Remote sensing of seismic disturbances in the lower ionosphere according to observations of lightning electromagnetic signals

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Abstract. Features of the remote sensing of seismic disturbances in the lower ionosphere are considered according to observation data of lightning electromagnetic signals passing over the earthquake epicentre, in Yakutsk. The technique has the ability to scan a large seismically active region or even several regions directly from one point, though in some azimuths there are limitations due to insufficiently high lightning activity. In last case, the receiving of signals at several spaced points is used.

1 Introduction

One of the urgent tasks of geophysical research is the search of earthquake precursors. The search is carried out in geophysical fields, as well as in the manifestation of lithospheric processes in other environmental parameters. Among these manifestations there are disturbances of the parameters of the ionosphere1-3. The most suitable method for detecting disturbances in the lower ionosphere is the use of low-frequency radio signals propagating in the waveguide "earth-ionosphere". To date, there is already enough evidence to develop this method for monitoring the seismic events4-10. Low-frequency signals of radiostations are commonly used as radio signal sources. Since VLF radio signals are controlled, it allows to calculate the amplitude and phase variations and to restore the disturbance parameters in the lower ionosphere according to them. But it is not always possible to find the necessary propagation path of radio signals. In this regard, in works11-12 it was additionally proposed to use natural signals - electromagnetic radiation of lightning discharges (atmospherics). This method gives the possibility to conduct a monitoring scan of a large seismically active region or of several regions directly from one point. At the same time, this modification of the method has its own particular qualities. In this paper, these features are considered in relation to the receiving point in the city of Yakutsk.

2 Method used to measure and analyse the parameters of atmospherics

To reveal the effects caused by seismic activity, atmospherics have been measured in the wintertime in Yakutsk, using a one-point lightning location system with increased sensitivity in order to increase the range of operation as compared to the summer period [1]. The lightning discharge direction is found using three antennas that receive the vertical electric and two horizontal magnetic components of the electromagnetic field. A signal in the range

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of 0.5–15 kHz, enhanced in receiving channels, is digitized by ADC and is entered into a personal computer. The direction toward lightning discharges is determined relative to the rms signal values coming from the magnetic antennas. The direction determination ambiguity is eliminated by comparing the signs of mutual correlation between the signal electric and magnetic components of an atmospheric. The maximal standard error in direction determination is ~2.5°. The temporal signal waveform, i.e., the number of positive and negative half-periods of the electric component exceeding the level equal to 0.1 of the signal maximal value, is used to roughly estimate the distance to a remote lightning discharge. The range coefficient is determined by converting the summer threshold values into the winter ones and is specified by comparing these values with the data of the satellite system for registering lightning discharges (LIS) and the WWLLN worldwide ground based network (http://thunder.msfc.nasa.gov, http://wwlln.net/).

We can anticipate that the effect of impending earthquake processes on the level of VLF signals received in Yakutsk will manifest itself if the dimensions of the disturbed region in the lower ionosphere correspond to those of the first Fresnel zones on the thunderstorm source–receiving point signal propagation path. As is known [2], the dimension of the Fresnel zones (F) depends on distance d and electromagnetic signal wavelength λ: F = (nλd1d2/d)1/2, where d = d1 + d2 (d1 and d2 are the distances from the epicentre to the thunderstorm source and receiver, respectively, and n is the zone number).

As initial data, we considered the variations in the amplitude of the atmospherics registered at night (00– 02 LT or 15–17 UT), when the flux of atmospherics was high owing to weak damping. At the same time, we additionally considered the atmospheric amplitude variations in the daytime, because interference effects can be observed in the night time, since signals propagate in the waveguide in the form of several modes. However, we can take into consideration that the number of atmospherics at a constant registration threshold is as a rule small in the daytime, since signal damping in the waveguide is more intense (on some days, it is impossible to obtain amplitude values with a low error). Therefore, we usually selected the daylight hours with the maximal intensity of atmospherics in a thunderstorm source (as is known, the thunderstorm activity maximum for each longitude is observed at approximately 17–18 LT). The method of analysis is as follows: The azimuth and distance to Yakutsk are determined for each selected earthquake. For an initial analysis, we select atmospherics, the propagation paths of which are located at a distance not more than the fifth Fresnel zone from the epicentre, and the distances of their thunderstorm sources are larger than the distance to the earthquake. To calculate the Fresnel zones, we accepted 10 kHz as the centre frequency of the spectrum of atmospherics. The average amplitude of atmospherics registered during an hour is determined (about and more than 1000 atmospherics are as a rule registered) [3]. The rms amplitude values are averaged, since signals are received in a broad band. The signal amplitudes have been led to the amplitude of one distance (the distance to an earthquake source) by using the dependence of the damping factor from distance (inversely proportional to distance) in a first approximation. This procedure is performed in order to decrease the effect of smearing and the displacement of signal sources (lightning discharges) from day to day [4]. Azimuthal scanning with a shift of one–two Fresnel zones is subsequently performed in order to specify the effective dimensions of the disturbed zones in the ionosphere. The earthquake characteristics were taken from the catalog (www.neic.usgs.gov/neis/eglists/significant.html).

