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MESOSPHERIC OZONE IN ARTIFICIAL MODIFICATION OF LOWER IONOSPHERE

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Abstract. We present some results of microwave observations of the middle atmosphere ozone under perturbation of the ionosphere by a power HF radio emission by the mid-latitude SURA heating facility (56N, 46E). New experiment was a continuation of studies to clarify the physical nature of the new phenomenon a decrease of the intensity of the microwave emission of the mesosphere in the ozone line when artificially impact on the lower ionosphere [1].

Methods and instrumentations. Investigation of the middle atmosphere ozone at the mesosphere altitudes and its response to high-frequency impact on the ionospheric plasma was studied using the method of microwave ground-based radiometry to measure the atmospheric spectrum in the ozone line [2] and the method of creating of artificial periodic irregularities (API) to diagnose of the lower ionosphere condition and measurement some ionosphere and mesosphere parameters [3]. The first results of these studies are given in [4]. To analyze the ionospheric condition and choose the radiation frequencies of the heating and diagnostics facilities for studying the lower ionosphere by the method of creating the artificial periodic irregularities, we used the data from vertical sounding by the DPS-4 ionosonde (Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation of the Russian Academy of Sciences (IZMIRAN)) in Troitsk (55N, 37E) and CADI ionosonde located near SURA heating facility (Radiophysical Research Institute, Lobachevsky State University of Nizhny Novgorod).

Figure 1. General view of a mobile microwave ozonemeter. Parameters of device: observation frequency – **110.8 GHz**; temporal resolution – **15 min**; band of the analysis of a spectrometer – **240 MHz**; frequency resolution – from **1** up to **10 MHz**; in measurements of spectra of a middle atmosphere ozone the method of absolute calibration is used; estimation of a vertical profile of ozone at altitudes from **20** up to **60 km** is carried out accuracy o **10** –**15%**.

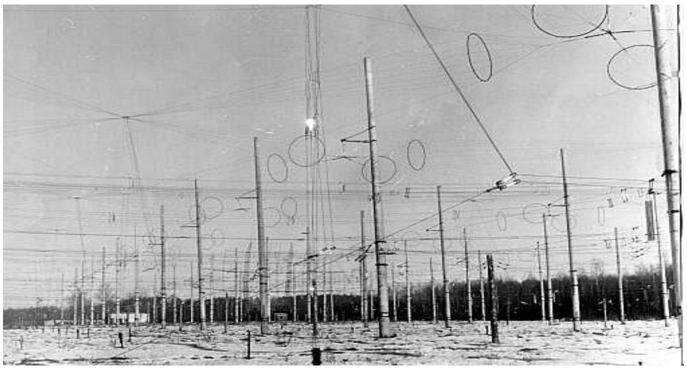


Figure 2. The SURA heating facility is intended for research of the nonlinear processes in ionospheric plasma under action of powerful HF radiation. Basis of the SURA facility are three radio transmitters with power **250KW** everyone (frequency range of transmitters **4-25 MHz)** and the 144-element phased array in the size 300 on 300 square meters. The SURA facility can radiate powerful **X** and **O** polarization modes radio waves at the frequencies from **4.3 MHz** up to **9.5 MHz** with the effective radiated power from **80 MW** up to **250 MW**.

Method of the ground-based microwave radiometry. The method of microwave ground-based radiometry is based on measuring the rotational emission spectra of small gas constituents of the atmosphere in the millimeter and sub-millimeter wave ranges. The advantage of the method over measurements in the infrared and optical wavelengths is its weak dependence on meteorological conditions and the presence of aerosols. Microwave observations of ozone can be performed around the clock. The mobile microwave ozonemeter consists of an uncooled heterodyne millimeter wave receiver and a multichannel spectrometer. Working device during campaign by an autumn of 2019 is shown in a Fig. 1. The receiver was tuned to the fixed frequency at 110836.04 MHz (the wavelength 2.7 mm). The spectrum analyzer consists of 31 filters with a variable band from 1 to 10 MHz and a full analysis band of 240 MHz. The device parameters allow one to measure the spectrum of the ozone emission line with accumulation for 15 min with an error of no more than 1–2%. Information about the content of the O_3 is contained in the measured radio emission spectrum of the middle atmosphere. The error of estimating of vertical profile ozone on its measured spectra does not exceed 10-15%.

