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In memory of M.I. Beloglazov

GROUND-BASED MICROWAVE MONITORING OF OZONE IN THE MIDDLE ATMOSPHERE ABOVE St. PETERSBURG AND TOMSK IN THE WINTER 2013-2014

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Introduction

Recently to study the nature of variation of ozone and temperature in the middle atmosphere are widely used means of microwave remote sensing as orbital and ground-based [1, 2]. Changes in ozone have a significant impact on radiation and thermal regime of the atmosphere. To interpret the results of these measurements, it is necessary to draw data on the temperature dependence of the height that can be presented in the form of zonal models [3], and in the form of measured values, for example, aerological or rocket sounding data. Very successful are the measurement results of vertical temperature profile by lidars which are located on the Earth's surface [4, 5]. It should be emphasized that the strongest impact of changes in the temperature profile on the results of microwave observations of ozone in the middle atmosphere will occur during the so-called sudden stratospheric warming [2]. Therefore, simultaneous measurement of the real variations of ozone and temperature occurring in the middle atmosphere can give the opportunity to explore the dynamic processes during modification of atmospheric circulation.

In this paper we present the results of measurements of ozone in the middle atmosphere in St. Petersburg (60°N, 30°E) and Tomsk (56°N, 85°E) using the same microwave ozonemeters during stratospheric warming in the winter of 2013-2014. Very important here is the use the same methods of observation and estimate of the vertical distribution ozone in the middle atmosphere. These results were compared with satellite data (OMI/Aura) on the total ozone content (TOC) and the altitude profiles of ozone and temperature in the layer of 20-60 km (MLS/Aura).

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 [6]. 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 filter with a variable bandwidth from 1 MHz to 10 MHz and a full analysis bandwidth of 240 MHz. 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%. 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 (VDO) in the atmosphere. The criterion of the accuracy of inverse problem solution is the best fit ozone spectral lines calculated by the retrieved profile of the O_3 concentration to the original experimental spectrum. The error of estimating the VDO on the measured spectra by above described device does not exceed 20%.

The results of observations and discussion

Fig. 1 shows the ozone variation in November-March, 2013-2014 over Peterhof (left panel) and in December-January 2013-2014 over Tomsk (right panel). In the left panel, the crosses are the data on total ozone content (TOC), which were obtained onboard device OMI/Aura [7]. The average value of the TOC for the entire observation period amounted to (323±4) DU. Since the February 11 well a noticeable increase in the TOC, which lasted for 10 days with the average value (413±8) DU. Maximum TOC 454 DU was marked on February17, 2014. The total ozone values before and after the disturbance are equal to (313±5) DU and (308±6) DU respectively. In addition, it can note a short-term increase in TOC on March 24 with the average value (388±7) DU. At the bottom left panel of Fig.

1 it is shown the temporal variations of the ozone content in the layer of 22-50 km according to the onboard device MLS/Aura $X_{O_3}^{MLS}(22-50km)$ in DU (open circles) and ozone content in the layer above 22 km, according to ground-based device $X_{O_3}^{MMW}(\geq 22km)$ in DU (filled circles). The device MLS/Aura uses a limb method of measuring atmospheric parameters [8]. We selected of ozone and temperature data, corresponding to the time span of the satellite over the Peterhof and Tomsk. For this purpose was chosen domain with coordinates (60±1.5)° N and (30±5)° E for Peterhof and (56±1.5)° N and (85±5)° E for Tomsk. Data $X_{O_3}^{MMW}$ correspond to the ozone concentrations obtained from day and night ozone spectra.