3 Results

In this work the examples of the effects of three earthquakes were considered. The first analyzed earthquake occurred in Japan (35.687° N, 140.695° E, http://earthquake.usgs.gov) on March 14, 2012. Magnitude of the earthquake was 6, and the focus was at a depth of 10 km. Distance from the epicenter to the point of receiving the signals (Yakutsk) was about 3000 km, and the main sources of signals of atmospherics in azimuth to the epicenter lies at distances 4200-5600 km from the receiving point. Thunderstorm was located above the ocean surface, and therefore the amount of atmospherics for hourly intervals averaging was not so much what is usually observed over land. The day-to-day variations of the amplitude of thunderstorm signals determined for the night conditions (15-16 UT), passed over the area of the earthquake epicenter, are shown in Fig. 1.

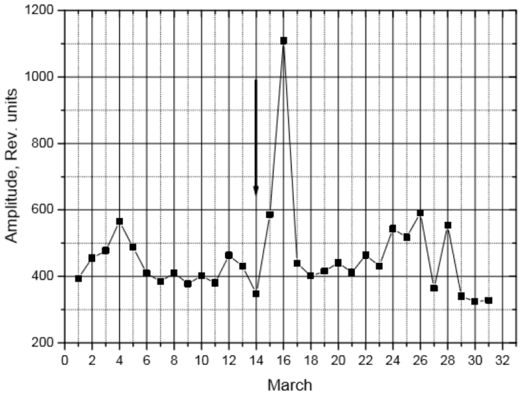

Fig. 1. Variations of average amplitude of atmospherics passing over the epicenter of the earthquake in Japan on 14.03.12.

The day of the earthquake in Fig. 1 marked by a vertical arrow. As follows from the figure, the effect of the lithospheric perturbations manifested in the amplitude of atmospherics two days after the event, namely 16.03.12 observed well-defined peak amplitude exceeded of the background signal level almost for 3 times. Ten days before the event (04.03.12) there was an increase of the amplitude of about 1.5 times, which in this case can be considered as a precursor of the earthquake.

One of these events (the second considered here lithospheric perturbation) took place in Indonesia with epicenter coordinates 1.788° N; 127.318° E, 07.01.09. Magnitude was 5, and focal depth (96 km) is almost twice the commonly used threshold.

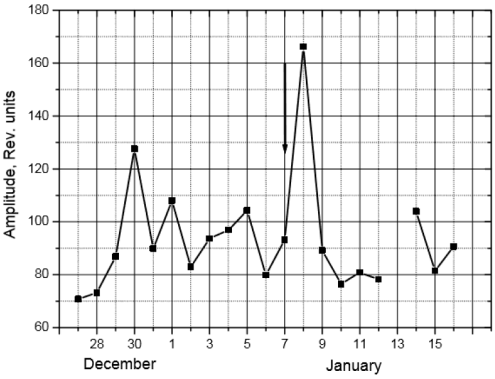

Fig. 2. Variations of average amplitude of atmospherics, passing over the epicenter of the earthquake in Indonesia on 07.01.09.

Variation of the mean amplitude of the night atmospherics (00-01 LT) in this event are shown in Fig. 2. Comparing with the above considering event 14.03.12, it may be noted that the effect of the earthquake followed the next day after the event, there is also well expressed - the peak of amplitude of nearly for 2 times above the level of amplitude in the previous week interval before the earthquake. The sharp increase in the amplitude of atmospherics observed 30.12.09, also almost 2 times higher the level in the preceding days, can be seen as a precursor of the earthquake.

