*"Physics of Auroral Phenomena", Proc. XXVIII Annual Seminar, Apatity, pp. 211-214 , 2005*


Polar Geophysical Institute

# JOINT OBSERVATIONS OF THE BEHAVIOUR OF POLAR OZONE DURING WINTER 2003/2004 IN THE NORTHWEST SECTOR OF THE ARCTIC

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The purpose of the present paper is studying spatial and temporal variations of stratospheric ozone by simultaneous measurements. The research has been performed in a rather interesting Arctic region where most frequently there are hurricanes in the winter stratosphere of the Earth - so-called winter polar vortex. As a rule, the centre of the vortex lies in this area [1]. The regions which are inside the vortex are characterized by the lowered content of stratospheric ozone in comparison with areas beyond the vortex. A peculiarity in the natural behavior of $O_3$ in the Arctic winter stratosphere is a strong variability of its losses in different years. Besides, the value of $O_3$ decrease strongly depends on the temperature [2, 3].

We present the results of simultaneous observations of stratospheric ozone in the winter 2003/2004 at heights from 20 to 60 km. The measurements were conducted by the ground-based microwave instruments, which are at the Polar Geophysical Institute, Apatity (67°N, 35°E), Russia and at the Institute of Space Physics, Kiruna (68°N, 20°E), Sweden. Besides, we used the results of balloon measurements of ozone vertical distribution from the surface up to the heights of 25-30 km performed by electrochemical cell type ECC-6A at the Meteorological Institute, Sodankylä (67°N, 27°E), Finland and at the Alfred Wegener Institute, Koldewey-Station (79°N, 12°E), Spitsbergen. Now this technique is the most exact one (3-5 %) for the measurements of ozone vertical distribution [4]. The study of ozone vertical profile in the upper atmosphere (heights from 20 up to 60 km) in Apatity and Kiruna was carried out by ground-based microwave radiometry technique. For this purpose, the millimeter wave-range radiometers with a high resolution analyzer of spectrum were used. The technique is based on the measurements and analysis of spectrum of atmospheric thermal radiation in the ozone resonance lines (the rotational transitions). In the observations in the Kola Peninsula the rotational transition $O_3$ $4_{0,4} - 4_{1,3}$ (resonance frequency 101736.8 MHz) and in Kiruna two transitions $O_3$ $14_{0,14} - 14_{1,13}$ and $11_{2,10} - 10_{3,7}$ (resonance frequencies 195430.4 MHz and 195721.2 MHz, respectively) were used. The parameters of microwave instruments permit to obtain qualitative spectra of atmospheric lines $O_3$ with the integration time of about one hour. With the use of retrieval procedure, they were transformed to ozone vertical profiles in the height range of 20-60 km. For processing the ozone spectra measured in Sweden, daily vertical pressure and temperature profiles were taken from the National Centers for Environmental Protection (NCEP). As a retrieval algorithm, the optimal estimation technique [5] was utilized. In the Kola Peninsula measurements, the vertical distribution of ozone was obtained using a fitting technique [6]. In these calculations both mean zonal monthly vertical distributions of pressure and temperature [7] and the data of temperature sounding for the observational region http://orbit-net.nesdis.noaa.gov/crad/st/amsuclimate/ [8] were used. The accuracy of the estimation of ozone vertical distribution is smaller than 20 % in the height range considered.

In Figures 1 and 2, the daily average ozone density and temperatures, obtained from the measurements in the winter 2003/2004 (since December to April) at the above Arctic stations, are shown versus time. In Figure 1 the time dependence of the daily mean ozone number density at altitude levels from 25 up to 60 km obtained by microwave sounding in Apatity and Kiruna in winters 2003/2004 is presented. There are also the AMSU temperature data at pressure levels 20 hPa (the height of approximately 25 km), 10 hPa (~ 30 km), 2 hPa (~ 40 km), 0.5 hPa (~ 50 km) and 0.1 hPa (~ 60 km) for Kola Peninsula region given by M.D. Goldberg from NOAA [8].