The method of the resonance scattering of radio waves on artificial periodic irregularities of the ionospheric plasma. Artificial periodic irregularities (API) were observed in 1975 for the first time in the experiments on studying the influence of high-power radio waves on the sounding radio waves reflected from the ionospheric F-region [5]. In the subsequent experiments, it was proved that API are formed in the field of a high-power standing radio wave resulting from interference of the radio waves, which are incident on the ionosphere and reflected from the latter, in the altitude range from the beginning of the D-region (50–60 km) to the altitude of reflection of a high-power radio wave. In the D-region, irregularities are formed because of the temperature dependence of the coefficient of the electron attachment to the oxygen molecules during triple collisions [3]. Periodic structure of the temperature and, as a consequence, plasma concentrations with the spatial period that is equal to half-length of a powerful radio wave in the plasma are formed because of no uniform heating of electron gas. Sounding of the created periodic structure with probe radio waves is a method for its diagnostics. Methods for determining many parameters of the ionosphere and neutral atmosphere have been developed. The main ones are the vertical velocity of the ionospheric plasma ant the neutral atmosphere, the temperature and the density of the neutral component, the electron density, some parameters of the sporadic E-layer including its ionic composition, an attachment and detachment of electrons to molecules, the ratio of the number of the negative ions to the number of electrons, variation of atomic and excited molecular oxygen and other characteristics of the ionospheric D and E regions. The combination of two methods for studying the atmospheric-radiation spectra in the ozone line during artificial ionospheric modification by high-frequency radio waves from the SURA facility was for the first time experimentally realized in September 2016. The results of these studies are presented in [4]. In Fig. 2 the general view of the SURA facility is shown.

The results of observations and discussion. Experiments with measuring the emission spectrum of the atmosphere in the ozone line were carried out from 10 to 12 September 2019. The SURA heating facility radiated into the zenith an extraordinary radio wave with a frequency of 4.7 MHz from 10:01 to 18:01 with an effective power about 100 MW for 30 minutes on September 11-12, 2019. The antenna of a mobile microwave ozonemeter was oriented in the same direction. In two days, thirteen of long 30-minute exposure to the ionosphere were carried out.

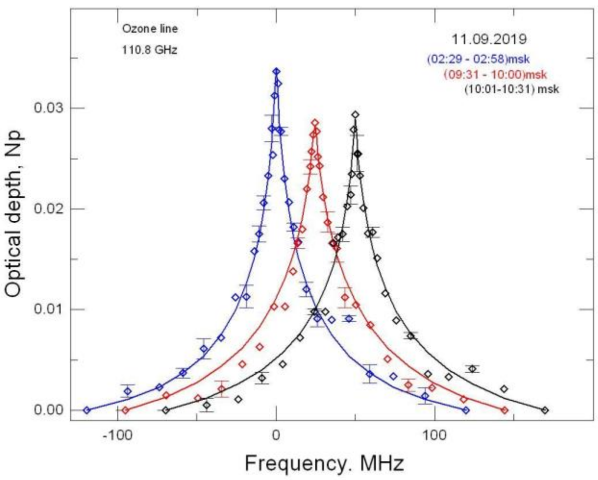


Figure 3. Modification of the ozone spectrum during artificial disturbance of the ionosphere for one of the heating session September 11, 2019.

