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THE MICROWAVE MONITORING THE VARIATIONS OF THE MESOSPHERIC OZONE (60 KM) IN WINTER 2022-2023 AT APATITY DURING SOLAR CYCLE 25

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Abstract
We present data continuous series of microwave observations middle atmosphere ozone in winter 2022-2023 above Apatity (67N, 33E). Measurements were carried out with the help of mobile microwave ozonemeter (observation frequency 110.8 GHz). The instrument allows to measure a spectrum of the emission ozone line for time about 15 min with a precision of ~ 2%. On the measured spectra were appreciated of ozone vertical profiles in the layer of 22 – 60 km which were compared to satellite data MLS/Aura. The minimal amplitude of the diurnal cycle mesospheric ozone (60 km) was registered in polar night 2022 – (1.06±0.02). The amplitude of a diurnal cycle represents of relation night to day ozone concentration (altitude 60 km).

Microwave ground-based equipment used in the experiment
Method ground-based microwave radiometry is based on measurements of thermal atmospheric radiation in vicinity the ozone line in the range of millimeter and submillimeter waves. Microwave observations are weakly dependent on weather conditions and the presence of atmospheric aerosols, and this is an advantage compared with observations in the optical and infrared wavelength ranges. In addition, the microwave ozone observations can run around the clock. In recent years it is managed to make a significant step forward towards the creation of a new generation of mobile microwave spectrometers. The device consists of an uncooled heterodyne receiver tuned to a fixed frequency 110836.04 MHz corresponding to a rotational transition of ozone molecules $6_{0,6} – 6_{1,5}$, and multichannel spectrum analyzer. In front of receiver is s module that includes an antenna (scalar horn) and a switch to calibrate accepted intensity of atmospheric ozone radiation. Information about the content of the ozone is contained in the measured radio emission spectrum of the middle atmosphere. The error of estimating the vertical distribution of ozone from the measured spectra by above described device does not exceed 10-15%. A detailed description of the spectrometer and the method of measuring ozone of the middle atmosphere in the millimeter wavelength range are given in [1, 2].

The results of observations and discussion
Microwave measurements of middle atmosphere ozone in Apatity were performed for winter season 2022 – 2023. It is necessary to note, that the given cycle of winter measurements were executed within the framework studies of variability of mid-atmospheric ozone in polar auroral latitudes during sudden stratospheric warming (SSW) and polar vortex. The previous microwave observations of mid-atmospheric ozone were performed for of 2017 – 2018, 2018 – 2019, and 2019 – 2020 winters [3].

These observations were executed during the minimal solar activity – 24-25 cycles. For a better understanding of the nature of ozone variations, it is necessary to have a data of temperature changes at attitudes of the middle atmosphere. Temperature changes indicate the influence of the polar vortex and SSW on the structure of the middle atmosphere. For this purpose, a height level of 10 hPa is usually chosen, at which remote airborne and ground-based can be compared with contact measurements. In Fig. 1, data for two winter seasons are given for temperature measurements at flights over Apatity by the MLS/Aura satellite instrument at a level 0f 10 hPa, which approximately corresponds to an altitude of 30 km. Changes of temperature for these seasons practically do not differ from each other. So the mean temperature from 26.11.2017 till 20.01.2018 had value (193.4±0.32) K, and from 07.12.2022 till 20.01.2023 had value (191.8±0.8) K. The maximal values of temperature for winter of 2017-2018 was achieved 16.02. (duration week), and for winter of 2022-2023 19.02. (duration three days). Thus, sudden stratospheric warming these winters has taken place in middle of February. Changes of thermal structure of a middle atmosphere within these two winters were almost identical, and as we shall see further, that variations of ozone of an average atmosphere at different high-altitude levels (from a bottom up to top) were completely unequal.

In Figure 2 of ozone density at altitude 60 km which were received from continuous microwave observations in December 25, 2019, 2021 and 2022 with temporal resolution 15 min are shown. In a figure quasi-periodic changes of mesospheric ozone with one or two maxima during round the clock are shown. The variability mesospheric ozone (60 km) which, probably, are caused by planetary waves, lay in limits from $4 \cdot 10^{09}$ mol/cm^3 up to $6 \cdot 10^{09}$ mol/cm^3. Thus, variability of ozone within day made almost 50 %. The last winters 2017-2018 and 2018-2019 in December over the Kola Peninsula was inside the strong polar vortex. It is possible that this behavior of ozone at an altitude of 60 km is connected precisely with this phenomenon. So there is a strong variability of ozone during the day for December 28, 2017. The increase in the concentration of O_3 from noon to night was almost 100%, which significantly exceeds the amplitude of the diurnal variation. The ozone concentration at a minimum, when averaging from 11:48 to 13:32 Moscow time, was $(3.63 \pm 0.12) \cdot 10^{09}$ mol/cm^3, and at the maximum from 21:00 to 22:27 Moscow time was $(7.19 \pm 0.27) \cdot 10^{09}$ mol.cm^3. On this day, the geomagnetic situation was low activity. It follows from recent model calculations that solar proton events and precipitation of auroral electrons can cause polar ozone variability by 12 – 24% in the mesosphere and by 5 – 7% in the middle and upper stratosphere [6-8].

