Moscow University Physics Bulletin Vol. 53, No. 4, pp. 13–16, 1998

Vestnik Moskovskogo Universiteta. Fizika UDC 551.510.534: 528.811

MILLIMETER-WAVE INVESTIGATION OF THE OZONE LAYER OVER MOSCOW REGION IN 1996–1997

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The altitude-time distribution of ozone in the stratosphere and mesosphere over the Moscow region was studied with the aid of a radio spectrometer operating in the 2-mm wave band in the period from January 1996 to May 1997. A significant reduction in the relative concentration of ozone was discovered at the altitudes of 30 to 40 km in winter periods.

INTRODUCTION

Investigation of the protective ozone layer and the ozonosphere monitoring over densely populated areas and large cities are important tasks, especially in view of a modern trend toward the deterioration of the ozone layer's condition, the discovery of its depletion over polar regions, and the formation of the Antarctic ozone hole. Most of ozone data come from ozone sonde balloons, from rockets, aircraft, and Earth satellites, and also from conventional ground-based optical techniques and lidars. The accumulated experimental data constitute a more and more comprehensive picture of the ozone layer's global status, which is important for predicting its future evolution. Unfortunately, the details of the altitude-time ozone distribution over particular regions at medium latitudes in the Northern hemisphere, including Moscow, have been studied less thoroughly.

The important task of the near-real-time monitoring of the ozone layer from the Earth surface was addressed at the Lebedev Physical Institute of the Russian Academy of Sciences. Monitoring techniques were developed and high-sensitivity millimeter-wave equipment was designed [1, 2] for measuring the ozone vertical distribution (OVD) in the stratosphere and mesosphere over the Moscow region. This equipment can produce OVD data at any time of the day and in different weather conditions, including those of poor optical visibility. The systematic observations conducted at the Physical Institute for the last ten years were efficient enough to quickly detect changes in the ozone concentration over the Moscow region and to explore the variations of these changes caused by atmospheric processes [3, 4]. The Institute's equipment was included into the global ozonometric network under the international programmes DYANA (1990) and CRISTA/MAHRSI (1994 and 1997). Below we describe the results of our regular millimeter-wave measurements of the atmospheric ozone conducted in 1996 and 1997.

METHOD OF STUDY

The observed ozone spectral lines are formed in atmospheric layers, for which the approximation of a local thermodynamical equilibrium is valid, at transitions between the molecules' rotational energy levels. The broadening of some ozone spectral lines in the millimeter spectral band up to mesospheric altitudes is due to molecule collisions, therefore the line widths at frequencies of about 100 GHz are proportional to the pressure up to an altitude of 70–80 km. The Doppler broadening prevails at higher altitudes. Therefore

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the very peculiar shapes of ozone spectral lines reflect the contributions of ozone molecule emission from different stratospheric and mesospheric layers. Using the shape of a spectral line recorded on the Earth surface one can reconstruct the vertical profile of ozone concentration in the stratosphere and mesosphere.

Thermal radio emission of ozone molecules in the 142.2 GHz line was measured with the aid of a low-noise radio spectrometer based in Moscow [2]. The ozone vertical profiles were reconstructed using well-known mathematical methods [5, 6]. In the observation data for the period of January 1996 to May 1997, the OVD reconstruction errors do not exceed 5–7% for altitudes below 50 km and 10% for the rest of the altitude range explored. The data on the overall ozone content in the atmosphere and on the vertical temperature and pressure profiles in the stratosphere, which were used in the processing and analysis of our observation data, were kindly submitted by the Central Aerological Observatory and the Hydrometeorological Center.

OBSERVATION DATA

The vertical ozone profiles produced are very dependent on atmospheric processes. Examples of the vertical ozone profiles recorded in 1996 and 1997 are given in Fig. 1. Figure 2 shows the time behavior of the relative ozone concentration C over the Moscow region at the altitudes H = 30–40 km, i.e., around its maximum (according to the model proposed in [7], the maximum of the OVD profile $C(H)$ lies at about 35 km).