In the next 30 minutes, the SURA facility was switched to the operating mode for the API creation and diagnosis. The microwave ozonometer operated at a frequency of 110836.04 MHz in the mode of continuous measurement of the radiation intensity in the ozone line. The measurement of each spectrum lasted 15 minutes, so that two ozone emission spectra were obtained in each heating interval of the ionosphere and during heating off. Thus, it was possible to compare the spectra of ozone during artificial disturbance of the ionosphere and after its termination. In addition to variations in the mesospheric ozone caused by the heating of the lower ionosphere by powerful HF radio waves, day-to-night measurements natural background variations in the ozone emission of the middle atmosphere were carried out. The most known natural ozone variations are its daily variations at altitudes of over 40 km associated with sunrise and sunset. Figure 3 shows the change in the ozone spectrum during artificial disturbance of the ionosphere for one of the heating session September 11, 2019. In Figure 3 the spectrum of atmospheric emission in the ozone line obtained on September 11, 2019 during the heating session at 09:31 (red marks) and the pause session at 10:01 (black marks), depending on the frequency of detuning from the operating frequency of 110836.04 MHz of the ozonemeter. The spectrum for the night session 02:29-02: 58 (blue marks) is also shown. For clarity, the spectra are shifted along the frequency axis to the right and left by 100 MHz. The vertical bars show the standard deviation when calculating the averaged spectrum. Solid curves (red, blue and black) show the spectra calculated using the vertical ozone distributions. The spectra were obtained for the altitude interval 22-60 km. The spectrum intensity is presented in units of the optical thickness. In Figure 3 the difference between the intensities of the spectra for September 11, 2019 for an artificially disturbed ionosphere from its undisturbed state is 3%, and the difference between night and day is 14%. The main result of measurements is a decrease in the intensity of atmospheric emission in the ozone line during heating by an average of (7 ± 1) % relative to the emission intensity during a pause in the operation of the facility. For individual sessions, the decrease was 9%. The difference between the spectra obtained during heating on and heating off sessions was small. The decrease in ozone concentration at the altitude of 60 km was 12%. The ozone concentration was calculated by the method presented in [6]. In some sessions, the reduction was up to 20%. Note that the relative value of the decrease in the ozone-line intensity during ionospheric heating is small and is in some cases comparable with the measurement error. However, the differences in the spectra during the heating on and heating off sessions are considered significant, since they were observed in all experiments on studying the ozone spectrum in an artificially disturbed ionosphere.

Figure 4 shows ozone density variations at the altitude of 60 km for three days during experiments at the SURA facility in September 2019, of which ozone observations with the disturbance of the ionosphere were carried out on September 11 and 12, 2019. In Figure 4 each black point is obtained for the corresponding intensity of the ozone line measured with an accumulation time of 15 minutes. Red and blue dots show ozone density values averaged over each heating and pause session. Of these, each point (except for the averaged values for the intervals of heating on and off) was also obtained for the corresponding intensity of the ozone spectral line. The horizontal lines show the ozone density values averaged over all heating sessions (red line) and pauses (blue line). In order not to clutter up the figure, the error in determining the ozone density, which is no more than 10%, does not show in the graph. Figure 4 clearly shows the correlation of ozone density variations with heating periods. The following features of ozone density variations are also visible.

