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# ACOUSTIC EFFECTS OF AN UNDERWATER EXPLOSION IN THE *D* REGION OF THE POLAR IONOSPHERE

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**Abstract.** Results of experimental researches of acoustic action of an underwater explosion by capacity 3-7 tons of trinitrotoluene (TNT) on the polar lower ionosphere are submitted. The experimental data were received with the medium wave radar (Tumanny, Murmansk region) by the method of partial reflections of radio waves. Parameters of the wave disturbances which were observable in the polar lower ionosphere during this event were determined.

## 1. Introduction

An underwater explosion of chemical explosive charges represents, basically, a source of gas-dynamic influences on environment, resulting in seismic, hydroacoustic, acoustic, and other effects. The significant number of theoretical and experimental works is devoted to research of underwater explosions [*Cole*, 1950; *Adushkin et al*., 2004]. In the work, results of observations of the surface phenomena during explosion and registration of hydroacoustic waves in water, seismic waves on ground, and acoustic waves in air on various distances from the epicenter of an explosion are submitted. Parameters of appearing waves, character of their attenuation with distance are listed, and their spectra are analysed. The characteristic feature of an underwater explosion is pulsations of the gas bubble produced by the explosion. The pulsations can be seen in wave forms of hydroacoustic, seismic, and acoustic waves and their spectra.

Under certain conditions acoustic waves can be spread in the ionosphere to big distances causing in it disturbances, which are the strongest and longest in the polar regions. Despite of significant successes in research of atmospheric dynamics, now we have only enough general idea about distribution effects and interaction processes of atmospheric waves with the ionosphere [*Gossard and Hooke*, 1978; *Gokhberg and Shalimov*, 2008].

The purpose of the work is experimental researches of an acoustic impact of an underwater explosion on the polar lower ionosphere by the method of partial reflections (MPR) of radio waves. Studying of mechanisms of influence of atmospheric disturbances on weakly ionized ionospheric plasma is important for solution of the various scientific and practical problems touching the problem of interaction of the lithosphere, the atmosphere, and the ionosphere.

## 2. Equipment and measurement technique

Reaction of the lower ionosphere to the underwater explosion was studied with MPR. At the heart of this method there is radiation of two wave modes as alternating pulses, or linearly polarized waves on frequencies in the range from 2 till 6 MHz [*Rapoport*, 1972]. At the first case we used separate reception of signals, which partially reflected by ionospheric irregularities, and measured their amplitudes. The amplitudes depended on time of the delay which determined the height of reflection. At the second case two orthogonal linear polarizations were received. Then signals of two circular components were formed by adding of the shifted phases by ±90°. In Russia it is only one radar of partial reflections which operates on a constant basis. It is near the village Tumanny, Murmansk region (69.0°N, 35.7°E) and belongs to PGI KSC RAS. Key parameters of the radar correspond to existing technological level of radars of the European countries.

The radar for research of the lower ionosphere consists of the transmitter, the receiver, the transmit-receive phased array and the automated system of data acquisition. The radar working frequencies are 2.60÷2.72 MHz; capacity of the transmitter at a pulse is about 60 kW; duration of the pulse is 15 μs; and the frequency of sounding is 2 Hz. Array consists of 38 pairs of the crossed dipoles, occupies the area of $10^5$ $m^2$, and has the width of the directional diagram about 20º at the level of half-power. In turn, two circular polarizations, which are amplified by the receiver of direct amplification with the band of 40 kHz, are received. Registration of amplitudes and phase differences of signals is carried out at the interval of heights of 50-240 km. The interval of recording of the data on height is from 0.5 till to 1.5 km. The detailed description of the equipment is submitted in the works *Tereshchenko et al*. [2003; 2011].

Amplitudes of ordinary and extraordinary components of the reflected signal were averaged for every minute at all of recorded heights. Using the average data of the amplitudes of reflections of radio waves the structures of the electron concentration *Ne(h)* by the method of differential absorption were calculated. Digital time series of parameters of the received signals were used to the spectral analysis by means of the short-time Fourier transform and wavelet transforms.

## 3. Results of measurements and analysis

As the source of disturbances at the circumterrestrial environment the explosion on the nuclear submarine (NS) "Kursk" was considered. According to seismic data of the network of stations on 12 August 2000 there were two seismic events in Barents sea with coordinates 69.604ºN and 37.160ºE [*Koper et al.*, 2001]. The first event was fixed at 7:28:27 UT with magnitude ML=2.2, the second was at 7:30:42 UT with magnitude ML = 4.2. The nature of the first event it was not possible to determine, but according to all attributes, the second event was a typical underwater explosion. By various estimations energy of the second explosion corresponded to 3-7 tons of trinitrotoluene (TNT).

In Figure 1 altitude-temporal dependences of the amplitude of reflections of the ordinary wave and the electron concentration are shown during the explosion on the NS "Kursk". The radar of PGI KSC RAS was situated about 70 km from the place of the explosion.

