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INFLUENCE OF HF POWERFUL WAVES ON THE OZONE CONTENT IN THE EARTH'S ATMOSPHERE

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Abstract. We present some results of microwave measurements of ozone number density variations in the mesosphere (in the ionospheric D-region at altitudes of ~ 60 km) under conditions when the ionosphere was pumped by high-frequency powerful radio waves radiated by the Sura heating facility, which is located near Nizhny Novgorod, Russia (coordinates: 56.15°N, 46.13°E). Determination of the ozone number density in the upper atmosphere was made using the method of the ground-based microwave radiometry, which is based on spectral measurements of thermal atmospheric emissions detected in the frequency range of the ozone radiation. The decrease of microwave emission intensity for the ozone line in HF-pumped atmosphere was first revealed.

Experimental arrangements

Experiments were arranged in the following manner. The Sura facility radiated *X*-mode powerful radio waves at the pump wave (PW) frequency of 4300 kHz with the effective radiated power P_{eff} = 80 MW. The pump beam was tilted 12° to the south from the zenith. In this direction it was directed by a mirror the beam of a mobile microwave instrument used to observe the $6_{1.5}$ to $6_{0.6}$ transition of ozone at 110.836 GHz. The instrument for emission intensity measurements (see Fig. 1) is comprised of a microwave heterodyne receiver and a multichannel spectrometer. Ozone line spectra were measured with the time resolution of 15 min by the use of the method of absolute calibration of registered emission intensity by means of two radiation standards, one of which was at the temperature of background air, whereas the second one was at the temperature of the liquid nitrogen boiling-point. To receive the emissions a ridged horn was used with half-power beam width of 5.4°, which is a few times smaller than the Sura antenna beam width of ~ 15°. Characteristics of the microwave instrument (ozonemeter) are the following: the noise temperature is of 2500 K; the bandwidth of analysis is of 240 MHz; the spectral resolution is of 1 to 10 MHz; the number of spectral channels is of 32 [1,2].

Fig. 1. The view of the microwave ozonemeter used in the measurements (twenty-four-hour observations) from March 14 till March 19, 2009.

With this technique, the observations do not depend on sunlight, may be conducted trough a moderately thick higher cloud cover, and are not significantly affected by aerosols. Retrieval of ozone vertical profiles was performed by the model-fitting method as described by de la Noe et al [3]. As retrieval procedure, model vertical distribution of pressure and temperature [4] were used. Uncertainty of retrieval depends on radio measurement errors and systematic artifacts of the ozone spectrum and generally is about 20 % at altitude region from 20 km up to 60 km.
During the heating experiments the ozonemeter operated at all times from March 14 till March 19. Such twenty-four-hour observations allowed finding also the diurnal variation of the ozone number density in the mesosphere at altitudes of ~ 60 km, which are a result of sunrise/sunset phenomena.

Experimental results

Heating of the ionospheric *D*-region was conducted on March 14 from 11:30 till 15:00 LT, on March 15 from 12:11 till 14:41 LT, on March 16 from 12:01 till 14:31 LT, and on March 17 from 11:40 till 13:10 LT. During these séances the Sura facility was operated on [30 min – on, 30 min – off] scheme. It allowed to obtain in twos ozone line spectra during both heater –on and –off periods. It should be mentioned that all experiments were conducted under quite geomagnetic conditions.
Fig. 2 displays the spectral data from microwave measurements made on March 14. In the left-hand panel of the figure it is shown spectra of ozone emission intensities registered when the atmosphere was HF-pumped (black line) and when the PW was switch-off (gray line). In the right-hand panel it is shown spectra of the ozone emission intensities registered under night (black line) and day (gray line) conditions. To produce these spectra high frequency and low frequency wings of the measured ozone line were overlaid and averaged in order to reduce the random noise component. Data represented in the left hand panel clearly demonstrate that the HF pumping of the atmosphere tends to decrease measured emission intensities at frequency offsets $|\Delta f| \leq 40$ MHz relatively to the line center. We have to emphasize that the value of such decreasing is comparable with the diurnal variation of ozone emission intensity.

