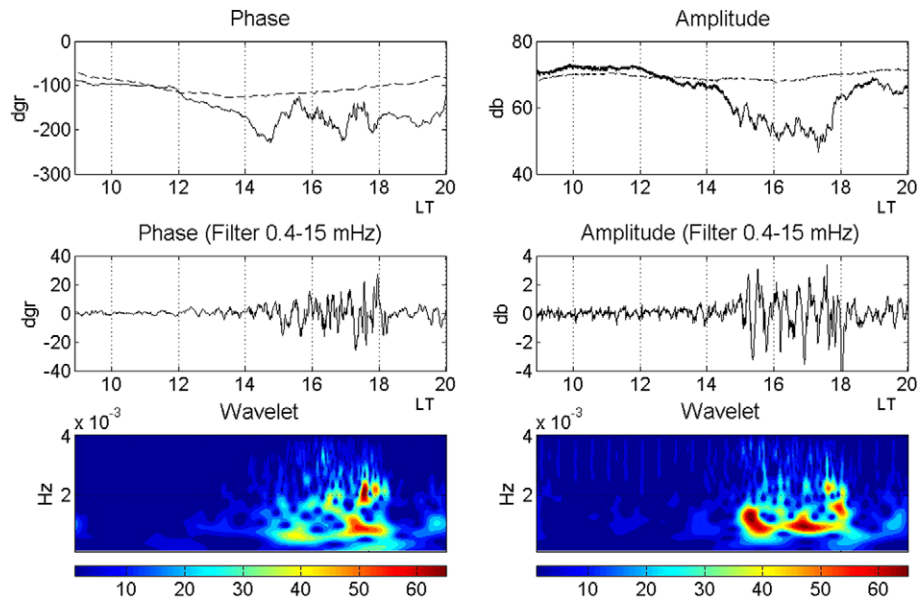


Fig. 3. Phase and amplitude anomalies (top two panels), filtered signals (middle panels) and their wavelets (bottom panels) for November 4, 2004.

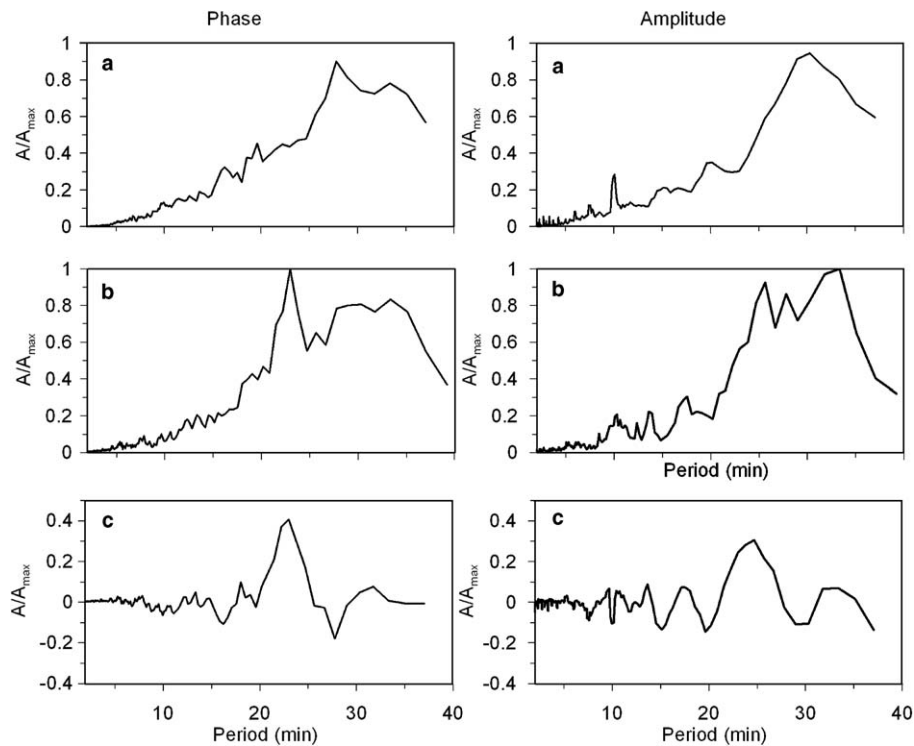


Fig. 4. Spectra of phase (left panel) and amplitude (right panel) of signal. (a) Averaged spectrum of 19 quiet days, (b) averaged spectrum of 12 anomalies days, (c) difference between normalized spectra of anomalies days and quiet days.

period of 1.5–2 mHz (8–10 min). The shorter periods (smaller than 4 min) are not revealed. The frequency range of the signal corresponds to the gravity wave frequency (Miyaki et al., 2002). The summary spectra of several anomaly days and several quiet days for November–December are presented in Fig. 4 together with the differential spectra. All the spectra have a rather similar shape

except the maximum with the period of 20–25 min both in phase and in amplitude during anomaly days.