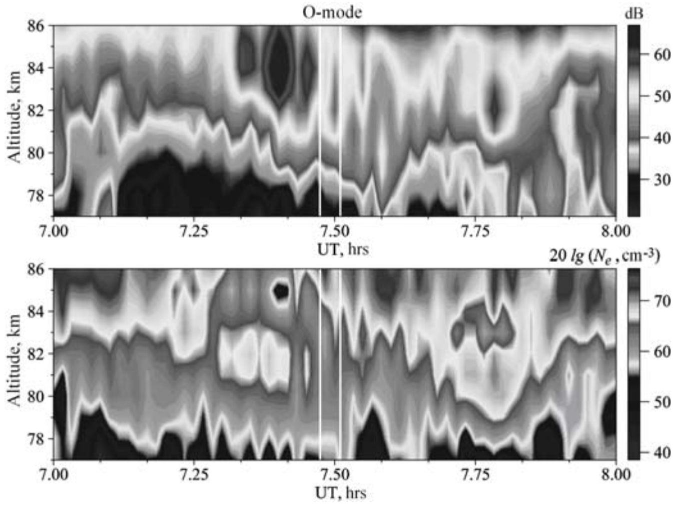


**Fig. 1.** Amplitudes of radio echo and the electron concentration as functions of time and heights (vertical lines are the moments of seismic events).

In the Figure wavy changes of considered parameters in the course of time are visible. Observable quasi-periodic processes can be caused by influence of a shock-acoustic wave (SAW). Time of distribution of the SAW up to the *D* region of the ionosphere is approximately equal to 4 minutes, and up to the *E* region it is about 6 minutes. Splashes in the amplitude of reflections are usually connected to amplification of intensity of heterogeneous structure of the electron density and increasing in the electron concentration. It is necessary to note, that there is a conformity of intensive reflections of the ordinary wave with a) the region of lower electron density (at 7:19÷7:31 UT) and b) the region of increased electron concentration (at 7:45÷7:48 UT).

The prominent feature of the observable events was that they occurred during a strong magnetic storm with Kp = 7.7 and Dst = 197 nT (Figure 2).

The analysis of time variations of the horizontal component of the geomagnetic field has shown, that, for 8 minutes before the first event, on the background of smooth reduction of the geomagnetic field two sharp increase of its amplitude by 70 and by 30 nT have taken place which have duration about 3 minutes each. The values of quasi-periods of disturbances were 3-6 minutes.

In Figure 3 the spectrograms received from the data of partial reflections for the concrete heights of 47.5 and 83.0 km are submitted. It can be seen, that ionospheric disturbances which have occurred before explosion are visible the most clearly at the height of 83 km. Interpretation of the signals is complicated, but the considered event, to all attributes, is typical one for starts of rockets or charged particles penetrations.

For the model of the isothermal atmosphere of the Earth the border between sound and internal gravity waves (IGW) lays in the field of the periods about 5 minutes [*Gossard and Hooke*, 1978]. From results of observations (Figure 3) follows, that the explosion generated in the lower ionosphere the infrasonic fluctuations with the period about 3 minutes and the IGW with the period of 6 minutes.

In Figure 4 variations of the total electron content (TEC) at the heights of 70-90 km in the mesosphere (the *D* region of the ionosphere) before considered events are shown.

With the purpose of revelation of ionospheric response of the SAW, time series of the TEC were subjected to procedure of removal of a linear trend. It turned out, that the obtained pulse ionospheric disturbance could be characterized by the *N*-shaped wave (compression with the subsequent exhaustion) with the periods of 8 and 16 minutes (Figures 4a, b).

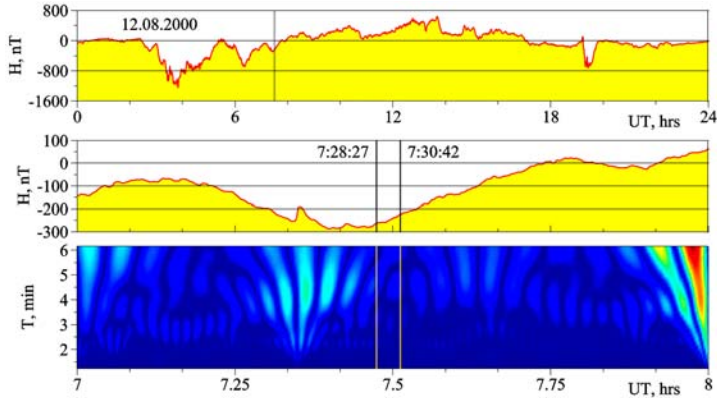


**Fig. 2.** Magnetograms of the *H*-component received at Tumanny and its wavelet spectrum during the underwater explosion.