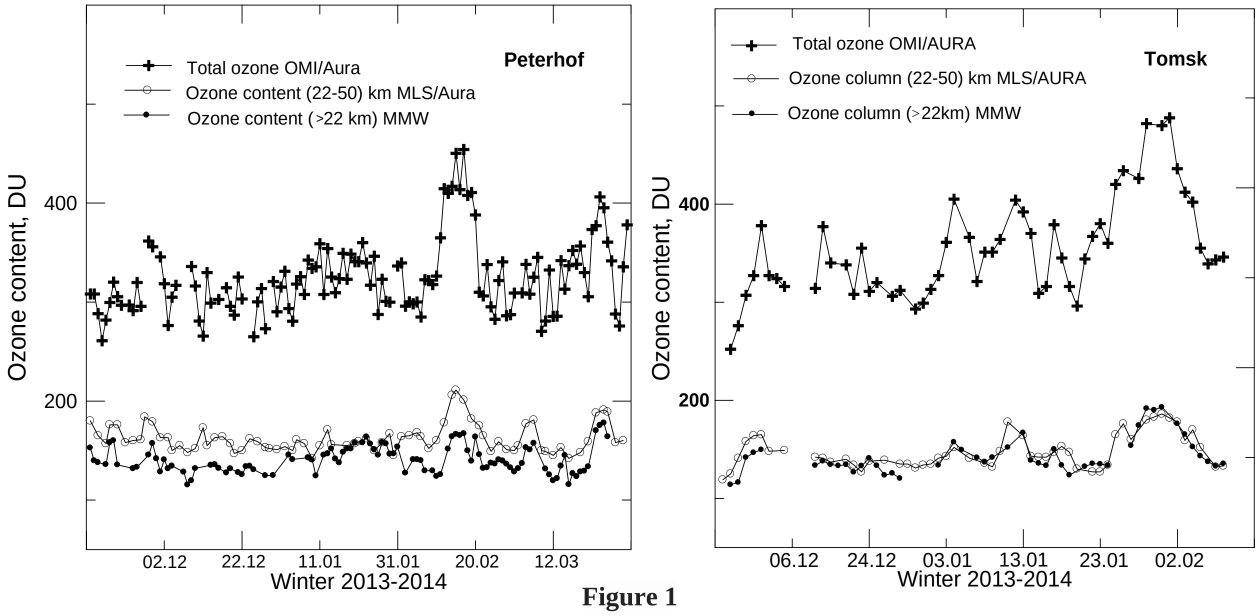

Figure 1

The difference between them is virtually nonexistent. Well observed perturbations of ozone layer in the middle atmosphere, which began in the middle of February and lasted until the end of March. The first maximum appeared on February 15, the second – on March 07 and the third - on March 25, 2014. The alternation of maxima occurred at time interval of about 20 days. Moreover, the time variations of ozone content obtained by satellite and ground-based microwave measurements are identical. The correlation coefficient between changes $X_{O_3}^{MLS}$ and $X_{O_3}^{MMW}$ in the period of "disturbances" had a value of 0.906. The correlation coefficient between these values from November to February 11 (up to time "disturbances") was 0.331, and for the total time of observations - 0.718. Systematic excess of ozone satellite data over ground-based data for the entire observation period amounted to the value of $X_{O_3}^{MLS} / X_{O_3}^{MMW}$ = (1.14±0.01). It is necessary to specify on one event marked in the left panel of Fig. 1, when the magnitude $X_{O_3}^{MLS}$ and $X_{O_3}^{MMW}$ since the mid to end of January 2014 was the same. Note that in January time variations of the TOC and $X_{O_3}^{MMW}$ are qualitative the same. The correlation coefficient between the changes of these values is 0.329 and the correlation coefficient between changes in the TOC and $X_{O_3}^{MLS}$ is equal to -0.012. Possible causes of this feature we will discuss below. In the right panel of Fig. 1 are shown the time variations of ozone in December, February 2013-2014 over Tomsk. Observation time was chosen due to the fact that according to several years of lidar sensing of the temperature over Tomsk, stratospheric warming happen here, usually in January [4]. As an example, observations of significant stratospheric warming in Western Siberia, one can cite the work [5]. The upper curve in the right panel of Fig. 1 shows changes of the TOC (OMI/Aura device), which reflect the ozone variations in the whole thickness of the atmosphere during the winter. It should be noted that the changes of TOC largely associated with the O_3 variations that occur in the region of the maximum of the ozone layer (the height of 20-24 km). The average value of the TOC for this time interval amounted to (354±7) DU. The specific behavior of TOC during this time is brief increase up to 483 DU (average of three days) at the end of January. The magnitude of the growth TOC was about 40% in comparison to calm of its development (before and after) disturbances. In the bottom right panel, Fig. 1 are shown the temporal variations of the ozone content in the layer of 22-50 km according to the onboard device MLS/Aura $X_{O_3}^{MLS}$ in DU (open circles) and the ozone content in the layer above 22 km, according to ground-based $X_{O_3}^{MMW}$ in DU (filled circles). The correlation coefficient between changes in ozone $X_{O_3}^{MMW}$ and TOC amounted to 0.905; between changes $X_{O_3}^{MLS}$ and TOC amounted 0.752 and between changes $X_{O_3}^{MMW}$ and $X_{O_3}^{MLS}$ amounted to 0.845. Temporal variations of ozone concentration during the entire observation period obtained from ground-based and satellite measurements are coincided. Especially notable increase ozone in late January 2014, registered both by onboard and ground-based microwave devices. The systematic excess of ozone on satellite microwave data over ground-based microwave data for the entire observation period amounted to the value of (1.03±0.01).