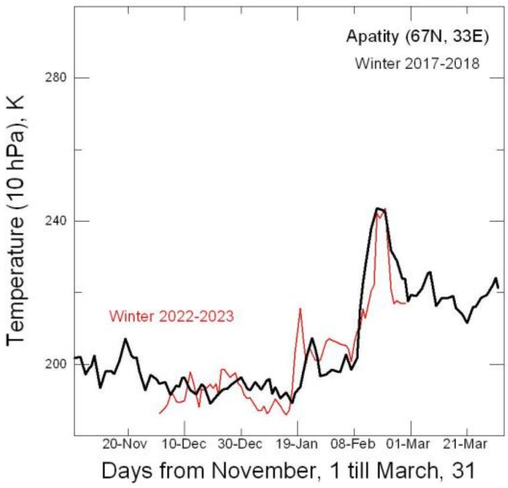

Figure 1. The time course of the temperature at the level 10 hPa above Apatity according to MLS/Aura for winter seasons: black solid thick line, November – March 2017 – 2018; red line, December – March 2022 – 2023.

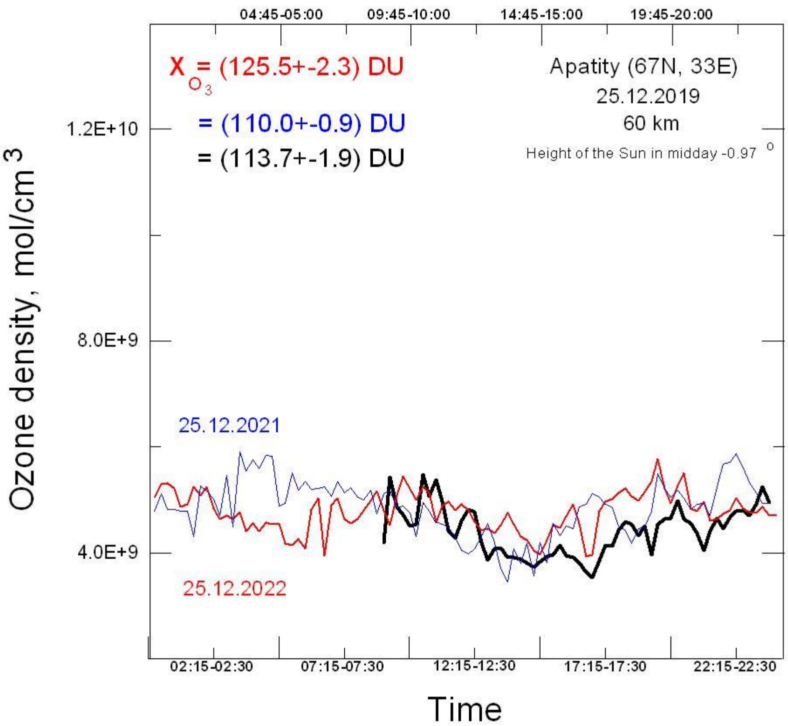

Figure 2. Diurnal variations of mesospheric ozone density (60 km) from MM-measurements in December 25, 2019 (black line), 2021 (blue line) and 2022 (red line) during polar night. Besides in figure the ozone content in a middle atmosphere $X_{O3}(h \geq 22km)$ for the listed days is given.

Table presents daily ozone variations at the altitude of 60 km over Apatity during the polar night from December 13, 2022 up to December 27, 2022. At 60 km, the ozone variability is controlled by both the photochemical processes that are determined by the sunrise and sunset and the dynamic processes that are with the sudden stratospheric warming and the polar vortex. How is it possible to distinguish an amplitude of diurnal ozone variations that are determined by photochemical processes. The authors propose to take the mean ozone values for the time intervals of 10:00 – 14:00 (noon) and 22 – 02:00 (midnight) and to consider the value of their ratio as the amplitude of diurnal variations. The least amplitude of a daily course mesospheric ozone was registered in December 2022 – (6 ± 2)%. The average amplitude of the daily variation for December 2017 is 23%, for December 2018 it is 26%, and for December 2019 it is 11% [3].

