The lower atmosphere response to seismic events using satellite data

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Abstract. Modern space technologies allow finding vertical profiles of temperature, pressure and humidity in the troposphere and stratosphere for the entire globe. Together with the use of signals from the GLONASS and GPS space systems, the data on the vertical profiles can detect the atmosphere effect of internal gravity waves excited during seismic events. The temperature time series of the atmosphere temperature at the isobaric levels of 450 and 200 hPa were studied in the period from February 1 to April 14, 2011 near the epicentral area of the earthquake in Japan, 2011. It was found that along with temperature fluctuations in the troposphere and in the stratosphere a mirror wave is observed, there are oscillations similar to those of the troposphere oscillations, but which are in opposite phase with them. The mechanism of the origin of the mirror wave is presented as well as the process of its simulation. It is shown that the troposphere and the stratosphere can be used as an antenna receiving infrasonic waves during seismic events, and space technologies as a means of recording these waves.

Keywords: Space Technologies, Geophysics, Vertical Profiles Atmosphere, Polytropic Atmosphere, Internal Gravity Waves, Temperature Inversion, Mirror Wave, Earthquake in Japan 2011.

Modern space technologies allow us to explore the Earth's atmosphere, to obtain vertical profiles of temperature, pressure and humidity in the troposphere and stratosphere for the entire globe [1-4]. NOAA spacecrafts, as well as Suomi NPP and Metop with ATOVS, ATMS and CrIS instruments are used for evaluating the vertical profiles of the atmosphere [5-7]. We used information from the Air Recourse Laboratory NOAA website on a $1^{o}\times1^{o}$ grid in latitude and longitude, set at intervals of 3 hours [8].

The vertical profiles data are applied in meteorology and aviation, these data allow us to estimate the tropospheric delay of signals of satellite navigation systems GLONASS and GPS [9]. Finally, these data allow us to observe interesting geophysical phenomena.

Slow oscillations of the earth's surface occur during seismic activity in the epicentral region of the earthquake, and acoustic (infrasonic) vibrations with a period of several days are emitted. Direct registration of such oscillations is extremely difficult.

However, they can be detected by indirect signs – by the excitation of internal gravitational waves (IGW) in the atmosphere [9]. Internal gravitational waves [10] provoke a change in the electron content in the ionosphere, the phenomenon can be revealed with the GLONASS/GPS receiving equipment [9, 11]. The IGW can affect the troposphere and the stratosphere.

A catastrophic earthquake of magnitude *M*=9 [12-16] occurred off the coast of Japan on March 11, 2011. It was accompanied by a tsunami and caused numerous victims among the population, as well as the destruction of the Fukushima nuclear power plant. The epicentral area of the earthquake was located in the Pacific Ocean, the epicenter coordinates are 38º N, 142º E. Figure 1 shows the of time series graphs of temperature changes in atmosphere at the isobaric levels of 450 and 200 hPa from February 1 to April 14, 2011 near the epicentral area of the earthquake. The arrows show the time of the main shock with a magnitude of *M*=9 and the strongest aftershock with *M*=7.

The isobaric level of 450 hPa corresponds to a height above sea level of about 6300 m, which is the troposphere. Let us call the graph at the level of 200 hPa a mirror wave (MW). The level of 200 hPa corresponds to height of about 12000 m and is located at the low level of the stratosphere. We take into account that the epicentral area of the earthquake is in the Pacific, there is no land there and, therefore, no orographic phenomena. It is known [9] that sea waves (except for tsunami waves) cannot excite waves in the atmosphere. Thus, it can be argued that temperature fluctuations in Fig. 1 are caused precisely by the internal gravity waves generated by seismic processes. The rare sampling step did not allow detecting the moments of seismic shocks, but infrasonic temperature fluctuations in the atmosphere (frequency is less 10-5 Hz) after the earthquake and in front of it are clearly visible.

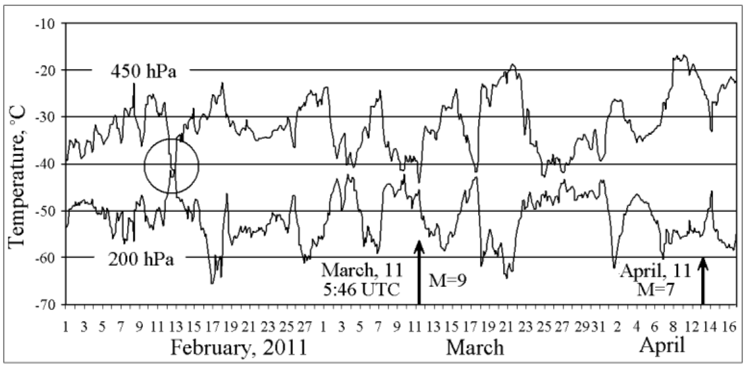

Fig.1. Temperature change at isobaric levels of 450 hPa and 200 hPa at a point with coordinates 38º N, 142º E in the Pacific in the epicentral area of the earthquake in Japan 2011.

