"Physics of Auroral Phenomena", Proc. XLV Annual Seminar, Apatity, pp. 136-139, 2022

Polar
Geophysical
Institute

DOI: 10.51981/2588-0039.2022.45.032

SIMULTANEOUS MICROWAVE MONITORING THE DIURNAL VARIATIONS OF THE MESOSPHERIC OZONE ON LEVEL 60 KM IN DECEMBER 2021 ON APATITY AND PETERHOF

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Abstract
We present data continuous series of microwave observation of the middle atmosphere ozone in December 2021 above Apatity (67N, 33E) and Peterhof (60N, 30E). The given winter is the initial stage the current 25 cycles of solar activity. Measurements were carried out with the help of two identical mobile ozonemeter (observation frequency 110.8 GHz). The parameters of each device allow 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 microwave data on the behavior of mesospheric ozone (altitude 60 km) indicate the presence of both photochemical and dynamic components in its changes.

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 60,6 – 61,5, 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 wave range are given in [1, 2].

Results of observations and discussion
Simultaneous microwave measurements of ozone on Apatity and Peterhof were performed for winter season 2021 – 2022. Microwave observations during December were carried out in form of continuous series (several days nonstop) with a time resolution of 15 min. It should be emphasized that the method of ground-based microwave radiometry is one of the few that allows you to continuously monitor the behavior of ozone in the entire middle atmosphere at specific place with high temporal resolution. **Figure 1** shows the temperature variations at level 10 hPa for winters 2018-2019 and 2021-2022 above Apatity. Sudden stratospheric warmings (SSW) were recorded for each of the winter season. It is known, that SSW influence on a middle atmospheric ozone [3-6].

We will focus on the daily variations of the ozone density at the altitude of 60 km during the most interesting events in the middle atmosphere, taking into account simultaneous measurements at two stations. At the altitude of 60 km, ozone variability is controlled by both photochemical processes, which are determined by sunrise and sunset, and dynamic processes, which are associated (SSW) and the polar vortex.

Figure 2 shows diurnal variations of ozone density (60 km) over Apatity (red bold line) and over Peterhof on the winter solstice on December 22, 2021. The height of the Sun above the horizon at noonday in Apatity was –1.01°, and for Peterhof + 6.68°.

Note that the diurnal changes in O_3 over Peterhof are displayed by averaged horizontal bold blue lines with the indication of errors. The length of these lines corresponds to the averaging time. Results of simultaneous microwave measurements show that there are more a high level of O_3 day and night density over Peterhof compared to Apatity by 13% and 25% respectively. How to separate the amplitude of the diurnal cycle of ozone which is determined by photochemical processes? We propose to take the average densities of O_3 for the time intervals 10:00 – 14:00 LT (noon) and 22:00 – 02:00 LT (midnight) and consider their ratio as the amplitude of the diurnal cycle. The amplitude of the diurnal cycle over Peterhof is 45%, and over Apatity - 32%. For comparison, the same figure shows the diurnal variability of O_3 on December 22, 2018 over Apatity (thin line) with amplitude of 30%. Thus values of ozone density for night and day 22.12.2018 exceed the appropriate density for 22.12.2021 approximately on 25%. Note that both December daily ozone fluctuations (**Fig. 2)** took place in calm geomagnetic activity and in the absence of dynamic disturbances in the middle atmosphere. The polar vortex over the Apatity broke down before the sudden stratospheric warming. In the winter of 2018-2019 SSW began on December 24 and ended on February 1, and lasted for almost 40 days [7]. Apparently, due to the absence of the influence of the polar vortex on the middle atmosphere the ozone concentrations at the beginning and end of the day differ from each other by less than 10%, i.e. significantly less than the amplitude of the diurnal variation, which is associated with photochemical processes.

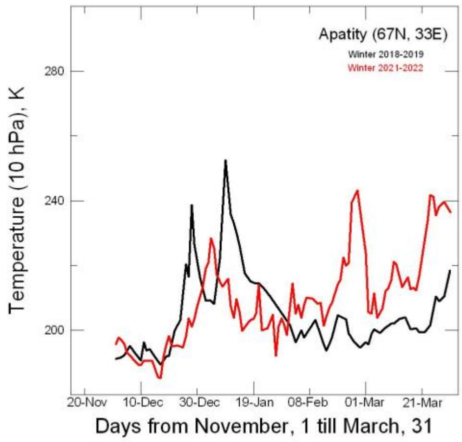

Figure 1. Changes of temperature at a level 10 hPa for winters 2018-2019 (black line) and 2021-2022 (red line) above Apatity (MLS/Aura data).