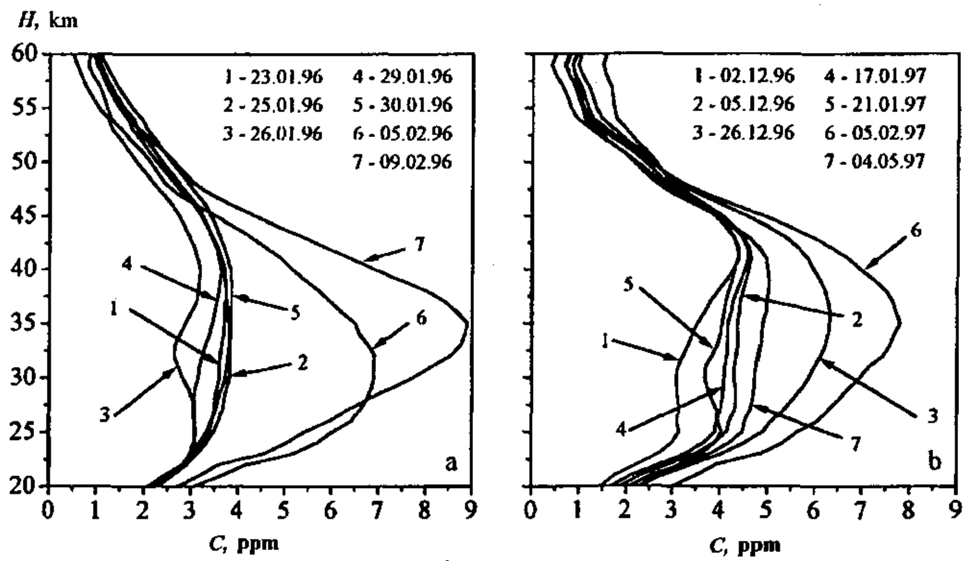

Fig. 1

Vertical profiles of relative ozone concentration $C(H)$, obtained from millimeter-wave observations over the Moscow region in early 1996 (a) and in late 1996/early 1997 (b).

Let us discuss the main features of the 1996 ozone distribution (Figs. 1a and 2a). The ozone concentration at 30–40 km was low throughout January and at some periods in February and March, decreasing to 40–50% of the mean model values [7] shown by a dashed line in Fig. 2. This significant decline in the ozone concentration at these altitudes over Moscow during the 1995/1996 winter occurred in the conditions of a stable winter circulation in the stratosphere of the northern hemisphere. Optical observations at the Central Aerological Observatory indicated that the total ozone content over Moscow in these periods was as low as 80–90% of the mean multiannual value [8].

In the period of February 5–12, 1996, a sharp increase was observed in the stratospheric ozone concentration (Fig. 1a, curves *6* and *7*), which correlated with the growth of the total ozone content in the atmosphere. That growth was due to the influence of a high-pressure region (stratospheric anticyclone) approaching Moscow, which caused the arrival of air masses with a higher ozone content. Later the anticyclone returned to lower latitudes, and the ozone concentration dropped again (Fig. 2a).

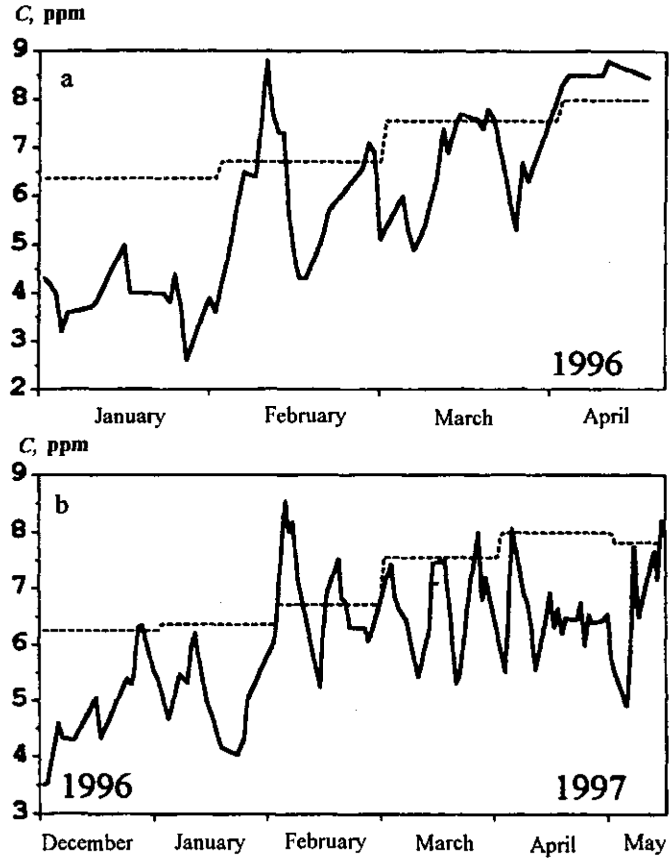

Fig. 2

Ozone content at the altitudes of 30–40 km over the Moscow region from millimeter-wave observations in the cold periods of 1996 (*a*) and 1996/1997 (*b*).