For this period of nighttime anomalies of the LF signal we found a significant shift in terminator times as shown in Fig. 5, illustrating the 3D image day-to-day sequences of diurnal variations of the amplitude of the LF signal for the period from October 1, 2004 till January 24, 2005. In

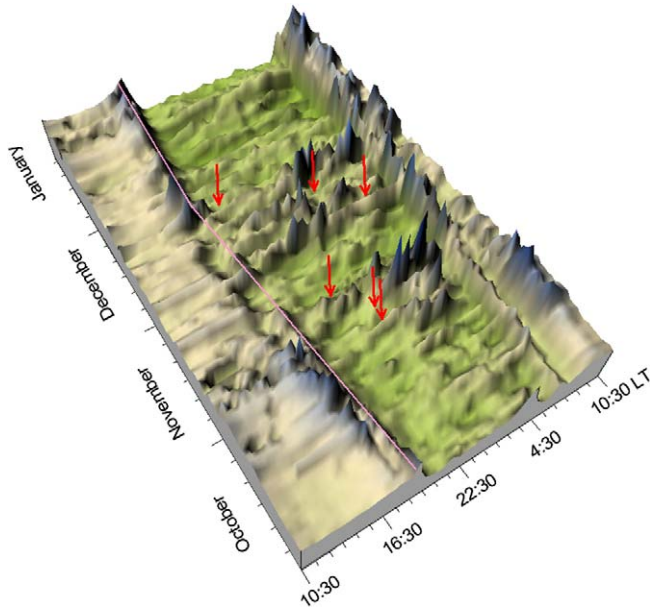


Fig. 5. 3D image of day-to-day sequences of diurnal variations of the amplitude of the LF signal for the period from October 1, 2004 till January 24, 2005. Arrows indicate the moments of earthquakes, and the line shows a normal position of the evening terminator.

addition to strong perturbations in nighttime it is easy to see the significant evening TT deviation from its normal position. The shift runs up to 2 h, and similar TT behavior is observed in the phase of the signal too.

4. Discussion and conclusion

Strong nighttime anomalies in amplitude and phase of the LF signal and significant evening shift in terminator times are found during the period of strong seismic activity in November–December not far from Hokkaido. Such a considerable and long deviation in TT for our wave path is revealed firstly for the 4 years of monitoring.

The solar terminator is a part of the atmosphere between the space illuminated by the Sun and the complete shadow space. The strongest variations of temperature,

pressure and electron density altitude profile in the atmosphere occur at solar terminator passage (Soloviev et al., 2004). The ionospheric plasma is unstable during the period of terminator transition and more than usually sensitive to external actions.

In our case, a shift in TT is observed in the evening that can be explained by the peculiar passage of the solar terminator across this wave path in the period of analysis. In Fig. 6 the positions of solar terminator with regard to the wave path are shown for the evening (16:30 LT) and morning (8:00 LT) of the first of December. Morning terminator comes up almost parallel to the wave path and the region from Kamchatka to Japan is illuminated in all parts practically at one time. At the same time the evening terminator is almost perpendicular to the wave path and night set in during two hours along the wave path. For all this period the lower ionosphere and the upper atmosphere remain in an unstable state and an external action, which is induced by preseismic processes in the earth crust, can stimulate an increase of plasma density perturbations inside the ionosphere and atmosphere, that affect the value and form of the registered LF signal due to multimode interaction.

The transformation of a plasma perturbation at the upper atmosphere and lower ionosphere into amplitude and phase variation of a subionospheric VLF signal was discussed in several papers (e.g. Molchanov et al., 1998) in supposition of some simplifications. A theory is presented suggesting that the observed effect can be explained by decreasing the effective height of the lower ionosphere. Recently Soloviev et al. (2004) have reported the relevant approach to the problem. Their paper presents a mathematical model, an asymptotic theory and an appropriate numerical 3D algorithm to interpret the observational facts.

Another theoretical problem is the way of energy transfer from the seismic source to the ionosphere. Indeed it is a problem of lithosphere–atmosphere–ionosphere coupling due to seismicity. Different possibilities are discussed at present (see comprehensive monograph Hayakawa and Molchanov, 2002). The probable mechanism of the atmosphere–ionosphere coupling is connected with the genera-



Fig. 6. Position of solar terminator with regard to the wave path in the evening (left) and in the morning (right) on December, 1.

tion of atmospheric gravity waves (AGW). This process was described in detail by Mareev et al. (2002) and Molchanov (2004). We demonstrate here the increase of the AGW intensity for the periods of 10–25 min (Fig. 4), that is in compliance with the theory.

Acknowledgements

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