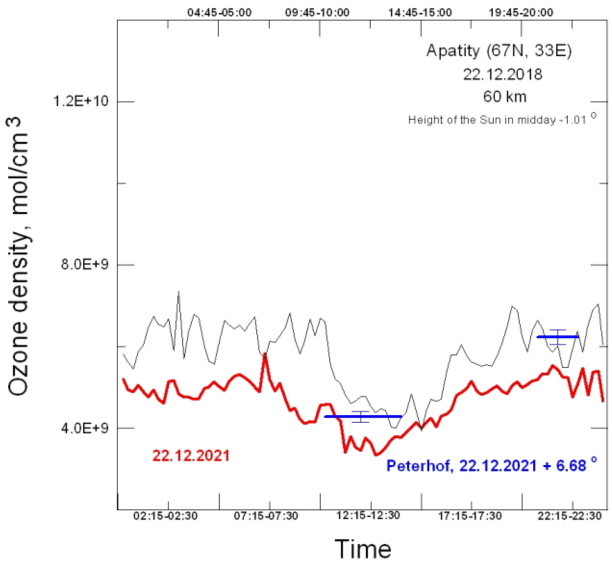

Figure 2

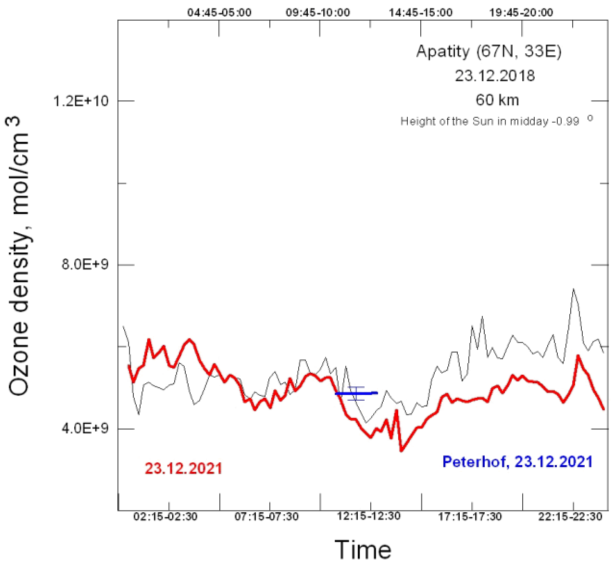

Figure 3

In **Figure 3** diurnal variations of ozone at 60 km which were received from continuous measurements (temporal resolution 15 min) in December, 23 2021 (bold red line) near to a winter solstice are shown. The amplitude of the diurnal cycle over Apatity is 26%. The horizontal bold blue line in the same figure represents average daytime of ozone density in measurements above Peterhof. For comparison, in the same figure shows the diurnal variability of O_3 on December 23, 2018 over Apatity (thin line) with amplitude of 20%. Temperature disturbance on December 22-23, 2021 in a middle atmosphere over Apatity are absent (see **Fig. 1**).

Figure 4 shows diurnal variations in ozone density (60 km) over Apatity during the polar night of December 27, 2021 (bold red line). The state of an atmosphere above Apatity near to a winter solstice refers to at polar night. It is necessary to note, that at polar night near to midday within several hours the atmosphere is lighted by the Sun and reactions of formation and destruction of ozone (Chapman cycle) are carried out. These changes in ozone density are compared with the daily cycle of ozone on December 27, 2017 (thin black line). The height of the Sun above the horizon at this date noonday was –0.88°. Both curves near noon time have a minimum concentration value of $4{\cdot}10^9$ mol/cm^3 and during a long time about 5 hours these values coincide each other. The amplitude of the diurnal cycle for December 27, 2017 is about 19%, and for December 27, 2021 it is about 28%. In **Fig. 4** there is a strong variability of ozone during the day for December 27, 2017.

