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RESULTS OF MICROWAVE MONITORING OF MIDDLE ATMOSPHERE OZONE IN POLAR LATITUDES FOR TWO WINTER SEASONS 2017-2018 AND 2018-2019

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Abstract
We present data continuous series of microwave observations of the middle atmosphere in winters 2017-2018, 2018-2019 and 2019-2020. In each of these winters sudden stratospheric warming were marked. Measurements were carried out with the help of mobile ozonemeter (observation frequency 110836.04 MHz), which was established at Polar Geophysical Institute in Apatity (67N, 33E). The parameters of the device allow to measure a spectrum of the ozone emission line for time about 15 min 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 and with the data of ozonesonde at station Sodankyla (67N, 27E). 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 [1].

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 a module that includes an antenna (scalar horn) and a switch to calibrate accepted intensity of atmospheric ozone line radiation. The beam width (by level -3 dB) of the horn antenna is 5.4°. The SSB noise temperature of the receiver is 2500 K. The SSB receive mode is provided by evanescent filter with direct losses of 0.5 dB and the suppression of the image channel of more than 20 dB. The spectrum analyzer consists of 31 filters with a variable bandwidth from 1 MHz to 10 MHz and a full analysis bandwidth of 240 MHz. Measurement of the spectra of thermal radiation is performed by a method of calibration for two "black body" loads that are at the boiling point of liquid nitrogen and at ambient temperature. Information about the content of the O_3 is contained in the measured radio emission spectrum of the middle atmosphere. Using the inversion of the obtained spectra it is possible to obtain data on the vertical distribution of ozone in the atmosphere. The error of estimating the vertical distribution of ozone on the measured spectra by above described device does not exceed 10-15%.

The results of observations and discussion
In Figure 1 changes of temperature at a level 10 hPa above Apatity for three winters 2017-2018, 2018-2019 and 2019-2020 during ground-based microwave observation of the middle atmosphere ozone were carried out are submitted. In Figure 2 vertical structures of temperature for a middle atmosphere for three winters at heights 25, 40 and 60 km are shown. It is known, that sudden stratospheric warming (SSW) when at heights of a middle atmosphere changes of temperature on ten degrees are observed, influence on structure of terrestrial atmosphere [2]. The winter 2017-2018 there was SSW in the middle of February, 2018. The warming lasted about a week. The maximum temperature rose to 240 K on February, 16, which is higher on 50 K of the mid-temperature the January. In the winter 2018-2019 SSW began December, 27 both has terminated February, 1 and there were duration almost 40 days (see Figure 2). Prominent feature of warming was presence of two maxima of temperature at height about 30 km. The first maximum of temperature had value 239 K (28.12.2018), that has made an increment concerning average temperature of the not indignant stratosphere in December till 24.12.2018 about 45 K. Second maximum of temperature has made 252 K 09.01.2019 which had concerning average temperature for the period from 01.02.2019

up to 01.03.2019 value 54 K. The winter 2019-2020 there was SSW in the middle of January, 2020. Duration of this warming has made some days. Thus, development SSW for two winters had completely different character. For us that the middle atmosphere during a winter solstice in December was not indignant of dynamic processes is important. It necessary to note, that in simultaneous microwave observation in subpolar and mid-latitudes Peterhof (60N, 30E) and Tomsk (56N, 85E) the essential difference on value and durations in indignations of a middle atmosphere ozone during SSW in the winter 2013-2014 was found out [3].

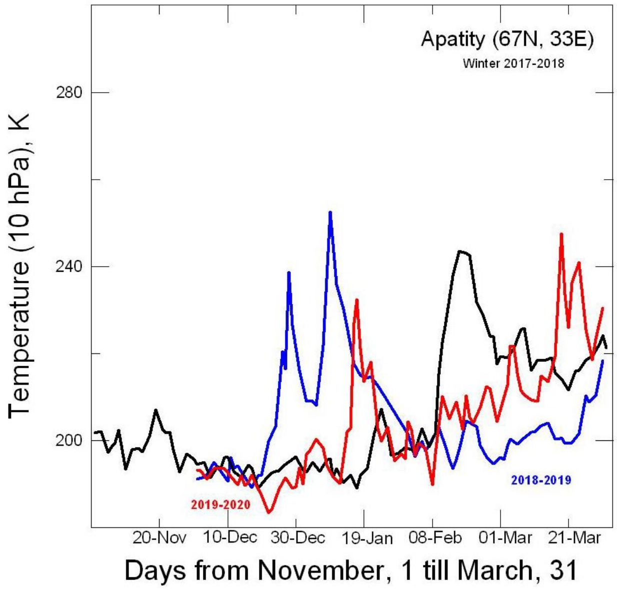

Figure 1. Changes of temperature at level 10 hPa for three winters over Apatity (MLS/Aura data).

