First experiments on studying the condition of the atmosphere and of the ionosphere in the Baikal region within nighttime during the seismic vibrator operation

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Abstract

We present the first results of studying the effect of a ~100-ton seismic vibrator operation on the atmospheric and ionospheric conditions. The investigation was performed in the Baikal region during nighttime, and comprised two experiments: the spring one (2013 April 11-12) and the summer one (2013 August 13-15). To hold the investigations, we used the network of the LW-MW-SW Doppler receivers and the ISTP SB RAS optical complex. The summer experiment was performed by involving GPS-receivers. The experiment showed that the amplitude modulation of the LW-SW signal propagating over the vibrator operation site and aside is absent or below the noise level. The SW-signal frequency 0.3-0.4 Hz increase surpassing the measurement dispersion for the referent days was revealed to exist. These temporal variations correlate well with the variations in the 577.7 nm atomic oxygen emission. A possible effect in the total electron content variations was recorded only in one case of the vibrator operation. In this case, a solitary wave with an ~ 0.15 TECU amplitude propagating at ~100 m/s was observed in TEC.

1. Introduction

One of the problems in studying the seismic-ionospheric coupling is investigating the effect of the seismic vibrations originating at special vibrators on the ionospheric conditions [4, 5]. Unlike earthquakes whose basic energy is concentrated within a comparatively short period, the operation of a seismic-wave controlled source may generate long-term and repeatable vibration signals. The previous investigations into the mechanisms for geophysical disturbance excitations by using low-frequency vibrators [3] showed that the generation of acoustic waves by seismic vibrations propagating from a vibrator may be considered the main mechanisms for forming geophysical disturbances.

A peculiarity of the experiment held is studying the response to vibrator-excited low-frequency seismic monochromatic oscillations in the upper atmosphere and in the ionosphere. The Baikal region (50-56°N, 102-112°E) is a seismic active region, which raises the practical significance of such studies. To perform monitoring and special experiments in studying the atmosphere and the ionosphere, a network of geophysical instruments [1] was deployed in the Baikal region. When conducting special experiments, additional mobile instruments were involved.

In this paper, we present the first results when studying the effect of the seismic vibrator on the atmospheric and on the ionospheric conditions in the Baikal region. Figure1 gives the geometry of experiments. The experiments described in the paper were performed in the 2013 spring (April 11-12) and in the 2013 summer (August 13-15).

The main active tool in the experiment was a debalanced seismic vibrator located near Babushkin (BBSH). The vibrator generates monochromatic and sweep signals in the 5 – 12.5 Hz frequency range. The impact of the dynamic torque is adjustable, ranging from two to one hundred tons. An active control circuit with feedback signal encoders was used in the centrifugal source control system. The source resonance concordance with the ground within the operation frequency range provides the seismic wave emission allowing to recover seismograms at up to 300-400 km from the source in the mode of recording linearly-frequency modulated signals, and record the vibrator monochromatic emission within spectra at 1500 km. During all the experiments, the vibrator operated at the same time, 13:00-13:40 UT, and 15:00-15:40 UT, and in one emission mode of the vibration fixed frequency. In each operation period, the vibrator functioned at the fixed frequencies within 5-7 Hz in the 10-min operation – 10-min pause mode. According to [2], such an operation mode of the vibrator is sufficient to form effects in the ionospheric E-layer during the daytime.

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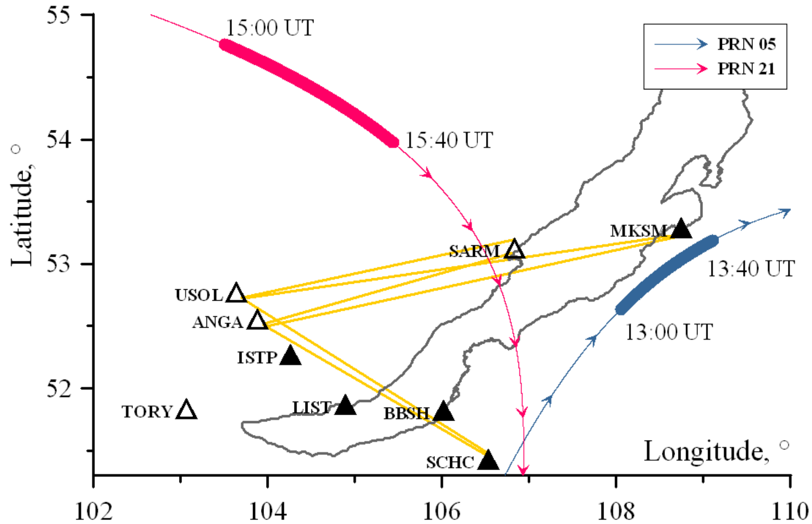

Figure 1. Geometry of experiments during the seismic vibrator operation. Lines show the LW-MW-SW signal reception paths (yellow) and subionospheric points' trajectories to GPS satellites (red and blue).