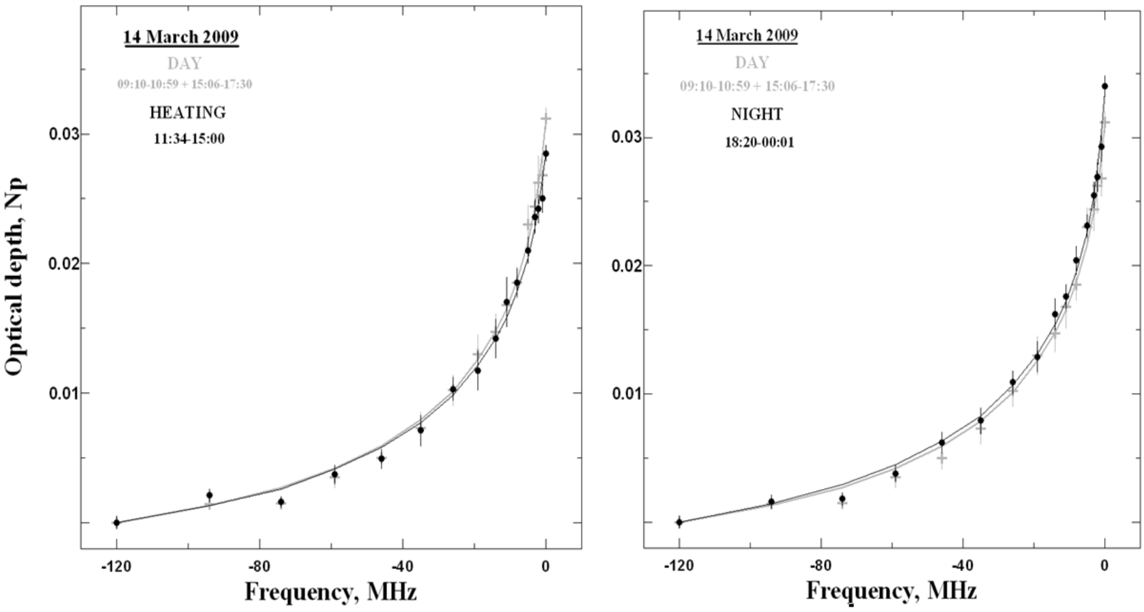

Fig. 2. Changes in ozone line spectral characteristics by HF pumping of the atmosphere (left panel) and the diurnal variation of the ozone line emission intensities (right panel). March 14, 2009.

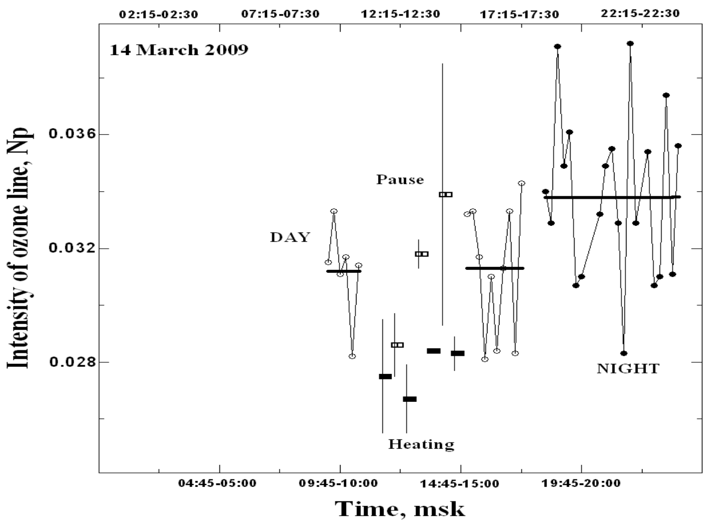

Fig. 3. Variations of the ozone line emission intensities obtained on March 14, 2009.

Fig. 3 demonstrates results of microwave measurements for the ozone line emission intensities carried out on March 14. Each point in the figure is average for 30 min of integral intensity near the line center. Black rectangles are related to measurements under HF-pumping conditions, whereas white rectangles are related to cases when PW was switch-off. When the atmosphere was HF-pumped, the decrease in emission intensity by approximately 10% is clearly seen here. Besides, in the figure horizontal bold lines show time-averaged intensities obtained during day and night hours of measurements.