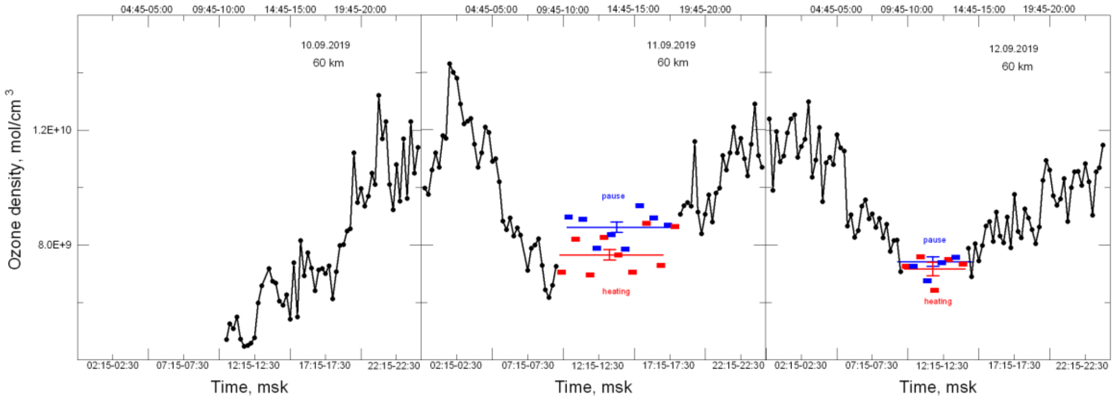


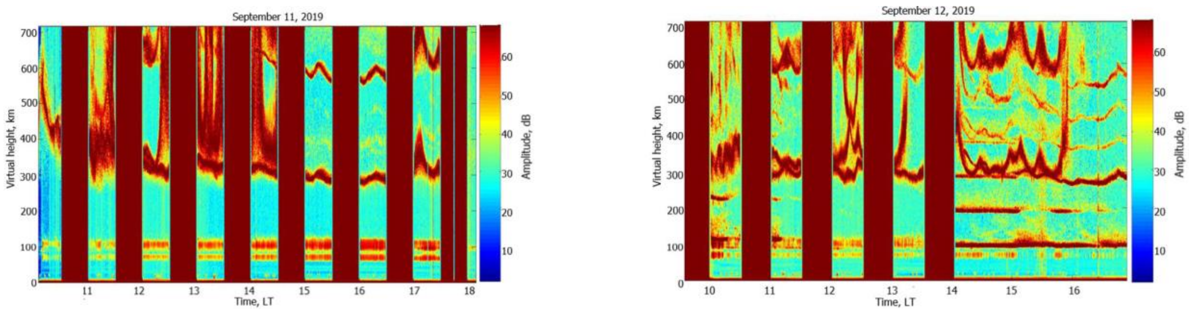
Figure 4. Continuous diurnal variations of the ozone density (60 km) during September 11 – 12, 2019.

1. A significant difference in the results on the change in the ozone density during the heating time for September 11 and 12, both in the average values for the whole day and for individual sessions. In September 12, changes in the ozone density during heating turned on to be on average very small and amounted to no more than 3%. On September 11, they were equal to 12% on average, and in some sessions they increased up to 20%. **2**. Relatively fast and deep variations in the ozone density are clearly visible, ranging from 30 to 50%. They are not related to the heating of the ionosphere, and are probably largely due to the dynamics of this region of the mesosphere, including winds with variations of the direction and magnitude of the velocity, developed atmospheric turbulence, a propagation of atmospheric waves, changes in the composition of the mesosphere at these altitudes over time, and other factors. **3**. One can see wavelike variations in the ozone density with a quasi-period from 45 minutes to 3 hours or more. **4**. Daily variations in the ozone density are visible, with noticeable differences occurring at night and during the day, which corresponds to the usually observed daily variation of ozone density with an excess of nighttime concentration values over daytime; the average amplitude of the daily change in the density of atmospheric ozone was about 40%. **5**. The change in the amplitude of the diurnal variation on different days of observations is clearly noticeable, which can be explained by the influence of natural dynamic processes on the ozone in the mesosphere.

Diagnostics of the lower ionosphere using the method of artificial periodic irregularities

To study the perturbations of the ionized component at the heights of the mesosphere and lower thermosphere, we used the method of resonant scattering of radio waves (the API technique).

Figures 5 and 6 shows the dependences of the scattered signal amplitude on the virtual height and the time on the days of ozone measurements on September 11 and 12, 2019. The Figures show signals both reflected from the ionosphere (virtual heights above 300 km) and signals scattered by artificial periodic irregularities in the height range of 60-130 km. For presentation in this form, the signal amplitude was averaged for every 12 second from the beginning of its recording. In Figures 5 and 6, red vertical stripes show 30-minute intervals of the SURA facility was turned on. As a rule, in the first minute of a 30-minute interval (end of the pause, or start of the heating), the CADI digital ionosonde recorded an ionogram. Figures 3 and 4 show that in the altitude interval 60-80 km, signals scattered by artificial irregularities were observed in the D-region. From the time-altitude signal amplitude dependences scattered shown in Figures 5 and 6 shows that 11 and 12 September status ionosphere was different that, in particular, manifested a difference in the behavior of API scattered signals.



Figures 5 and 6. The virtual height-time dependence of the scattered-signal amplitude in September 11 and 12, 2019.

Conclusion. The paper presents and discusses the results of comprehensive studies of the Earth's lower ionosphere at mesospheric heights by creating artificial periodic irregularities of the ionospheric plasma with simultaneous measurement of the atmospheric emission spectrum in the ozone line by ground-based microwave radiometry. The purpose of the experiments was to study the possible effect of artificial influence on the ionosphere by powerful high-frequency radio emission from the SURA facility on the concentration of mesospheric ozone at an altitude of 60 km. The correlation between the decrease in the intensity of the emission spectrum of the atmosphere in the ozone line and the period of switching on the powerful heating facility, found in other observations, was confirmed.

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