"Physics of Auroral Phenomena", Proc. XLIV Annual Seminar, Apatity, pp. 168-171, 2021

Polar Geophysical Institute

DOI: 10.51981/2588-0039.2021.44.039

THE MICROWAVE MONITORING OF THE MIDDLE ATMOSPHERE OZONE ON KOLA PENINSULA DURING LAST THREE WINTERS

Y.Y. Kulikov[1], A.F. Andriyanov[1], V.G. Ryskin[1], V.M. Demkin[2],
V.I. Demin[3], A.S. Kirillov[3], V.A. Shishaev[3]

[1]*Institute of Applied Physics, Nizhny Novgorod*
[2]*High School of Economy, Nizhny Novgorod*
[3]*Polar Geophysical Institute, Apatity*

Abstract

This work presents long-term investigation of a nature of the middle atmosphere ozone variability using a method ground-based microwave radiometry. Measurements were carried out with the help of mobile microwave ozonemeter (observation frequency 110836.04 MHz) which was established in Polar Geophysical Institute at Apatity (67N, 33E). The parameters of the device allow to measure a spectrum of the emission ozone line for time about 15 min with a precision of ~ 2%. The error of estimating the vertical distribution of ozone on the measured spectra by above described device does not exceed 10-15%. 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 and with the data of ozonesondes at station Sodankyla (67N, 27E). The analysis of the microwave data on behavior of polar mesospheric ozone in past winters shows, that sudden stratospheric warming (SSW) can cause significant and long influence on its diurnal variation which should be determined by photochemical processes.

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 general character of the ozone variations in the middle atmosphere during three winters

Microwave measurements of ozone of the middle atmosphere in Apatity were performed for three winter seasons 2017 - 2018, 2018 - 2019 and 2019 - 2020. First our microwave observations in polar latitudes during these winter seasons were carried out in form of continuous series (several days nonstop) with a time resolution of 15 minutes. 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 ozone variations at altitudes of 25, 40 and 60 km (three winters). Sudden stratospheric warmings were recorded for each of the winter season. Ozone data obtained from ground-based microwave observations are indicated by separate crosses. Solid lines indicate ozone data at selected altitudes which were obtained from onboard MLS/Aura observations over Apatity.

The analysis of microwave observation data in Apatity indicates the appearance of low ozone densities at altitudes from 20 to 60 km in the winter polar middle atmosphere. At one time, a stable relationship of a simultaneous decrease of temperature and O_3 concentration at the level of 25 km was established, that repeated in different years (winter-spring season) [3, 4]. For example, in December 2002, the average ozone density at an altitude of 25 km had a value of $(1.99 \pm 0.23) \cdot 10^{12}$ mol/cm^3, and the temperature at 20 hPa dropped below 195 K. According to the zonal model of the middle atmosphere [5] the ozone density at this altitude in December exceeds the monthly average measured one by (30-50)%. Low temperatures are a sign of the impact on the stratosphere of the polar vortex, the degree of its influence varies from year to year. The vortex prevents the exchange of air masses between polar and moderate latitudes, and this leads to a significant decrease of temperature at altitudes of 20-30 km. And why the ozone density decreases at altitudes of about 25 km inside the vortex is not entirely clear. The lifetime of ozone at these altitudes is about a month. Variations of O_3 concentration at altitudes of 25 and 40 km for the seasons 2017-2018 and 2018-2019 are in satisfactory agreement with the data of on-board observations. And the ozone variations are controlled by both the polar vortex and the SSW that occurred during these winter-spring seasons. In the winter of 2019-2020 stratospheric warming was short-lived, and the temperature at the level of 25 km again returned to low values - significantly below 200 K. The average daily vertical profiles of ozone concentration at selected altitudes of 25, 40 and 60 km for three winters - 2017-2018, 2018-2019 and 2019-2020 were obtained from ground-based microwave observations in polar latitudes too. These data are labeled by bold crosses. For an altitude of 60 km the diurnal variation of O_3 concentration is shown which is associated with sunrise and sunset. Night and day concentrations of O_3 are indicated by bold and translucent crosses, respectively. Solid lines indicate the onboard data (MLS/Aura) during the flight over the Apatity.