Data presented in the table below summarize measured ozone number densities at altitudes of ~ 60 km retrieved from spectral data obtained under different conditions. The effect of the decrease of the ozone number density during atmosphere pumping is clearly visible. The value of such decreasing, obtained by data averaging over all days of measurements, is, on average, of ~ 17%. It should be mentioned that the diurnal variation of the ozone number density, additionally obtained during our measurements, is, on average, of ~ 42%, which is close to its commonly observed magnitude.

Date	Time, msk	O_3 number density	
14.03.2009	09:10 – 10:59	$(9.37\pm0.48)\cdot10^{9}$	DAY
	11:34 – 15:00	$\mathbf{(8.03\pm0.38)\times10^{9}}$	**HF PUMPING**
	15:05 – 17:30	$(9.09\pm0.42)\cdot10^{9}$	DAY
	18:20 – 00:01	$(1.28\pm0.06)\times10^{10}$	*NIGHT*
15.03.2009	00:16 – 06:18	$(1.21\pm0.07)\times10^{10}$	*NIGHT*
	06:18 – 12:14	$(9.60\pm0.50)\cdot10^{9}$	DAY
	12:18 – 14:48	$\mathbf{(8.31\pm0.29)\times10^{9}}$	**HF PUMPING**
	14:48 – 17:56	$(9.23\pm0.21)\cdot10^{9}$	DAY
	17:56 – 23:56	$(1.44\pm0.07)\times10^{10}$	*NIGHT*
16.03.2009	00:11 – 05:05	$(1.36\pm0.07)\times10^{10}$	*NIGHT*
	06:20 – 12:15	$(9.55\pm0.40)\cdot10^{9}$	DAY
	12:19 – 14:33	$\mathbf{(7.32\pm0.47)\times10^{9}}$	**HF PUMPING**
	14:33 – 17:56	$(9.01\pm0.24)\cdot10^{9}$	DAY
	17:56 – 23:47	$(1.19\pm0.06)\times10^{10}$	*NIGHT*
17.03.2009	00:01 – 05:15	$(1.36\pm0.05)\times10^{10}$	*NIGHT*
	06:13 – 11:43	$(9.82\pm0.35)\cdot10^{9}$	DAY
	11:43 - 13:13	$\mathbf{(8.97\pm0.49)\times10^{9}}$	**HF PUMPING**
	13:28 – 17:59	$(9.67\pm0.30)\cdot10^{9}$	DAY
	18:02 – 23:45	$(1.22\pm0.05)\times10^{10}$	*NIGHT*

Conclusion: HF-induced decreasing in the ozone number density at altitudes of ~ 60 km is, on average, **(1.17±0.03)**

Possible nature of the observed decreasing in the ozone number density

It is well known that in the ionospheric D-region negative oxygen ions appear due to the following process:

$$e + 2O_2 \rightarrow O_2^- + O_2,$$

the rate of which is increased with electron temperature growth. One branch of transformation of O_2^- to others ions is

$$O_2^- + O_3 \rightarrow O_3^- + O_2, \text{ and further } O_3^- + CO_2 \rightarrow CO_3^- + O_2.$$

The last reaction goes for very short time. It is therefore concluded that both ozone number density and emission intensity for the ozone line have to decrease with electron temperature growth.

Our estimations have shown that at used PW power of ~ 80 MW the value of electron temperature growth can be of (20– 40) % at altitudes of ~ 60 km. This is responsible for the increase of O_2^- number density by (15 – 30) % and, as a result of that, for the decrease of the ozone number density by like amount, which is close to its value obtained in our experiments.

Following results were obtained during these experiments:

1. D-region HF pumping causes to the decrease of the content of the neutral ozone in 17% at a height of about of 60 km. After pump wave switches-off the ozone content is restored.
2. Averaged diurnal variations of the mesospheric ozone content at a height of about of 60 km, which are connected with sunrise and sunset phenomena, has the magnitude of about of 40%.

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