A so-called final stratospheric warming was observed in late February and in March 1996. In that period, the main baric formations in the stratosphere — the polar vortex (a cyclone) and the Aleutian anticyclone — were moving actively, and jet streams, transporting ozone-rich air masses from low to high latitudes, were generated. These processes caused variations in the ozone content over the Moscow region in late February and March 1996 (Fig. 2*a*). This stratospheric warming was later replaced by the spring rearrangement of the stratospheric circulation, which was accomplished by mid-April. The ozone content increased, which is typical of that period.

A specific feature of the 1996/1997 cold season was a significant perturbation in the stratospheric dynamics in the second half of November and in December 1996. At that time, the polar vortex center shifted significantly from the North Pole toward Europe, which was accompanied by the drop of the relative ozone content at 30–40 km to 3.5 ppm (i.e., 3.5×10^{-6}; see Fig. 1*b*, curves *1* and *2*, and Fig. 2*b*) and by the reduction of the total ozone content in the atmosphere over the Moscow region to 75–85% of the mean value. In the third decade of December the perturbation ended, the polar vortex center returned to the North Pole, and the OVD became close to the model value [7] (Fig. 1*b*, curve *3*, and Fig. 2*b*).

In the first half of January 1997, the polar cyclone grew deeper and shifted again toward Moscow in the period of January 17–21. A simultaneous reduction was observed in the ozone content at 30–40 km (Fig. 1*b*, curves *4* and *5*, and Fig. 2*b*) and in its total content in the atmosphere. In the beginning of February 1997, the ozone content at 30–40 km abruptly increased to 8.5 ppm (Fig. 1*b*, curve *6*, and Fig. 2*b*); the total ozone content also increased. These effects were caused by the formation of an anticyclone in the stratosphere over Europe.

Interestingly, the subsequent variations of the ozone content over the Moscow region, which occurred up to late February and the beginning of March, coincided in time with the motions of the stratospheric polar vortex. The ozone content increased when the vortex moved away from Moscow and decreased when it was approaching. In April, the polar vortex often shifted toward Europe, which caused a decline in the ozone content in the stratosphere above Moscow, as recorded by a millimeter-wave spectrometer (Fig. 2*b*). In contrast with the spring of 1996, the 1997 spring restructuring of the stratospheric circulation began later and terminated in the beginning of May. The influence of the polar vortex on the ozone layer over Moscow was observed on May 4–5, when the relative ozone content at 30–40 km dropped to 4.7 ppm (Fig. 1*b*, curve *7*, and Fig. 2*b*). This decline was due to the arrival of polar vortex air masses over Moscow (the vortex center was located at 56° N., 35° E. at that time). The summer type of circulation settled finally by May 9, when the spring restructuring was over, the last remnants of the polar cyclone disappeared, and the data of millimeter-wave observations indicated the presence of ozone-rich air in the stratosphere over the Moscow region, which is typical of the spring period (Fig. 2*b*).

CONCLUSION

The results of the Lebedev Physical Institute's 1996/1997 OVD measurements conducted with a millimeter-band ground-based spectrometer confirmed the data reported in [1, 3, 4], which had been obtained earlier using the same technique and indicated a significant influence of dynamic processes on the vertical ozone profile. An important result of this study is the discovery of a strong ozone layer depletion at the altitudes of 30–40 km in the cold periods of these years. The relative concentration of ozone at these altitudes might drop as low as 50–60% of the mean model value. These changes were up to 10–25% higher than the accompanying decline of the total ozone content in the atmosphere.

The observed dependence of the ozone content variations at 30–40 km on the motions of the main baric systems of the stratosphere and on the location of the polar vortex proves an important role of stratospheric dynamics in the ozone distribution in this layer. However, in order to interpret the strong ozone content variations observed in the millimeter waves, one should take into account the influence of not only dynamical but also photochemical processes, whose role becomes more important at altitudes above 30 km. Our results provided new important information on changes that occur in the stratosphere. The discovered depletion of the ozone layer over the Moscow region calls for further monitoring of this layer.

We are deeply grateful to I.I. Sobel'man, Corresponding Member of the Academy for his support. Thanks are also due to G.M. Kruchenitskii and T.V. Kadygrova (CAO) and to T.S. Kruzhkova (Hydrometeocenter) for their aerological sensing data.

This work was supported by the Russian Foundation for Basic Research (grant no. 96-02-19093a).

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