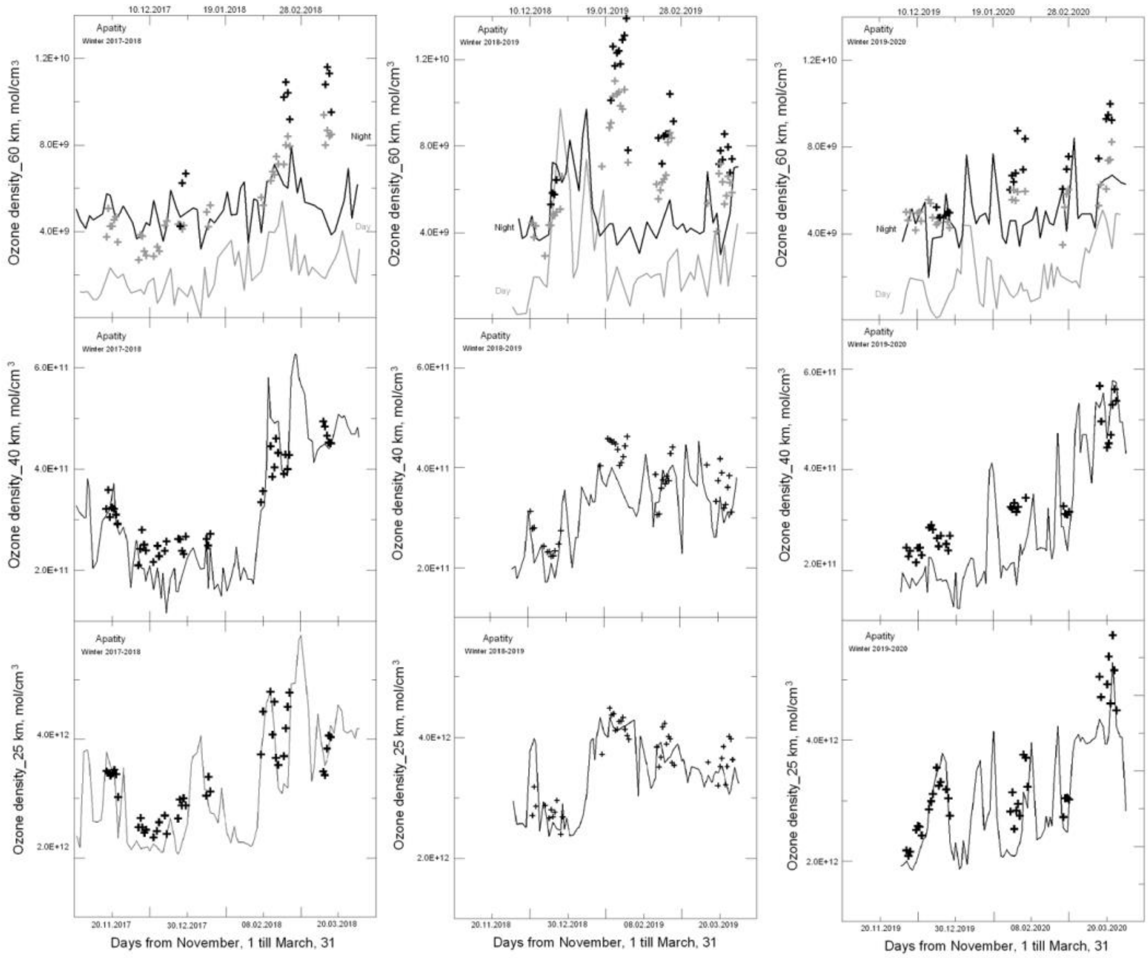

Figure 1. The ozone concentrations at altitudes 25, 40 and 60 km for three winters. The ground-based microwave measurements (crosses); satellite MLS/Aura millimeter wave measurements (continuous lines).

It should be looking at systematic difference in the behavior of mesospheric ozone (60 km) data from ground-based and on-board measurements (see the upper part of Fig. 1). It should be noted that on-board measurements surely register the diurnal variation of mesospheric ozone. Ozone concentration data were obtained for night flights (bold solid line) and daytime flights (translucent solid line) over Apatity. Ground-based measurements of O_3 with a time resolution of 15 minutes showed a strong and long-term influence of SSW on mesospheric ozone. A possible consequence of stratospheric warming is short-term (several days) splashes of O_3 at an altitude of 60 km. They are especially noticeable for the winters of 2017-2018 and 2018-2019. Apparently these disturbances are specific for the polar latitudes [6]. The third winter of 2019-2020 was significantly different from previous winters. The polar vortex occurred this winter provided very low temperatures in the altitude interval of 20-30 km for a long time (about two months – December-January) and stratospheric warming in mid-January 2020 was very weak and not long-term. Thus, conditions were created for the spring lack of ozone over the Kola Peninsula. Nevertheless Fig. 1 (right panel) shows that in March there was a lot of ozone in the altitude interval from 20 to 40 km. Deficit of ozone content occurred in the lower stratosphere (12-20 km) above the Northern Ocean, Western Hemisphere in March 2020 [7].