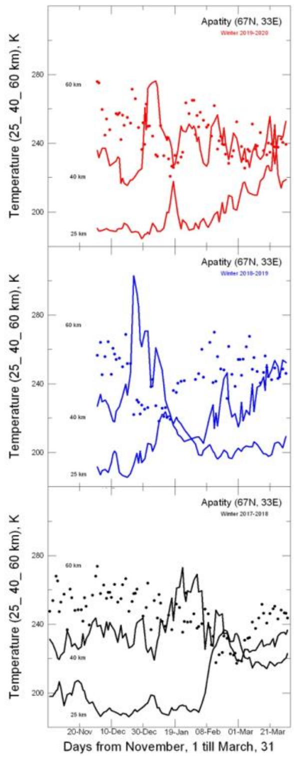

Figure 2. Vertical profiles of temperature at separate heights 25, 40 and 60 km (MLS/Aura data).

In Figure 3 diurnal variations of ozone at 60 km which were received from continuous measurements December, 27-28 2017 before SSW near to a winter solstice are resulted.

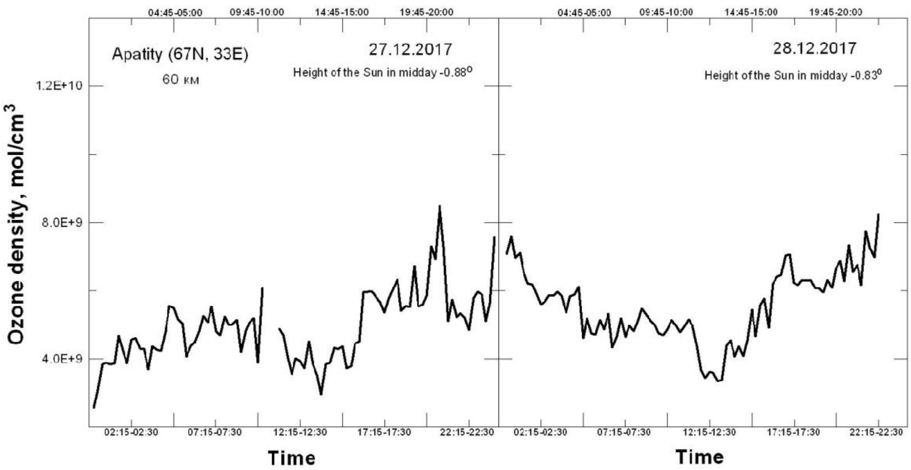

Figure 3. Diurnal variations of mesospheric ozone obtained by ground-based microwave radiometry in polar night above Apatity. Note the significant variations in the O_3 density, which apparently are not associated with sunrise and sunset. The amplitude of changes in ozone density reached 80%.

The data given in Figure 3 show on a priority of dynamic processes above photochemical in polar mesosphere. Decreasing of ozone density in midday concerning midnight has made 25%. The values of the ozone density increase at night, mainly due to the absence of O_3 photodissociation and the changing [O]/[O_3] ratio [4]. Decreasing of ozone concentration in midday concerning midnight has made 25%. The attention a significant divergence (in 1.5-2 times) in ozone concentration at night for 27.12.2017 and 28.12.2017 pays to itself. Probably, it is caused by horizontal carry of air in mesosphere.

In Figure 4 the diurnal variations of the mesospheric ozone at 60 km for 14-15 March 2018 which was obtained in continuous microwave measurements later on SSW and near spring equinox is submitted. The average amplitude of diurnal changes of ozone was about 30%. It is important to note, that average of ozone density (60 km) for midday and midnight in March differed from similar values in December almost twice.

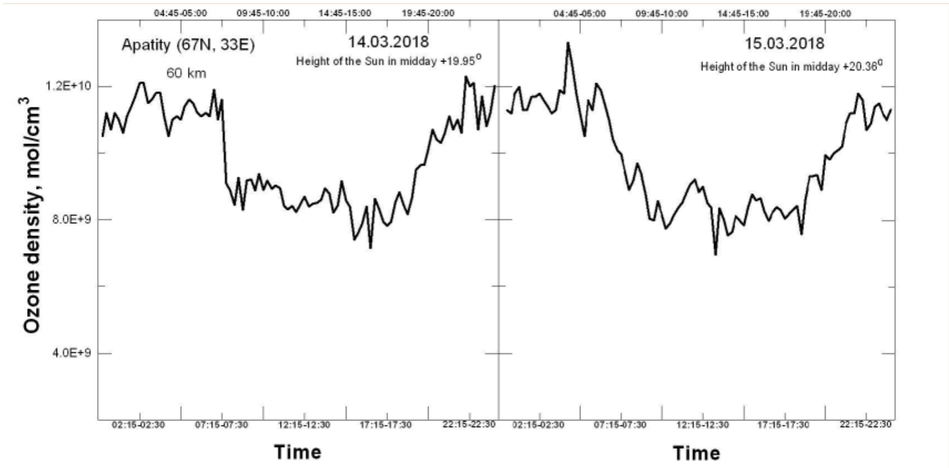

Figure 4. Diurnal cycle of ozone density at height 60 km in continuous series of microwave measurements in March 15-16, 2018. Temporal resolution of 15 min.