The time series shown in the graphs contain significant wave oscillations. The standard deviation of temperature is σ=4.7 K for the time series at the isobaric level of 200 hPa and σ=4.5 K for the time series at the level of 450 hPa. The correlation coefficient between the temperature series at the levels of 450 and 200 hPa is R=-0.76 for the period from February 1 to April 14. The largest negative correlation coefficient falls on the period from February 27 to March 28 and is equal to R=-0.86. Further, the correlation coefficient began to increase and in June became positive. Variations in the electron content in the ionosphere during the period of seismic activity associated with the earthquake are considered in [9].

Fig. 2 shows the “background” graph of temperature fluctuations for the same point with the coordinates of 38º N, 142º E in July 2011, when seismic events have almost stopped. The temperature time series in Fig. 2 are similar to each other. The paired correlation coefficients for the time series in July-August at the levels are positive and are in the range R=0.26-0.75. The time series have a standard deviation of σ=1.6 K for a level of 200 hPa and σ=1.8 K for a level of 450 hPa.

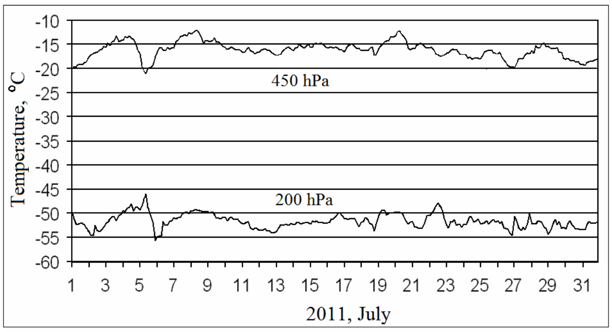

Fig. 2. Temperature variations at isobaric levels of 200 and 450 hPa in the Pacific Ocean, point with coordinates of 38º N, 142º E.

In the troposphere the temperature decreases with height, for the standard troposphere, *a* constant vertical temperature gradient α=0.65 K/100 m is adopted, the temperature dependence on the height z above sea level has the form $T=T_0-\alpha z$, T_0=288.15K [11]. In this case, the dependence of pressure p on height is described by the barometric formula for a polytropic atmosphere [17-18]:

$$p = p_0 \left(\frac{T_0 - \alpha z}{T_0} \right)^{\frac{g}{R_c \alpha}} \tag{1}$$

In (1) p_0=1013.25 hPa, g is the acceleration of free fall, R_c=287m^2/(s^{2}K) is the specific gas constant of dry air. The dependence of temperature on pressure is nonlinear:

$$T = T_0 \left(\frac{p}{p_0} \right)^{\frac{R_c \alpha}{g}} . \tag{2}$$

The origin of the mirror wave is easy to understand, given that the temperature in the stratosphere increases with height, starting from the upper tropopause boundary z_1: $T=T_1+\beta(z-z_1)$, where β<0. Instead of (2) we have

$$T = T_1 \left(\frac{p}{p_1} \right)^{\frac{-R_c|\beta|}{g}} = T_1 \left(\frac{p_1}{p} \right)^{\frac{R_c|\beta|}{g}}, \tag{3}$$

where T_1 and p_1 are the temperature and pressure at the height z_1.

Let's consider a possible model for the excitation of waves in the troposphere [6-7]. Let the pressure at the ground level change according to the law: $p_0' = p_0 + P\cos(\omega t)$, for example, due to the influence of meteorological factors or due to the movements of the earth's crust. It is assumed that the infrasonic waves excited by a change in pressure move with the speed of sound and during the passage of the wave the state of the air medium does not have time to change (adiabatic approximation), this allows using the equations of atmospheric static, which include (1), (2) and (3).

In Fig. 3 on the left is a model of the atmosphere. The dependence of temperature on height is depicted as two straight lines: *AB*, where the temperature decreases linearly with height and the *BC*, where it linearly increases. Thus, we have two sections of a polytropic atmosphere.

