EFFECTS IN THE VARIATIONS OF THE AMPLITUDE OF LOW-FREQUENCY RADIO SIGNALS AND ATMOSPHERICS PASSING OVER THE EPICENTER OF DEEP EARTHQUAKES

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Abstract. The search for possible earthquake precursors is one of the urgent problems of geophysics. One of the possible tools for detecting the seismic activity is observations of disturbances in the lower ionosphere caused by the effect of lithospheric processes with the help of low-frequency radio signal observations. In a sufficiently large number of studies, it is shown that phase variation of signals of low-frequency radio stations observed a few days before the earthquake can be considered as precursors. The monitoring measurements of characteristics of the electromagnetic radiation of lightning – atmospherics, are also proposed as a variant of this method. It is shown that the earthquakes with the magnitude greater than 5 and the depth not exceeding 50 km are manifested in the form of increasing hourly average amplitude of atmospherics on the day of the event or within three days thereafter. Effects of the amplitude increase in the previous earthquake during the days preceding the earthquake are considered as precursors. At the same time, it has been found that the deep-focus earthquakes also apparently cause disturbances in the ionosphere. In this work examples of manifestations of deep-focus earthquakes in the amplitude variations of the low-frequency radio signal and atmospherics are considered.

Introduction. One of the possible tools for detecting the seismic activity is observations of disturbances in the lower ionosphere caused by the effect of lithospheric processes with the help of low-frequency radio signal observations. In a sufficiently large number of studies, it is shown that phase variation of signals of low-frequency radio stations observed a few days before the earthquake can be considered as precursors [see, for example: Biagi et al., 2001]. The monitoring measurements of characteristics of the electromagnetic radiation of lightning – atmospherics, are also proposed as a variant of this method [Mullayarov et al., 2007]. From observations of atmospherics passing within the first Fresnel zone over earthquake epicenters it is shown that the earthquakes with the magnitude greater than 5 and the depth not exceeding 50 km are manifested in the form of increasing hourly average amplitude of atmospherics on the day of the event or within three days thereafter. Effects of the amplitude increasing in the previous earthquake during the days preceding the earthquake are considered as precursors. It can be assumed that conditions of not deep and strong magnitude are necessary to transfer sufficient energy of the seismic processes to ionospheric heights that can cause detectable perturbation. At the same time, it has been found that the deep-focus earthquakes also apparently cause disturbances in the ionosphere [Mullayarov et al., 2014]. In this work examples of manifestations of deep-focus earthquakes in the amplitude variations of the low-frequency radio signal and atmospherics are considered.

Methods. The measurement procedure is sufficiently described in [Mullayarov et al., 2007]. The signals are received at Yakutsk (\(\phi = 62.1^\circ\ N, \lambda = 129.7^\circ\ E\)) with three antennae: vertical electrical one (monopole) and two orthogonal magnetic antennae (loops). The error in measuring the azimuth of incoming signals does not exceed 2°. The distance up to the source of atmospherics (lightning) is roughly estimated by the four parameters of the signal waveform. The data are regularly compared with those of the world wide lightning location network WWLLN [http://wwlln.net]. The comparison with the data of WWLLN shows that although the distance estimation accuracy is very low (no better than 25 % of the distance), this method allows rather confident detection of the amplitude variations of the atmospherics, which can be associated with the manifestation of lithospheric processes.

The effects of seismic activity have been analyzed on the variations of the hourly averaged amplitude of the signals. The atmospherics with the paths lying within the first Fresnel zones over the epicenter centered in azimuth towards the earthquake epicenter are selected for the analysis.

When we had a weak thunderstorm activity in the areas that lie farther off the epicenter of the earthquake, we used the results of measurements at additional stations. One of these stations is located southwest of Yakutsk in the distance of 660 km (Neryungri). Additionally, analysis of seismic disturbances in the lower ionosphere has been made by measuring the signal amplitude of VLF radio transmitter. Usually
the amplitude variations of the signals of the transmitter in Japan (Ebino, 22200 Hz), in Australia (North West Cape, 19800 Hz) and in Hawaii (Lualualei, frequency 21400 Hz) were analyzed.

Results. The earthquake that took place on June 26, 2014 in Philippines was examined at first. The value of the magnitude was 5.6 and the focus depth was 76.6 km (the earthquake was not clearly "deep" but had the focus at the depth more than usually considered - more than 50 km). The earthquake was registered at 11:52:03 UT for the epicenter at φ=13.58°N, λ=120.69°E. The azimuth from the north of Yakutsk to the seismic epicenter was 191°, and the distance was 5400 km. Before that event, one earthquake had occurred approximately at that direction on June 22, 2014 but at the distance more than the fifth Fresnel zone from the main path of the atmospherics to Yakutsk.