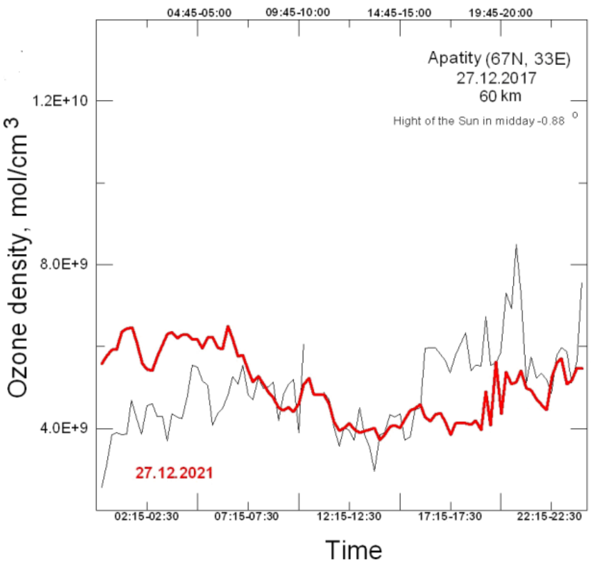

Figure 4

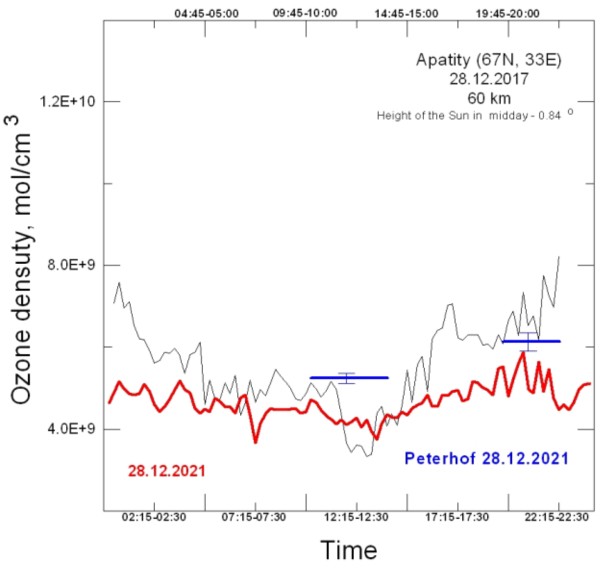

Figure 5

For example for this date the increase in the ozone density, which was averaged over 2 hours from time period 00:00 - 02:00 LT to 22:00 - 24:00 LT was equal to 56%, which significantly exceeds the amplitude of the diurnal cycle. These days geomagnetic activity was insignificant. It should be noted that in December 2017, the middle atmosphere over the Kola Peninsula was inside the polar vortex. Perhaps this behavior of ozone at an altitude of 60 km is due to its influence. In the winter season of 2017-2018, SSW over Apatity began just in mid-February [8].

Figure 5 shows diurnal cycle of mesospheric ozone (60 km) over Apatity during the polar night of December 28, 2021 (bold red line). The height of the Sun above the horizon at this date noonday was –0.84°. The amplitude of a diurnal cycle of ozone density (60 km) above Apatity had value of 12 %. In **Figure 5** shows the behavior of ozone at altitude 60 km the same day over Peterhof are displayed by averaged horizontal bold blue lines with the indication of errors. The amplitude of a diurnal cycle of ozone density (60 km) above Peterhof had value of 17 %. For comparison, the same figure shows the diurnal variability of O_3 on December 28, 2017 over Apatity (thin line) with amplitude of 63%. This day, apparently, there was a strong influence of a polar vortex on a middle atmosphere down to height of 60 km. Note the significant variations in the O_3 density, which are not associated with sunrise and sunset. The amplitude of changes in ozone density exceeds known modeling representations.

Conclusion

• The average amplitude of a daily course мезосферного ozone above Apatity in a continuous series of microwave observations from December, 21 till December, 29 2021 has made value (20±3) %.

• Variability of mesospheric ozone density (60 km) which occurs because of photochemical processes considerably can concede to variations O which are caused atmospheric dynamic - type a polar vortex or SSW.

Acknowledgments

The work was supported within frame of State task IAP RAS the project number 0030-2021-0008.

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