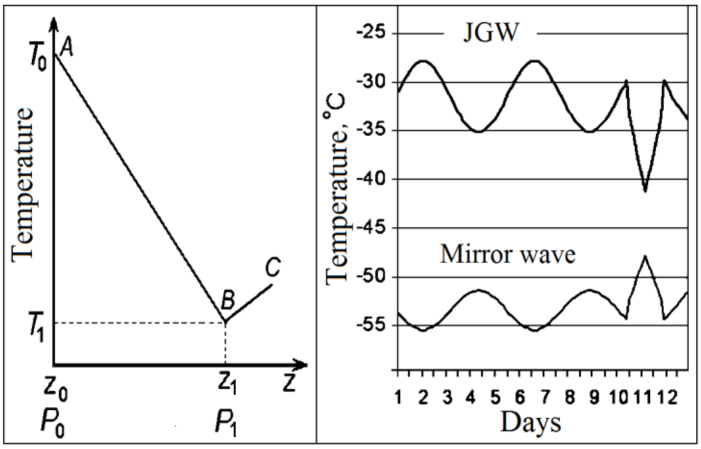

Fig. 3. Simulation of an internal gravity and a mirror waves.

We assume that for these sections the temperature T_1 and the pressure p_1 coincided at the break point *B*. The temperature at the isobaric level *p* is defined by (1). In the upper right part of Fig. 3 there is a graph of the time dependence of a model infrasound wave at a level of p = 450 hPa, representing in some approximation an internal gravitational wave. Here T_0, p_0 and α are defined the same as for the standard atmosphere, with P=80 hPa. This graph also shows the “surge” of temperature that simulates a seismic event.

Let the temperature T_1 be set at point *B*, then the pressure at that point can be represented as

$$p_1 = p_0'\left(\frac{T_1}{T_0}\right)^{\frac{g}{R_c\alpha}} \tag{4}$$

In the interval *BC* the temperature can be estimated according to this formula

$$T = T_1\left(\frac{p}{p_1}\right)^{\frac{-R_c|\beta|}{g}} = T_1\left(\frac{p_1}{p}\right)^{\frac{R_c|\beta|}{g}} = T_1\left(\frac{p_0'}{p}\right)^{\frac{R_c|\beta|}{g}}\left(\frac{T_1}{T_0}\right)^{\frac{|\beta|}{\alpha}}. \tag{5}$$

Using (5) for T_1= 213.15 K, p = 200 hPa, β= -4, a mirror wave was constructed, shown in Fig. 3, bottom right.

When IGW is excited changes in surface temperature are not taken into account. In addition, it is not taken into account that the mirror waves depend not only on IGW, but also on the state of water vapor in the troposphere. Nevertheless, the graphs in Fig. 3, from a qualitative point of view, reflects the observed phenomena in a correct way.

The waves in the atmosphere depicted in Fig. 1 and 3 are analogous to waves in a stratified ocean, which were discussed by V.V. Shuleikin [19]. At the water-air interface, there are surface waves excited by the wind. Particles of water in them move along elliptical paths. In the ocean the average density of water increases downwards; there is a boundary between waters of different densities. When a surface wave moves up and down, either a rarefaction or an overpressure occurs at the boundary. Due to the condition of maintaining hydrostatic equilibrium (continuity condition), water particles move upward under the base wave sole and down under its crest at the boundary. In oceanology, the newly formed wave is called the internal (gravitational) wave [19]. Surface and internal waves move in opposite phase. In the troposphere IGW is the surface analog and the MW in the stratosphere is the analog of the internal wave.

It is believed that the infrasonic oscillations of the earth's crust are one of the forerunners of the earthquake, but there are significant difficulties in detecting such oscillations. The results presented above show that the troposphere and stratosphere can serve as an antenna that receives these oscillations and space technologies as a means of recording. However, at the present level of development neither these techniques nor other methods of seismic control show reliability in making short-term earthquake predictions.

Nevertheless, using data on the vertical profiles of the atmosphere, it is possible to outline area and some features of the location of seismic phenomena. In Figure 1 it can be seen that on February 12, 2011, a month before the main seismic event, for a short time (3-6 hours) two differently directed temperature “surge” appeared at the levels of 450 and 200 hPa (they are shown in a circle). This might be a result of the movement of tectonic plates, a precursor of the main shock, as well as of the multidirectional fluctuations in temperature on March 2, 7 and 10.

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