In Figure 5 shows the behavior of ozone at height 60 km in January 24-25, 2019. A January series of measurements was carried out during a middle atmosphere disturbance caused by SSW in winter 2018-2019 and in January 31, 2020.

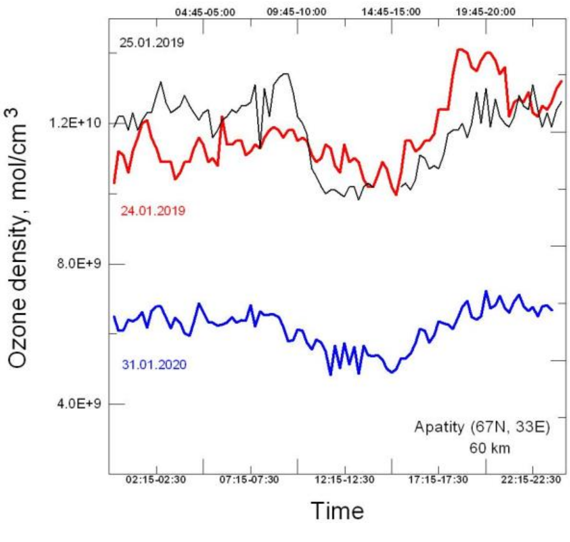

Figure. 5. Influence of atmospheric circulation on ozone amount in polar mesosphere for different winters. Winter 2018-2019 – red line; winter 2019-2020 – blue line.

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 ozone content in mesosphere considerable can differ from winter to winter. Apparently, dynamic processes through SSW influence transfer of ozone from low latitudes.

The numerical data on an average daily course of mesospheric ozone which is connected to rising and sunset are collected in the Table at the end of the text for December 2017, 2018 and 2019.

Table. Diurnal variations of mesospheric ozone during the polar night.

Date	Mesospheric ozone density (60 km), mol/cm^3		Tropospheric attenuation, Np
	Midday 10:00 – 14:00 msk	Midnight 22:00 – 02:00 msk	
26.12.2017	$(4.32\pm0.15)\cdot10^{09}$	$(4.25\pm0.23)\cdot10^{09}$	(0.2026±0.0004) (0.2195±0.0015)
27.12.2017	$(4.12\pm0.20)\cdot10^{09}$	$(6.24\pm0.22)\cdot10^{09}$	(0.2069±0.0005) (0.2146±0.0035)
28.12.2017	$(4.28\pm0.16)\cdot10^{09}$		(0.2073±0.0007)
average	$\mathbf{(4.24\pm0.0005)\cdot10^{09}}$	$\mathbf{(5.24\pm0.70)\cdot10^{09}}$	
20.12.2018	$(4.35\pm0.12)\cdot10^{09}$	$(5.30\pm0.13)\cdot10^{09}$	(0.2107±0.0006) (0.2575±0.0060)
21.12.2018	$(4.34\pm0.12)\cdot10^{09}$	$(5.84\pm0.14)\cdot10^{09}$	(0.3133±0.0049) (0.2312±0.0023)
22.12.2018	$(4.77\pm0.15)\cdot10^{09}$	$(5.76\pm0.19)\cdot10^{09}$	(0.1985±0.0021) (0.2122±0.0018)
23.12.2018	$(4.80\pm0.12)\cdot10^{09}$	$(6{,}44\pm0.12)\cdot10^{09}$	(0.2262±0.0022) (0.2575±0.0020)
24.12.2018	$(4.95\pm0.18)\cdot10^{09}$		(0.2209±0.0007)
average	$\mathbf{(4.64\pm0.11)\cdot10^{09}}$	$\mathbf{(5.87\pm0.20)\cdot10^{09}}$	
20.12.2019		$(5.21\pm0.06)\cdot10^{09}$	(02893±0.0151)
21.12.2019	$(4.50\pm0.06)\cdot10^{09}$	$(4.73\pm0.10)\cdot10^{09}$	(0.3708±0.0054) (0.3927±0.0040)
25.12.2019	$(4.54\pm0.05)\cdot10^{09}$	$(4.83\pm0.09)\cdot10^{09}$	(0.3885±0.0099) (0.3696±0.0080)
26.12.2019	$(4.27\pm0.08)\cdot10^{09}$	$(5.01\pm0.08)\cdot10^{09}$	(0.2158±0.0021) (0.2345±0.0013)
average	$\mathbf{(4.44\pm0.07)\cdot10^{09}}$	$\mathbf{(4.94\pm0.09)\cdot10^{09}}$	

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.

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