Consider the character of the variability of ozone and temperature at selected heights middle atmosphere 25, 40 and 60 km above the Peterhof and Tomsk. In Fig. 2 shown the temporal variations of ozone concentration and temperature (MLS/Aura data) at these altitudes above the Peterhof in winter 2013-2014 On the bottom of the figure shown the variation of ozone (filled circles) at a height of 25 km, according to ground-based microwave sensing and temperature (bold curve) at the same height according to the database MLS/Aura [8]. Decreasing of temperature at a height of 25 km started from mid December 2013. Temperature minimum 191.5K was observed on the end of December and the beginning of January 2014. A gradual increase of temperature was lasted during one month, and temperature maximum was reached value of 225.4K on February 15, 2014. The increment of this value over the average temperature for January 2014 was about 27K and for February - 16K. Such a change of the thermal structure of the middle atmosphere shows the development of minor stratospheric warming, which were mentioned by us earlier over Apatity (67°N, 33°E) [9]. The correlation coefficient between changes of ozone $N_{O_3}^{MMW}(25km)$ and temperature at the altitude of 25 km for the entire observation period was positive and amounted to 0.487, up to a peak temperature increase (mid-February) – 0.237, and during the maximum phase of the stratospheric warming is 0.546. Similar values of the correlation coefficient between ozone and temperature at 25 km, obtained from orbit, equal to 0.308, -0.018 and 0.639 respectively. The ratio of the concentration of ozone at the altitude of 25 km on satellite and ground-based data for the entire observation period had a value of (1.04±0.04).

The above mentioned development of the stratospheric warming over the Peterhof occurred under the classical scheme from top to bottom. This fact is confirmed by detected changes of ozone and temperature at the altitude of 40 km, which shifted in time relative to the data at a height of 25 km (Fig. 2, mid panel). The increase temperature and ozone at 40 km ahead approximately two weeks of temperature change and ozone at the altitude of 25 km. Our microwave observations in the polar latitudes has repeatedly confirmed this scenario [9-12]. Noteworthy (Fig. 2) significant perturbation of ozone at levels of 40 km (mid panel) and 60 km (top panel), which began in the second half of January 2014. The increase in ozone at 40 km relative to the unperturbed period was about 70%.