We used the LW-MW-SW Doppler receiver network to study the effect of the vibrator operation on radio wave passing. The receiver network included digital receivers of direct numbering, WinRadio Excalibur and QS1R, located at the Sarma (SARM), Maksimikha (MKSM) and Lake Shchuchye (SCHC) observatories. The Angarsk radio transmitting center (ANGA) with the 500-kw radio transmitter (234 kHz and 576 kHz) was used as the LW-MW transmitter. A 50-kw SW transmitter at the ORDA ISTP SB RAS observatory (3447 kHz, Usolye-Sibirskoye, USOL) was used as a SW radio wave transmitter. The Angarsk transmitter operated 24 hours except the 17:00-21:00 UT pauses. The Usolye transmitter operated in the 24-h 3-min emission - 2-min pause mode.

In some experiments, we involved the ISTP SB RAS optical complex [1] to measure the Earth upper atmosphere atomic oxygen glow intensity.

During the summer experiment, deployed was a network of GPS receivers extended along the USOL-SCHC line, and a GPS receiver was installed in MSKM (Figure 1). The mean distance between the GPS receivers (ISTP, LIST, BBSH, SCHC) was about 60 km.

2. Passing of low-frequency (Hz) seismic oscillations into the nighttime ionosphere

To study the passing of low-frequency seismic oscillations into the ionosphere during nighttime, the 2013 August 13-15 experiment was performed. The seismic vibrator operated in the standard mode (described above) within 13:00-13:40 and 15:00-15:40 UT. In the experiment, two groups of the LW and SW radio signal propagation paths were analyzed: one group of paths passed over the seismic vibrator operation site (USOL-SCHC, ANGA-SCHC), the other group of paths was 200 km north-eastward from the former (USOL-MKSM, USOL-SCHC). A spectroscopic data processing of the Doppler sounding data was performed with a 60-s time window that corresponds to the 0.02-Hz spectral resolution. We analyzed the signal spectrograms along the USOL-SCHC, USOL-MKSM, ANGA-SCHC, ANGA-MKSM paths. The analysis showed that there were no additional spectral lines associated with the vibrator operation frequency (surpassing -20 dB of the main signal level).

3. Results of joint optical and Doppler observations during the vibrator operation

Joint experiments on observing ionospheric and optical effects accompanying the vibrator operation were performed in March-May, 2013, during new moons. Figure 2 (a, b) presents the measurement results of the 577.7-nm optical emission and the SW-signal characteristics at 3447 kHz at the USOL-MKSM path in the 2013 April 11-12 experiments (the path was 200-km northeast of the vibrator). Black lines mark the parameter dispersion on the 2013 April 8-10 and 13-25 referential days. The upper atmosphere optical airglow was recorded from the area north of the vibrator (at about 230 km north).

From Figure 2, one can see that there are synchronous 0.3-0.4 Hz increases in the SW-signal frequency (which corresponds to the ionosphere's downward motion at about 100-200 m/s) surpassing the measurement dispersion for 2 referential weeks. These frequency temporal variations agree well with the atomic oxygen 577.7-nm emission variations. The lag of the Doppler shift bursts relative to the vibrator operation start is about 20-40 minutes. Similar bursts were also traced in other experiments at the Usolye - Maksimikha path during the vibrator operation. The bursts were observed with about 2-h period, which corresponds to the vibrator power-on periods. No steady effect in the amplitude and spectral width variations in the received SW signal was observed. A similar effect of the SW signal frequency increase was also observed in other experiments during the vibrator operation when optical experiments were not performed.

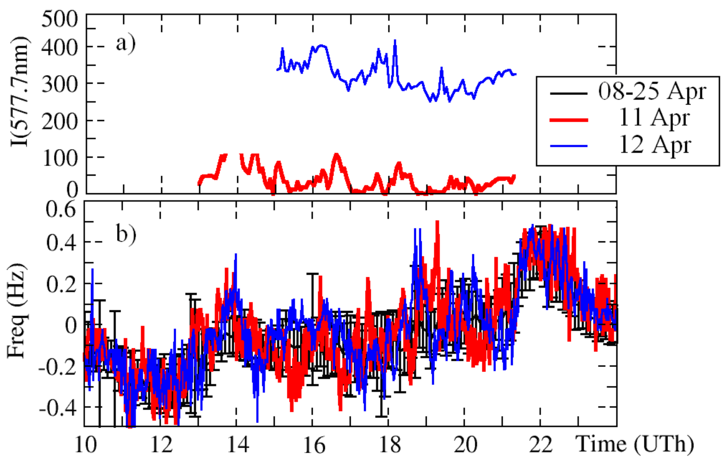

Figure 2. Results of optical (a) and Doppler observations (b) in the 2013 April 11-12 experiment. Black lines show dispersion of the Doppler measurement values for the 2013 April 08-25 referential days.