4 Severe thunderstorms and atmospheric circulation

An increase in the amplitude of atmospherics propagating over an earthquake epicentre reflects the variations in the parameters of the lower ionosphere under the action of seismic processes. An increase in the electron density, which can be interpreted as an increase in the wave reflection coefficient, is usually considered. For paths with a medium length (2000–4000 km) and a small number of wave reflections from the ionosphere (wave mode propagation can actually be considered), taking into account the boundary conditions, we can anticipate that seismic processes during earthquake preparation should not only manifest themselves in variations in the amplitude of atmospherics, but also in changes in the Ez/Hτ ratio, where Ez is the vertical component of the electric field (registered experimentally) and Hτ is the tangential (horizontal) component of the wave magnetic field received by two crossed loop antennas. Indeed, proceeding from the known condition Ez/E = where ε' is complex relative permittivity dependent on the conductivity of a medium σ (on the electron density in our case), we can anticipate a change in the Ez/Eτ ratio and, correspondingly, in the ratio of the received components of the atmospheric field (Ez/Hτ) (assuming that the impedance of the underlying surface at a receiver point does not change on the time interval where seismic effects are observed). To verify such a possibility, we not only analyzed the amplitude of atmospherics but also the UEz/UHτ ratio, where UEz is the voltage tapped off from the vertical electric antenna and UHτ is the total voltage tapped off from the horizontal magnetic antennas. Before measuring the remote atmospherics, we set the gain factors of the measuring channels so that UEz/UHτ ≈ 1. Note that the variations in the signal amplitude of atmospherics, the sources of which are located at larger distances than the earthquake source, are considered. Figure 3a presents the variations in the Ez/Hτ ratio for the considered event on December 2, 2005. The value of this ratio decreased seven to eight days before the earthquake and then increased. Another example of variations in the Ez/Hτ ratio is shown in Fig. 3b for an event on March 4, 2010, on Taiwan. Such a behavior of the Ez/Hτ ratio is observed in most considered events (see Fig. 3c, which presents the average variations in this ratio for nine earthquakes, obtained using the epoch superposition method; the day of the earthquake is considered as day zero). Figure 3c indicates that the Ez/Hτ ratio is by 15–20% higher than the undisturbed level (normalized to 1) 15–20 days before the earthquake; however, the large rms error in determining the average value does not make it possible to consider that this result is significant. At the same time, the decrease in the Ez/Hτ ratio three to eight days before the earthquake is significant with a probability of 95%.

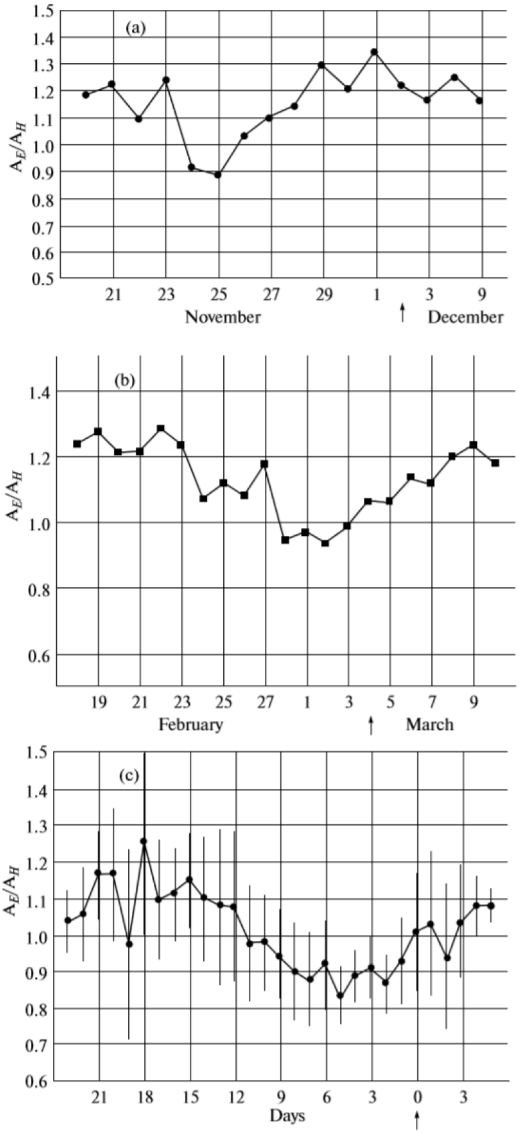

Fig. 3. (a) Variations in the Ez/H ratio during the event of December 2, 2005; (b) variations in the Ez/H ratio during the event of March 4, 2010; and (c) averaged variations in the Ez/H ratio.

Observations of LF electromagnetic signals of lightning discharges (atmospherics) can be used for complex monitoring of disturbances in the lower ionosphere caused by shallow-focus seismic processes. Such earthquakes with magnitudes larger than 4.0 and preceding lithospheric processes manifest themselves in an amplitude characteristics of atmospherics. This makes it principally possible to additionally use the characteristics of electromagnetic signals from lightning discharges for complex monitoring of disturbances in the lower ionosphere caused by seismic processes.

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