INVESTIGATION INTO THE OZONE PROBLEM AT THE INSTITUTE OF SOLAR-TERRESTRIAL PHYSICS, SIBERIAN BRANCH OF THE RUSSIAN ACADEMY OF SCIENCES

G.A. Zherebtsov, E.S. Kazimirovskii, V.D. Kokourov, and V.V. Koshelev

Institute of Solar-Terrestrial Physics,
Siberian Branch of the Russian Academy of Sciences, Irkutsk
Received March 27, 1996

First results of investigations into the ozone problem obtained at the Institute of Solar-Terrestrial Physics, Irkutsk, are presented. Variations of the total ozone content over East Siberia are described based on the data from the network of ozonometric stations and satellite measurements (Nimbus–7, TOMS, NASA–USA). Orographic effects in the ozone distribution are considered, as well as possible relationship between the ozone and parameters of the lower ionosphere. Our further investigations are connected with the organization of satellite monitoring and improvement of the instrumentation for ozone measurements from the ground.

INTRODUCTION

In the processes of transfer and transformation of energy from the Sun to the Earth, the middle atmosphere (the region between the tropopause and turbopause, i.e. in the altitude interval about 10–100 km) plays an active and important role. This part of the atmosphere includes the ozone layer concentrated mainly in the stratosphere with the maximum ozone content at altitudes 20–25 km. In the physics of the upper and middle atmosphere, as well as among global ecological problems, the problem on atmospheric ozone occupies one of the leading places. Interest to the ozone problem results from the need to have a reliable model of the upper and middle atmosphere based on the clear understanding of the full set of complex physicochemical processes occurring in it, as well as from possible severe consequences of anthropogenic impact on the ozone layer.

The stratosphere generally and the stratospheric ozone specifically play an important part in the climate formation. Ozone can be considered as a possible link between the solar activity and weather-climate changes. The variations in the ozone distribution or concentration can cause changes in the flux of solar radiation (of the UV range, first of all), the degree of heating the stratosphere, and following variations of the atmospheric circulation. An important part playing by the stratospheric ozone is its function as a buffer zone, where the energy inflow from external sources is modulated, filtered and then transferred into the troposphere (or reflected).

It is commonly accepted now that the dynamics of the ozone layer is sensitive to natural (space, meteorological, orographic, tectonic, etc.) and anthropogenic impacts. On the whole, the situation with studying ozone can serve as a good illustration of still persisting imperfection of the global system for observing the environment and serious gaps in theoretical and experimental researches into the processes occurring in the atmosphere.

Certainly, the main difficulty is the complexity of interacting dynamic, radiative and photochemical processes (see Fig. 1). In addition, creation of adequate global models is difficult due to the lack of reliable experimental data for many regions of the Earth that is often noticed in the resolutions of international scientific organizations and conferences. The wast territory of East Siberia is among such regions. At the same time, East Siberia is of particular importance in many respects, for example, as a region of stationary anticyclone in the center of Asian continent. Just in this region the records of low total ozone content (by 30–35% lower than the many-year norm) was recently (in winter-spring 1995) observed.[1]

Institute of Solar-Terrestrial Physics, SB RAS, situated in the East Siberia has the unique instrumental complex for studying solar and geomagnetic activity, physics of the ionosphere and the middle atmosphere, as well as the database of many-year series of observations. Plans of Institute for the near future are to complete this complex with the data of ozone measurements from both the ground and space, to analyze the spatiotemporal ozone variations with due regard for external factors, and to obtain new information about regional features of this variations and about correlation between the processes in the middle and the upper atmosphere. All these directions are in a complete agreement with the national and international programs on studies in atmospheric and solar-terrestrial physics. This paper is devoted to some first results of our investigations in the above fields.

0235-6880/96/09 801-05 $02.00

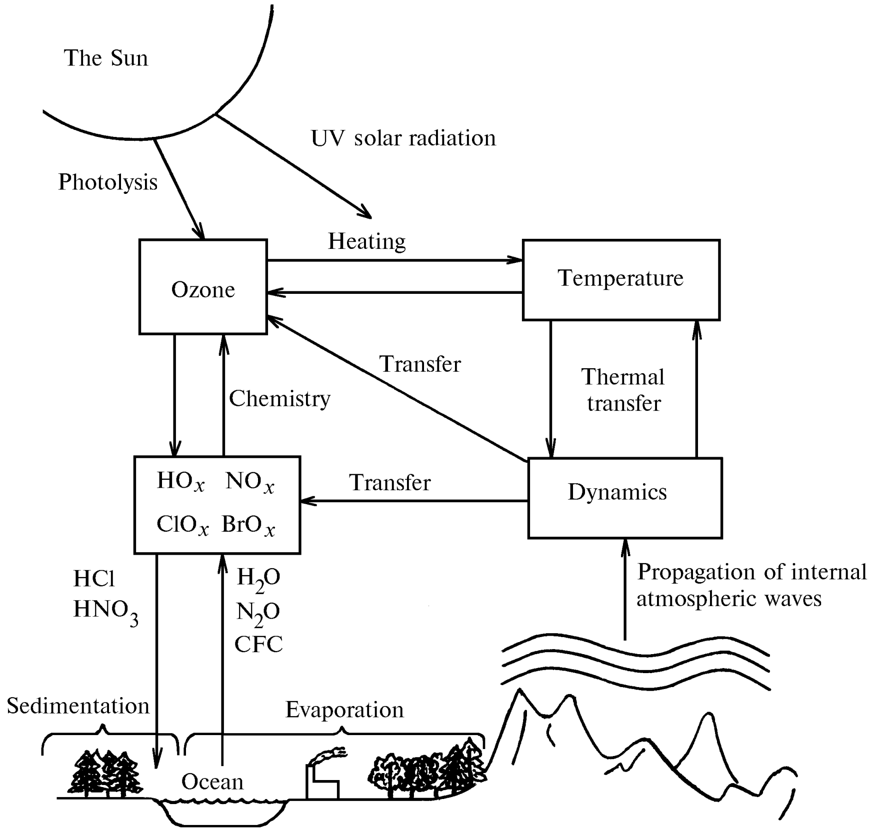

FIG. 1. Scheme of physicochemical processes influencing the ozone distribution.