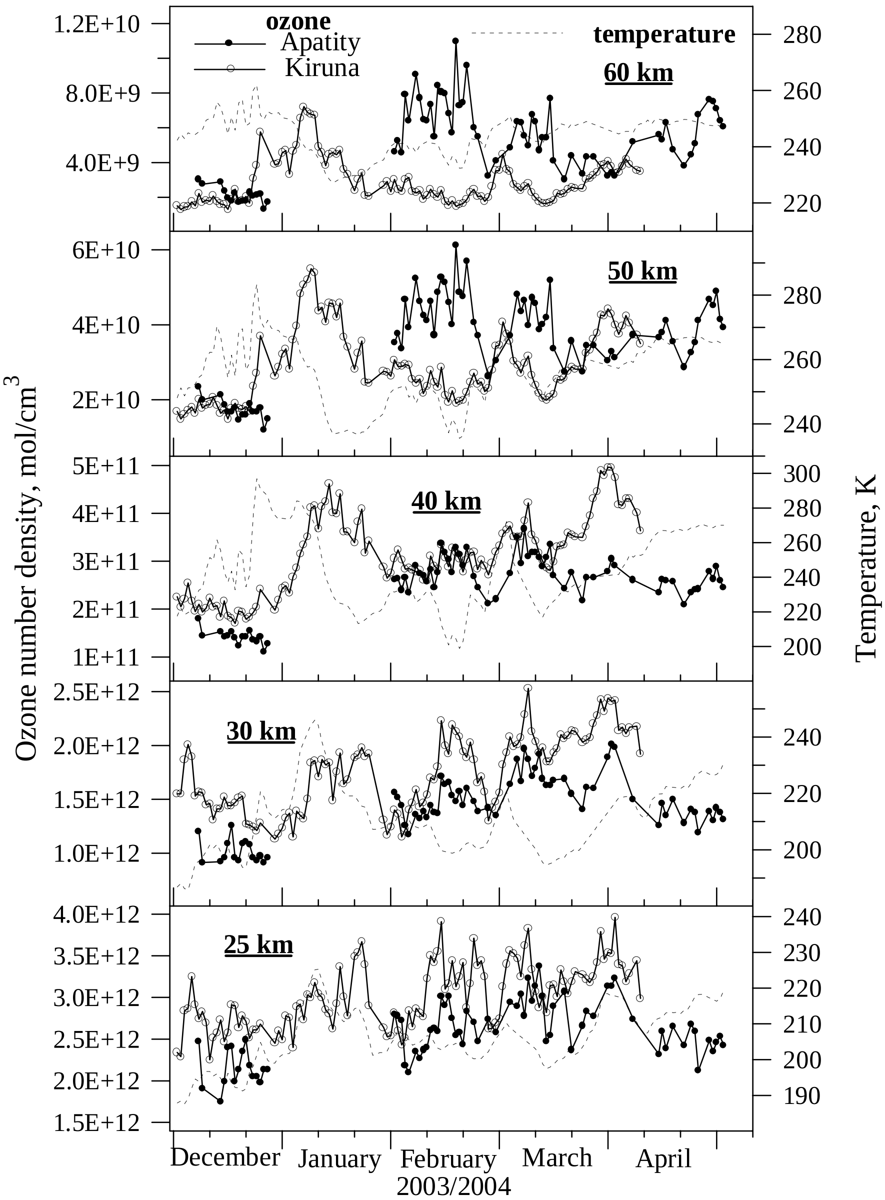

Fig.1

Figure 2 shows time dependences of ozone and temperatures at the height level of about 25 km measured during simultaneous observations in Apatity, Kiruna, Sodankylä and Ny Ålesund in the winter of 2003/2004. The measurements of the ozone content at these two stations were conducted by the electrochemical cell type ECC - 6. In Figure 2, the open rectangles indicate the time periods when the stations appeared outside the vortex. As compared to the winter of 2002/2003 when extremely low stratospheric temperatures in November - December were observed, in the winter of 2003/2004 the lower stratosphere was warmer. Practically for all period of observation the stratospheric temperature at the height of 25 km did not drop below 200K except December 2003. The average temperature for December at this height (above all the stations) was equal to about 195K. The lowest ozone number density $2.4\times10^{12}$ mol/cm$^3$ during winter 2003/2004 was measured. The least average $O_3$ density was measured in Apatity - $2.1\times10^{12}$ mol/cm$^3$, and the largest one in Kiruna - $2.7\times10^{12}$ mol/cm$^3$.

Since January 2004, strong ozone oscillations at the height of 25 km on Koldewey-station (see Fig. 2, the upper panel) have been observed that apparently testify that the air mass above the station is outside the vortex or at its edge. These changes have almost double amplitude. The increase of temperature and ozone from December to January occured practically simultaneously. Further, from January to the middle of April, a steady decrease of ozone and temperature is observed. At the same time, above other stations a monotonous increase of both ozone and temperature is registered. The analysis of the ozone-to-temperature relation at the height of 25 km in the winter 2003/2004 above Apatity shows that their correlation coefficient is negative. An earlier positive correlation between the changes of these values in the lower stratosphere was registered [2]. In winter 2002/2003 this relation appeared to be stronger than for all previous seasons of microwave observations in the Kola Peninsula, with the correlation coefficient of ozone density at height of 25 km and temperature under the pressure of 20 hPa equal to + 0.66 [ 3 ]. For the winter 2003/2004 it is necessary to point out the distinction between the ozone density measured in Sodankyla and