The total content on March 12, 2020 was 205 DU. According to the authors [7] the reason for the decrease of ozone content is the chemical loss associated with chlorine radicals.

In Figure 2 represents the data of ozone concentrations at an altitude of 25 km in the winter-spring periods 2017-2018 and 2019-2020 according to ground-based (Apatity) and onboard (MLS/Aura) measurements on millimeter waves in comparison with contact measurements that were performed at the Sodankyla station using ECC-4 type ozonesonde. Distance between Apatity and Sodankyla about 400 km to the west.

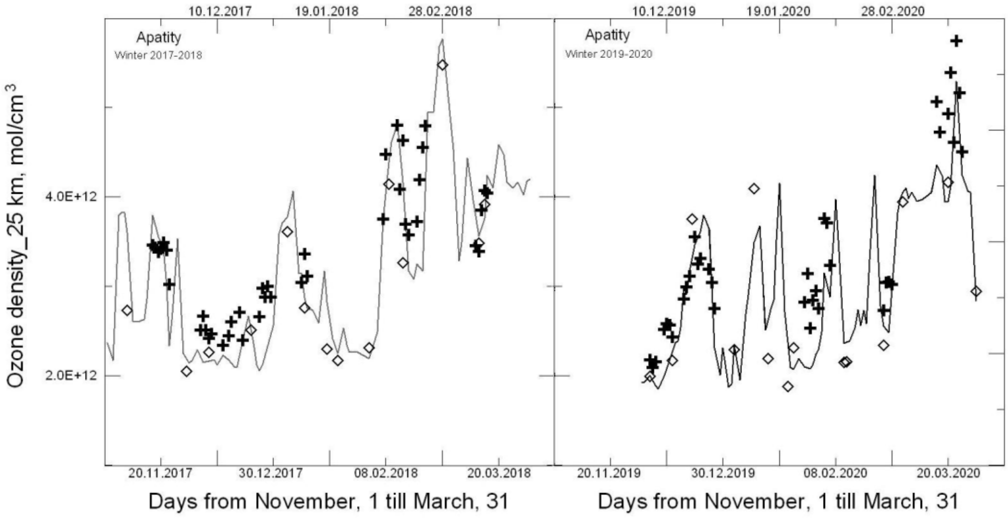

Figure 2. Comparison of the data of ozone concentration (altitude 25 km) which were received by remote sensing and contact methods during winter-spring seasons 2017-2018 and 2019-2020 above Apatity. Crosses – daily average of ozone concentration from ground-based microwave measurements; continuous lines – data of ozone from satellite (MLS/Aura); open rhombuses – data of ozone from ozonesonde ECC-4 at station Sodankyla.

Comparison of remote and contact methods has shown the satisfactory consent in an estimation of concentration of ozone in an interval of height of 20-30 km. In December 2017 and 2019 completely different character of behaviour of ozone concentration (25 km) in the period of very low temperatures in a stratosphere which was confirmed with independent methods of measurements is marked. In December 2019 fast and short-term growth of concentration of ozone from $2 \cdot 10^{12}$ cm^{-3} up to $4 \cdot 10^{12}$ cm^{-3} was observed.

In a Fig. 3 diurnal variations of ozone at 60 km which were received from continuous measurements (temporal resolution 15 min) in December, 28 2017 near to a winter solstice before SSW and February 20 2018 after SSW are resulted.