Table
Diurnal variations of mesospheric ozone concentration, (mol/cm^3) on altitude 60 km during the December 2022

	10:00 – 14:00	22:00 – 02:00	
		$(4.49\pm0.12)\cdot10^{09}$	
13.12.2022	$(4.77\pm0.17)\cdot10^{09}$		

14.12.2022	$(4.16\pm0.10)\cdot10^{09}$		
		$(4.78\pm0.15)\cdot10^{09}$	
15.12.2022	$(4.59\pm0.27)\cdot10^{09}$		
		$(5.27\pm0.24)\cdot10^{09}$	
16.12.2022	$(4.30\pm0.10)\cdot10^{09}$		
		$(4.51\pm0.12)\cdot10^{09}$	
19.12.2022	$(4.33\pm0.14)\cdot10^{09}$		
		$(4.00\pm0.11)\cdot10^{09}$	
20.12.2022	$(3.67\pm0.15)\cdot10^{09}$		

24.12.2022	$(4.45\pm0.10)\cdot10^{09}$		
		$(5.07\pm0.06)\cdot10^{09}$	
25.12.2022	$(4.73\pm0.09)\cdot10^{09}$		
		$(4.67\pm0.06)\cdot10^{09}$	
26.12.2022	$(4.46\pm0.07)\cdot10^{09}$		
		$(4.53\pm0.09)\cdot10^{09}$	
27.12.2022	$(4.40\pm0.12)\cdot10^{09}$		
average	$\mathbf{(4.38\pm0.09)\cdot10^{09}}$	$\mathbf{(4.66\pm0.13)\cdot10^{09}}$	**(6 ± 2)%**

Conclusion

- The ground-based measurements over Apatity in several last winters revealed significant changes in mesospheric ozone registered during the period when the study region was within the polar vortex area and during the sudden stratospheric warming.
- The variability of mesospheric ozone (at altitude of 60 km), which occurs due to the photochemical processes, can be significantly lower than ozone variations caused by the atmospheric dynamics: the polar vortex or the SSW.
- The minimal amplitude of the diurnal cycle mesospheric ozone (60 km) was registered **in polar night 2022 – (1.06±0.02).**

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References
1. Kulikov Y.Y., Krasilnikov A.A., Ryskin V.G., Shanin V.N., Shchitov A.M. Ground-based microwave instrument to research of stratospheric ozone (some results of observations). Proc. XXX Annual Seminar, Apatity, pp. 218-221, 2007.
2. Krasilnikov A.A., Kulikov Y.Y., Mazur A.B., Ryskin V.G., Serov N.V., Fedoseev L.I., Shvetsov A.A. Detection of «ozone clouds» in the upper stratosphere of the Earth by means of microwave radiometry technique. Geomagnetism and Aeronomy (Eng. Transl.), V. 37, pp. 385-391, 1997.
3. Kulikov Y.Y., Andriyanov A.F., Demin V.I., Demkin V.M., Kirillov A.S., Ryskin V.G., Shishaev V.A. Long-term microwave observations of middle atmospheric ozone in Apatity during three winters. Geomagnetism and Aeronomy, V. 63, No. 5, pp. 608-619, 2023. doi: 10.1134/S001679322360056X
4. Куликов Ю.Ю., Андриянов А.Ф., Демин В.И., Демкин В.М., Кириллов А.С., Рыскин В.Г. О природе переменности мезосферного озона в полярных широтах в зимние сезоны. XXVIII Всероссийская открытая научная конференция (Йошкар-Ола, 16-19 мая 2023 года). Сборник докладов. С. 420 – 423, 2023.
5. Куликов Ю.Ю., Белаховский В.Б., Демин В.И., Демкин В.М., Кириллов А.С., Лосев А.В., Рыскин В.Г. Явления в полярном озоне средней атмосферы в феврале-марте 2023 года. Первая научная конференция имени профессора Михаила Игоревича Панасюка «Проблемы космофизики». Тезисы доклада. Дубна, 10 – 13 июля 2023.
6. Seppälä A., Clilverd M.A. Energetic particle forcing of the Northern Hemisphere winter stratosphere: Comparison to solar irradiance forcing. Frontier in Physics, V. 2, 2014. https://doi.org/10.3389/fphy.2014.00025
7. Matthes K., Funke B., Andersson M.E. et al. Solar forcing for CMIP6 (v3.2). Geosci. Model Dev., V. 10, No. 6, pp. 2247–2302, 2017. https://doi.org/10.5194/gmd-10-2247-2017
8. Lee J.-H., Jee G., Kwak Y.-S., Hwang H., Seppälä A., Song I.-S., Turunen E., Lee D.-Y. Polar middle atmospheric responses to medium energy electron (MME) precipitation using numerical model simulations. Atmosphere, V. 12, No. 2, ID. 133, 2021. https://doi.org/10.3390/atmos12020133