4. Results of experiment at the GPS-receiver network

To analyze the seismovibrator effects in the ionosphere, we used the data from the receivers located in Irkutsk (ISTP), Listvyanka (LIST), Maksimikha (MKSM), at Lake Shchuchye (SCSH), and immediately in the vibrator installation site, in Babushkin (BBSH). Figure 1 presents the location of these points. The measurements were taken at 1 Hz. From the obtained data, we calculated the total electron content (TEC) variations on the "receiver-GPS satellite" lines-of-sight (LOSs). After the filtration with a 2-20 min window, the TEC variations were analyzed for a respond to seismic events.

Analyzing the dynamics of the various-origin TEC disturbance propagations for 2013 August 14 showed the presence of two disturbances whose possible sources might be the vibrator-induced oscillations. The first was recorded near the seismovibrator at about 12:30 UT. The other started propagating around 15:00 UT. The amplitude of both disturbances was, on average, about 0.15 TECU. Analyzing their spatial-temporal parameters allowed us to determine an approximate propagation velocity. In the first case, it was ~ 100 m/s, in the other it was about 80 m/s.

One can see these disturbances most clearly on the LOS to the receiver located in MKSM. Figure 3a shows the TEC variations recorded at this station on August 14 (red) and 16 (dark blue) by using the PRN05 satellite signals. One can see that there is a disturbance with an ~ 0,3 TECU amplitude that started around 12:30 UT. Figure 3b presents the TEC variations recorded on the «receiver - PRN 21 satellite» LOS on August 13 (black), 14 (red) and 16 (dark blue). One can see an ~ 0,15 TECU disturbance in the 2013 August 13 TEC variations that started at 15:00 UT. Figure 1 shows the subionosperic points' trajectories of the LOSs to the PRN 05 and PRN 21 satellites with dark blue and red lines, respectively; the thickened sites are those the data for which are given in Figure 3.

These data show that, during the vibrator operation, no defined isolated TEC disturbances were practically observed. On August 14, recorded were two disturbances with comparatively large amplitudes whose sources could have been the vibrator-excited seismic waves. However, the recording of the first one starts at about 12:30 UT, i.e., 30 minutes before the facility was powered on, and, obviously, it is not associated with its operation. The recording of the other started with the facility's power-on at 15:00 UT, and it is, apparently, related to its operation.

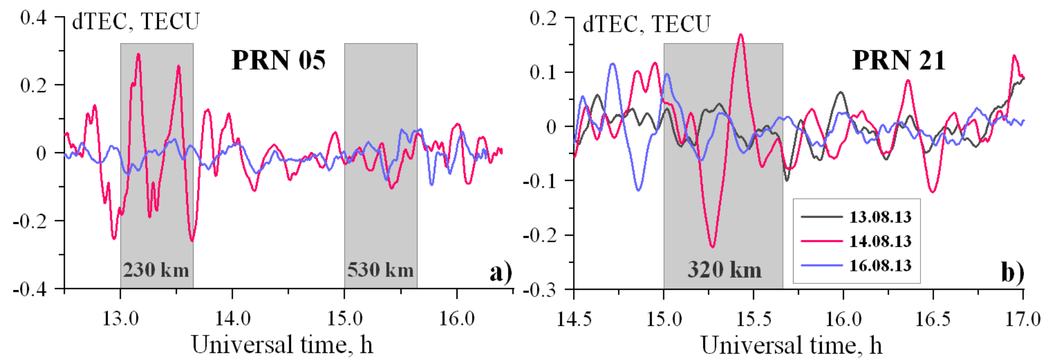

Figure 3. TEC variations on the days of the vibrator operation: 2013 August 13 (black) and 2013 August 14 (red); on 2013 August 16, on the day after the experiment (dark blue) on the LOSs to the PRN05 (a) and PRN21 (b) satellites. Gray rectangles mark the temporal boundaries of the vibrator operation, numerals show the distance from it to the LOS subionosperic point in the middle of the operation interval (for 2013 August 14).

Conclusions

The paper reviews the first results of the investigations into the effect of a seismovibrator on the atmospheric and ionospheric conditions. The research was done in the Baikal region during nighttime.

Experiment showed that at the seismovibrator operation in the fixed frequency mode (10-min operation at 5-7 Hz and a 10-min pause), the amplitude modulation of the signal propagating over the vibrator operation site and aside the latter is absent or below the noise level in the LW and SW range.

From the first experiments, there were revealed 0.3-0.4 Hz increases in the SW-signal frequency surpassing the measurement dispersion for 2 referential weeks. These temporal variations agree well with the atomic oxygen 577.7-nm emission variations. The lag of the Doppler shift bursts relative to the vibrator operation start is 20-40 minutes. Similar bursts were traced in other experiments during the vibrator operation.

The presented data on diagnosing the vibrator effects on the ionosphere via the GPS-interferometry techniques show that well-defined isolated TEC disturbances were not practically observed during its operation. On 2013 August 14, there were two recorded disturbances with comparatively large amplitudes whose sources could have been the vibrator-excited waves. However, the recording of the first one started at about 12:30 UT, i.e., 30 minutes before the vibrator power-on, and, apparently, it was not associated with its operation. The recording of the other started with the vibrator power-on at 15:00 UT, and may be associated with its operation.

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