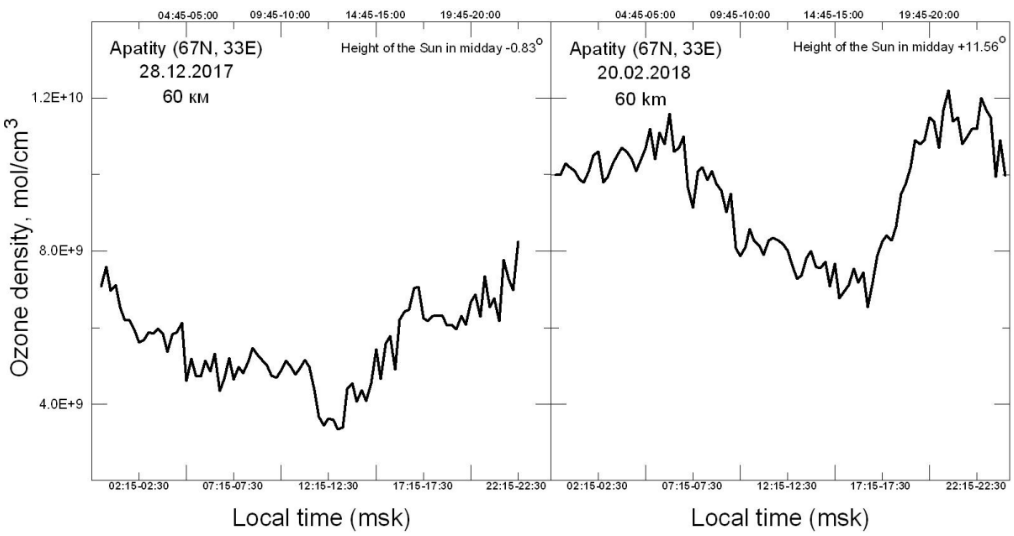

Figure 3. Diurnal variations of mesospheric ozone obtained by ground-based microwave radiometry in polar night (left panel) and in middle of February 2018 after sudden stratospheric warming (right panel) above Apatity.

Note the significant variations in the O_3 density, which apparently are not associated with sunrise and sunset. The amplitude of changes in ozone density reached 80%. The data given in a Fig. 3 show on a priority of dynamic processes above photochemical in polar mesosphere. The average decreasing of ozone density in midday concerning midnight has made 25%. The right panel of a Fig. 3 specifies significant influence of warming on mesospheric ozone.

Conclusion

- The analysis of the microwave data on behavior of polar mesospheric ozone in past winters shows, that SSW can cause significant and long influence on its diurnal variation which should be determined by photochemical processes.
- Thus is important, that microwave observations were carried out during a deep minimum of a solar cycle.
- It is established, that the mesospheric ozone amount can change from winter to winter almost in up two times. Apparently, dynamic processes through SSW influence on transfer of ozone from low latitudes.

Acknowledgments

The work was supported the Russian Foundation for Basic Research, grant number 18-45-520009.

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, P. 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. Geomag. Aeron. (Eng. Transl.), V. 37, P. 385-391, 1997.
3. Kulikov Yu.Yu., Ryskin V.G., Krasilnikov A.A. Microwave sounding measurements of the ozone layer in the polar and mid-latitude stratosphere in the winter seasons of 1998-2001. Izv. Acad. Sci. Atmos. and Oceanic Phys., V. 39, P. S56-S61, 2003.
4. Kulikov Y.Y., Ryskin V.G., Krasilnikov A.A., Kukin L.M. Microwave observations of ozone variability in the high-latitude stratosphere in winter of 2002-2003. Radiophysics and Quantum Electronics, V. XLVII, № 2, P. 134-141, 2005.
5. Keating G.M., Pitts M.C., Young D.F. Ozone reference models for the middle atmosphere (New CIRA). Handbook for MAP, V. 31, P. 1-36, 1989.
6. Kulikov Yu.Yu., Poberovskii A.V., Ryskin V.G., Yushkov V.A. Detection of large fluctuations in ozone content in the middle atmosphere during sudden stratospheric warmings and subpolar latitudes of the Arctic. Geomagn. Aeron., V. 60, P. 254-262, doi:10.1134/S0016793220020097, 2020.
7. Manney G.L., Livesey N.J., Santee M.L., Froidevaux L., Lambert A., Lawrence Z.D., Millán L.F., Neu J.L., Read W.G., Schwartz M.J., Fuller R.A. Record-low Arctic stratospheric ozone in 2020: MLS observations of chemical processes and comparisons with previous extreme winters. Geophysical Research Letters, V. 47, Is. 16, article id. E89063, 2020.