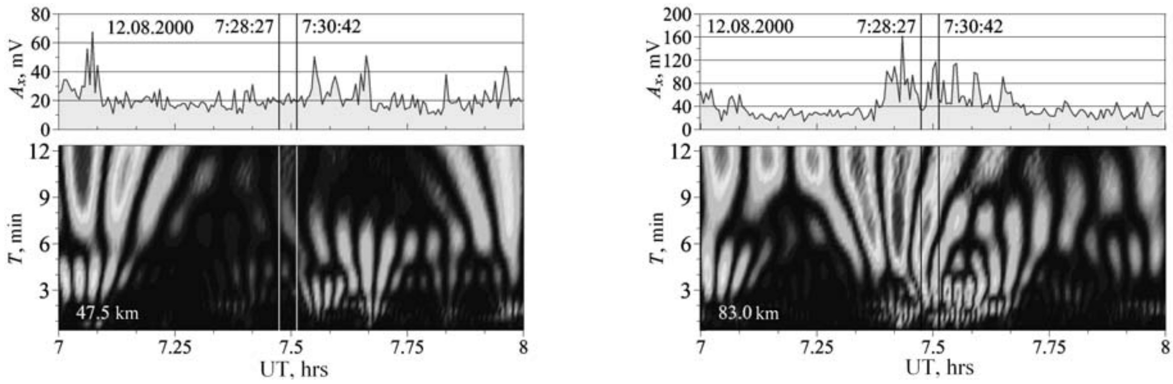


**Fig. 3.** Variations of amplitude of reflections and its wavelet spectrum during the underwater explosion.

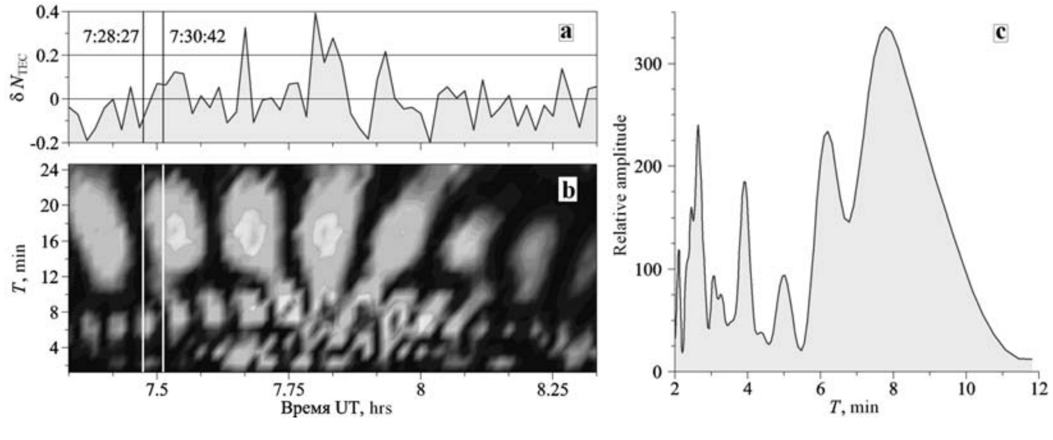


**Fig. 4. a)** fluctuations of the total electron content in the mesosphere on 12 August 2000 from 07:20 till 08:20 UT, **b**) their wavelet spectrum, and c) their Fourier spectrum.

At the same time, the amplitude of $\delta N_{TEC}$ exceeds the level of background fluctuations at least in 2-4 times that indicates about essential influence of the explosion on the lower ionosphere. The first significant disturbances of TEC have arisen in 10 minutes after the explosion. It was observed three splashes $\delta N_{TEC}$ during 20 minutes. Phase speed of quasi-periodic disturbances (300 m/s) is close to speed of sound at the heights of the *D* region of the ionosphere. In Figure 4c it is visible, that the underwater explosion leads to generation or amplification of infrasonic waves with the periods from 2 till 4 minutes and IGW with the periods of 6, 8 and 16 minutes.

An underwater explosion forms a bubble of hot gases and pressure inside the bubble is much higher, than in the environment. The gas bubble in process of rise to the surface of water quickly extends and forms in water a shock wave. An output of the shock wave to the surface of water and the subsequent formation of a water column or a sultan, and then its rise and destruction during break of products of explosion into the atmosphere force neutral gas to radiate AGW which spread in different directions and upwards from the source. The AGW modulate parameters of the ionosphere (by means of interactions of particles). It leads to generation of wave disturbances in the ionosphere. As the density of the atmosphere decreases exponentially with height, conservation of energy of disturbances leads to the situation when the amplitude of a wave grows as it spreads upwards. Therefore in the ionosphere it is possible to register disturbances which are hardly distinct on the atmospheric noise background of the surface layer.

Thus on the basis of the data of the method of partial reflections it has been established, that the underwater chemical explosion was accompanied by amplification of wave activity in the polar lower ionosphere on frequencies of infrasonic and internal gravity waves.

## 4. Conclusions

Results of radar research of acoustic action of the underwater explosion by capacity 3-7 ton of trinitrotoluene on the polar lower ionosphere have been submitted.

Infrasonic and internal gravity waves were registered in the *D* region of the polar ionosphere during this event. Spectra and parameters of observable waves are determined.

It is shown, that the most typical feature of the ionospheric response of the considered underwater chemical explosion was the pulsation of the total electron content in the mesosphere as the *N*-shaped wave with the periods of 6-8 minutes and with the amplitude exceeding the level of background fluctuations in 2-4 times.

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