Fig. 1a shows the paths of the signals of atmospherics from the direction to epicenter of the referred earthquake and the signal of the Australian radio station (North West Cap, 19800 kHz). In fig.1b the amplitude variations of the average amplitude of atmospherics at all hours of the day before and during the earthquake are shown (unfortunately, there are no data before 16.06.2014). There was a significant increase in the amplitude of the atmospherics signal 21-22.06.2014 with a maximum at 05 UT which can be considered as a precursor of the earthquake. In the signal of the south transmitters in Australia an additional significant increase in the amplitude was observed from 09 to 14.06.14 (fig.1c).

Fig. 1. Paths of the signals of atmospherics from the direction to epicenter of the earthquake of 16.06.2014 and the signal of the Australian radio station (a), the amplitude variations of the average amplitude of atmospherics at all hours of the day before and during the earthquake (b) and the variations of signal of the transmitters in Australia (c).
As it is known, one of the main causes of disturbances in the ionosphere is geomagnetic disturbances. In this connection, consideration of the geomagnetic situation has shown that the increase in the signal amplitude of the south transmitter observed from 09 to 11.06.14 can be connected also with geomagnetic disturbances, because the increase in the amplitude in this interval corresponds to the recovery phase of a weak magnetic storm (Dst-index was up to −40 nT). Thus, there are two increases in the amplitude of the signal which can be considered as precursors: one of them – 2 days before the earthquake.

Variations of the average amplitude of atmospherics before and during the next two cases of a deep earthquake are shown in fig. 2. The first earthquake with a magnitude 6.3 occurred on 24.12.2009 in Primor'e, Russia has a very deep focus – 362 km. One day before the earthquake the average amplitude increased more than twice (fig. 2a). In the second earthquake that took place on 26.02.2010 at the depth of 95 km a clear increase of the average amplitude of atmospherics (precursor) was observed during 2 days before the earthquake (fig. 2b).

![Fig. 2. Amplitude variations of the average amplitude of atmospherics before and during a very deep earthquake (depth 362 km) with a magnitude 6.3 occurred on 24.12.2009 in Primor'e, Russia (a), and earthquake with a magnitude 5.4 occurred on 26.02.2010 near Japan (b).](image)

The behaviour of the average amplitude of atmospherics before and during the earthquake of 27.12.2011 near Japan on the same depth (95 km) is shown in fig. 3. The amplitude began to increase 2 days before the earthquake and reached the maximum on the day of the earthquake.

![Fig. 3. The behaviour of the average amplitude of atmospherics before and during the earthquake of 27.12.2011 near Japan on the depth 95 km.](image)
In this case, it can be assumed that a precursor passes on the earthquake effect without a gap.

Finally, we considered the earthquake which took place on 05.05.2011 in Indonesia with a magnitude 5.1 and a focus depth of 230 km. This earthquake differs from other analyzed cases because it has no precursor. The behaviour of the average amplitude of atmospherics before and during the earthquake of 05.05.2011 is shown in fig. 4. The very obvious effect of the earthquake started on the 2-nd day after the earthquake (usually the effect in the average amplitude of atmospherics was observed on the 1-3 day after the event).

Discussion. According to the observations of atmospherics passing within the first Fresnel zone over earthquake epicenters in Yakutsk [Mullayarov et al., 2007, 2011], it is found that earthquake effects were expressed as an increase of hourly average amplitude of atmospherics on the same day or within 3 days after the event. Possible precursors of earthquake also appeared in one-day increases in the amplitude of atmospherics mainly 5 - 12 days before the event. The analysis shows that the seismic effects in the amplitude of atmospherics are observed in the case of sufficiently strong (magnitude $M \geq 5$) and not very deep earthquake (usually no deeper than 50 km). Conditions of not deep and strong magnitude are necessary to transfer sufficient energy of the seismic processes to ionospheric heights that can cause detectable perturbation. At the same time, in [Mullayarov et al., 2014] the effects of the earthquake with magnitude of 8.2 occurring in the Sea of Okhotsk on 24.05.13 not far from the Kamchatka Peninsula at a depth of 609 km have shown that even deep earthquakes may have precursors in the form of disturbances in the lower ionosphere. In the above-mentioned event of 26.06.2014 in Philippines the earthquake of 24.05.13 has two precursors. One of them was observed 2 days before the event. In the second precursor there probably was also an effect of geomagnetic disturbances. Note that the event of 24.05.13 has been thoroughly considered, using simultaneous observations at two points (opposite sited relative to the epicenter of the earthquake) and both atmospherics from different directions and signals of some radio stations. The geomagnetic condition was also taken into account.

Thus in the present work we confirm that a deep earthquake, unlike earthquakes at depths less than 50 km, may have two precursors, wherein the second precursor is observed within 1-3 days before the event.

Conclusions. In this work examples of manifestations of deep-focus earthquakes in the amplitude variations of the low-frequency radio signal and atmospherics are considered. It is shown that deep-focus earthquakes have a different character of the precursor in comparison with a not very deep earthquake.
(usually no deeper than 50 km). The deep-focus earthquakes may have two precursors, the second of them is observed within 1-3 days before the event, while a not very deep earthquake has usually one precursor 5 - 12 days before the event.

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**References**