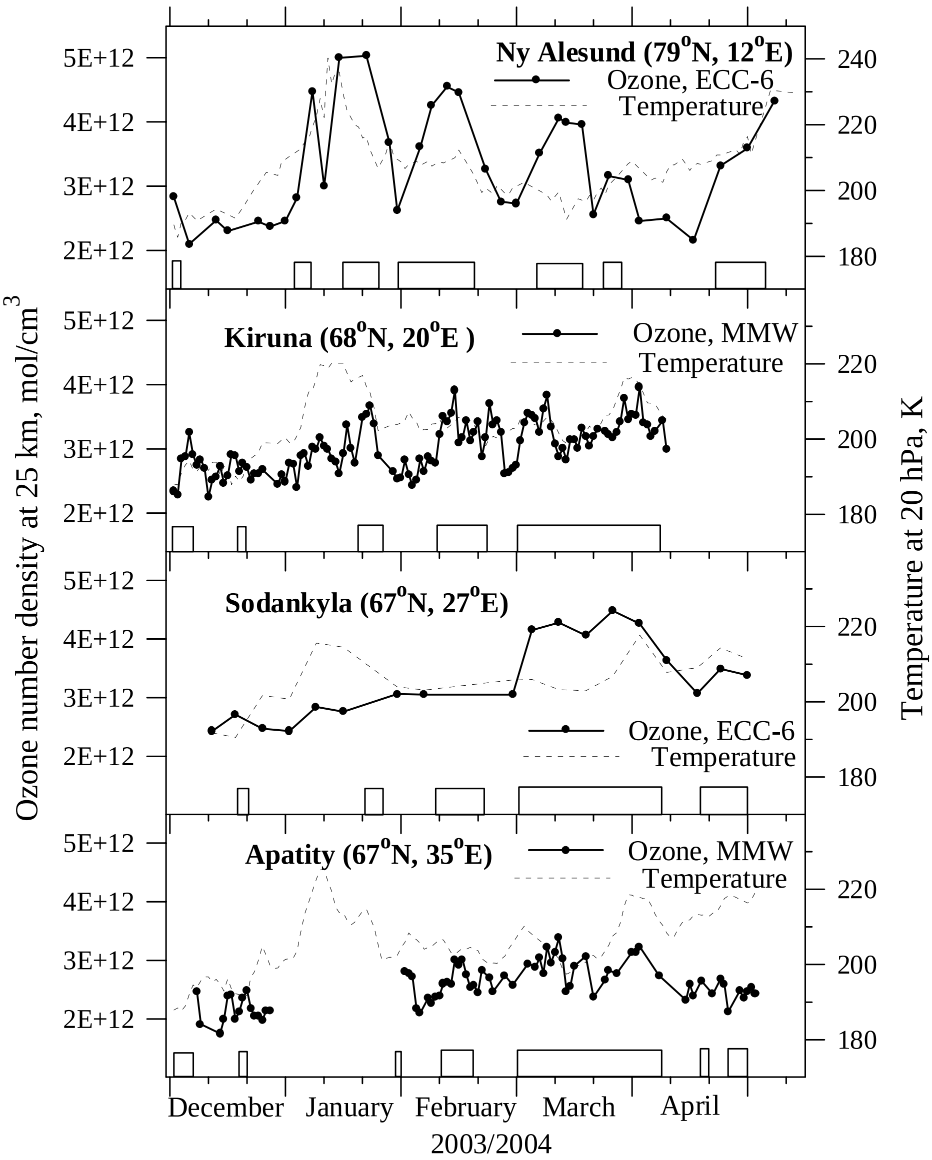


Fig. 2

Apatity. Especially large difference (almost twice) was observed in March 2004. The distance between these stations is about 400 km. A comparison of the results of ozone measurements at the height of 25 km during the winter campaign SOLVE 1999/2000 showed a small difference - about 10 % [9]. It can be noted that during the winter of 1999/2000 in the stratosphere a steady polar vortex was persisting for a long time. Apparently, after vortex formation, the low values of temperature and ozone density were inside it. The values of ozone density varied a little over the entire area occupied by the vortex.

In Figure 1 the ozone evolution at heights 25, 30, 40, 50 and 60 km according to the microwave sounding in Apatity and Kiruna in the winter of 2003/2004 is shown. Here, the variations of stratospheric temperature in the same height range above Apatity according to satellite AMSU data are also presented. For the winter of 2003/2004 the correlation coefficients between ozone and temperature in the height range from 30 to 60 km are negative. The magnitude of ozone density at the heights from 25 up to 40 km measured in Kiruna exceeds that in Apatity, except for short time periods when these values were coincident. At the heights of 50-60 km there were revealed an essential difference in the ozone content, which may testify about the occurrence of a spatial layer, which is inhomogeneous in ozone, probably due to different meridional transport. One of the interesting results of this paper is that an ozone reduction (about 30-50 %) was found at heights from 25 up to 40 km in the first half of April 2004, which was observed at all stations. A similar decrease of $O_3$ at the same time was registered by UARS/HALOE [10] at the latitude of 68°N and near the height of about 40 km. In our opinion, the reason for the ozone decrease is an unusually high amount of nitrogen oxides $NO_x$ ($NO+NO_2$) which is possibly related to the powerful solar storms in October - November 2003. Further, the authors of paper [11] analyzed $NO_x$ and $O_3$ data from numerous satellite instruments. By late January, the satellite data indicated a systematic descent of $NO_x$-rich air in the vortex that finally caused unprecedented $NO_x$ enhancement and $O_3$ reduction in the upper stratospheric vortex in the period from March to May 2004.

Simultaneous measurements in the winter 2003/2004 revealed the occurrence of meridional asymmetry in the distribution of ozone content above 20 km in polar latitudes. The reason for this spatial inhomogeneity might be a very warm stratosphere in the season 2003/2004 (compared to the winter 2002/2003), so that the vertical structure of the polar vortex was weakly developed. Besides, we have found an extraordinary springtime ozone reduction at heights from 25 km up to 40 km.

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