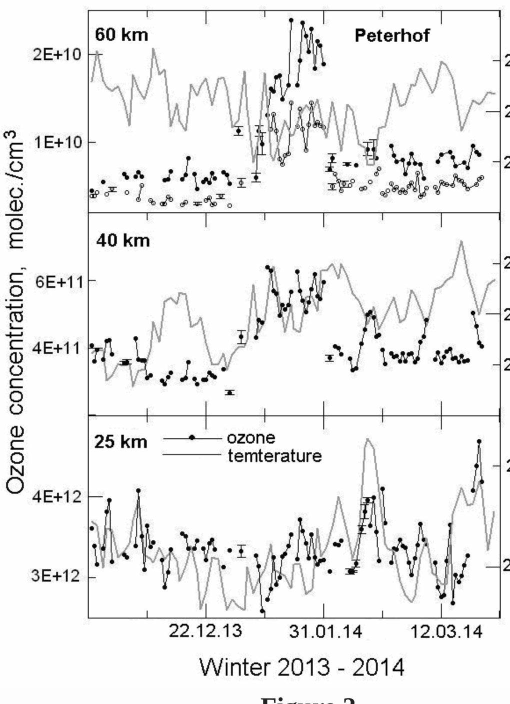

Figure 2

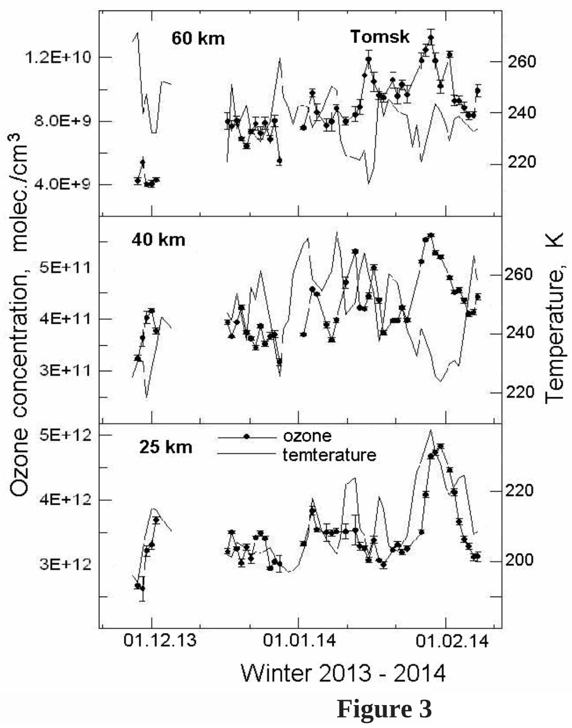

Figure 3

Discrepancies between satellite and ground-based data, excluding the second half of January, were not observed within the accuracy of 10%. However, during the development of the warming in the middle and upper stratosphere satellite device is not noted disturbances in the ozone layer in contrast to the data obtained from the surface of the Earth. Perhaps it is related to specific limb measurement method, often used in satellite measurements, which provides a spatial horizontal resolution of several hundred kilometers, far worse, than a ground-based device. In this case it takes place the averaging of the signal of the atmospheric radio emission along the antenna beam during its scan. The consequence of this it becomes possible to obtain in such measurements smoothed values of ozone density along the satellite swath. The quality of these data will be especially critical near the sharp front baric boundary. In any case, the above-noted fact requires further study when data obtained by orbital and ground-based instruments are compared.

Consider the nature of the changes of ozone and temperature in the middle atmosphere in winter 2013-2014 over Tomsk. In Fig. 3 shows the behavior of ozone and temperature at heights of 25, 40 and 60 km from the end of November to February. The lowest ozone concentration according to ground-based microwave sensing was observed at all heights on the end of November 2013, this was followed by a gradual increase of ozone with minor variations until the end of January 2014. All this time the Tomsk was on the edge of the polar stratospheric vortex [*http://www.pole-ether.fr/etherTypo/index.php?id=1663&L=1*]. Air masses at the edge of the cyclone characterized by a high velocity along its borders and extreme instability of its composition, which may cause our observation of the variability of the ozone content. This fact is also confirmed by the analysis of back trajectories of air masses, the calculation of which was performed due to the British atmospheric data centre BADC [*http://badc.nerc.ac.uk*]. The trajectories that were calculated for the levels of the middle atmosphere from 10 to 50 hPa, were cyclical and covered a large area of the circumpolar area. In the third decade of January, the polar vortex is slightly deformed and moved in a westerly direction, resulting in Tomsk was out boundary of this cyclone. Circulation in the middle atmosphere has changed dramatically, the speed of air masses decreased. At all heights visible increase of the ozone number density at this time. And at the height of 25 km, the increase of ozone is 1.5 times was accompanied by a temperature rise of about 20K. It was found that the temperature increase outpaced the increase ozone concentration by about two days. However, synchronous change of ozone concentration and temperature indicates the dynamic nature of these processes, in contrast to the levels of 40 and 60 km where the relationship between ozone and temperature is determined by photochemical processes [13]. In Fig. 3 shows that at altitudes of 40 and 60 km of changes in ozone and temperature occurred mainly in antiphase.

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