1. VARIATIONS OF THE TOTAL OZONE CONTENT (TOC) OVER EAST SIBERIA FROM THE DATA OF THE NETWORK OF OZONOMETRIC STATIONS

The ozone field over the region of East Siberia was studied based on the data of six ozonometric stations situated in the interval between 50 and 70°N, and 86 and 113°E for the observational period 1973–1989 (Ref. 2). The analysis showed that typical for all six stations is the TOC annual behavior with maximum in spring, and in the latitude interval 50–60°N TOC peaks in March, while in the interval 60–70°N the peak is shifted to April. Series of every-day observations (using the linear interpolation for small gaps) after excluding trends (high-frequency filtration of the data) have been subjected to spectral analysis by the Blackman-Tewky method for studying the short-period variations, whereas the series of monthly average data have been processed using the same technique but for studying the long-period variations. In the spectra obtained, the annual cyclicity is well pronounced and a small maximum is observed associated with the half-annual variation. Spectral peaks for the periods of 3–6, 8–9, 12–14, 25–28 and 30–32 days are typical in the short-period variations. It is difficult now to give clear physical interpretation for all the observed periods, but some of them coincide with the natural synoptic tropospheric periods and the periods of internal atmospheric planetary waves.[3] The periods close to 27 and 13.5 days can be assumed to have the solar origin and to be connected with the period of the Sun rotation and, consequently, with the periods of action of solar active areas on the near-earth space.

In connection with the widely discussed question about the tendencies in TOC change, we have estimated these trends for a number of East-Siberian stations and discovered, for all the cases, the systematic TOC drop in time by several Dobson units an year.

As known, there is the database of highly accurate global measurements of the total ozone content made from onboard Nimbus–7 satellite with TOMS spectrometer for the period 1978–1992. NASA Goddard Space Flight Center, the USA, kindly put this database at our disposal. One computer program, comprising the database software, gives a user the possibility to obtain the series of daily and monthly averaged values of TOC for the region above a preset point, if the user set the coordinates of this point.[4] Figure 2 shows the corresponding data array for station Irkutsk (52°28′N, 104°02′E). One can see that TOC variability is highest in the winter–spring period, and TOC reaches its maximum in March.

Figure 3 shows the same array by years with the estimate of interannual trend (–2.29 Dobson units an year) with the average value of 373.9 Dobson units.

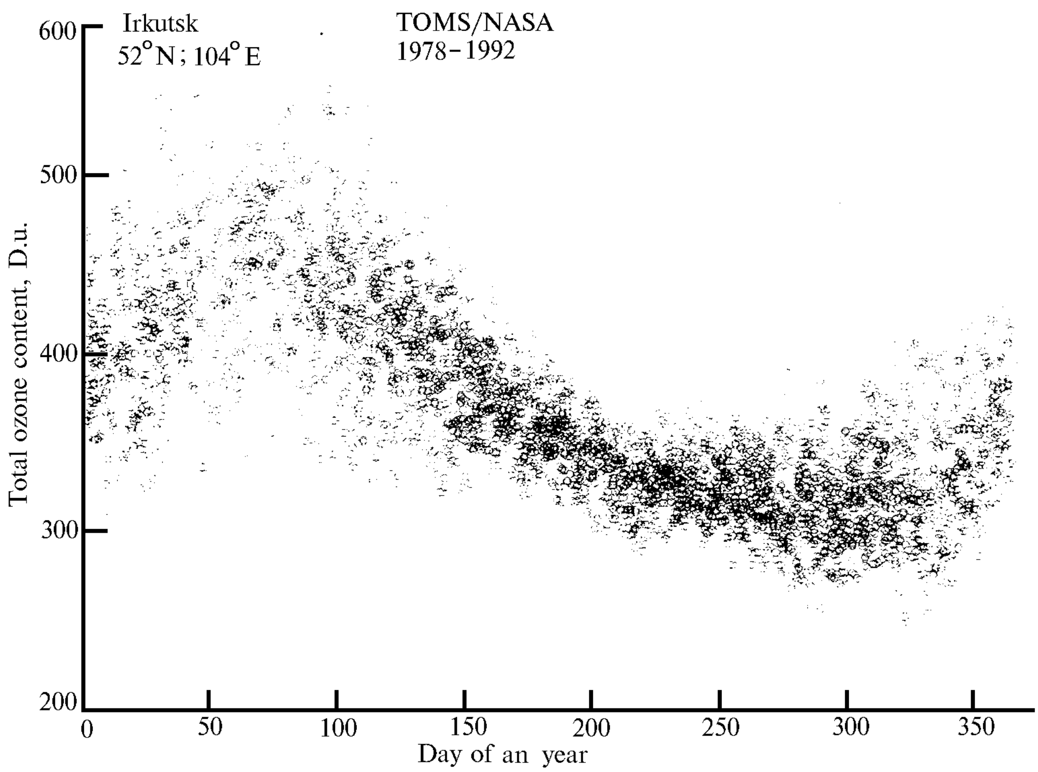

FIG. 2. Averaged annual behavior of the total ozone content over Irkutsk.

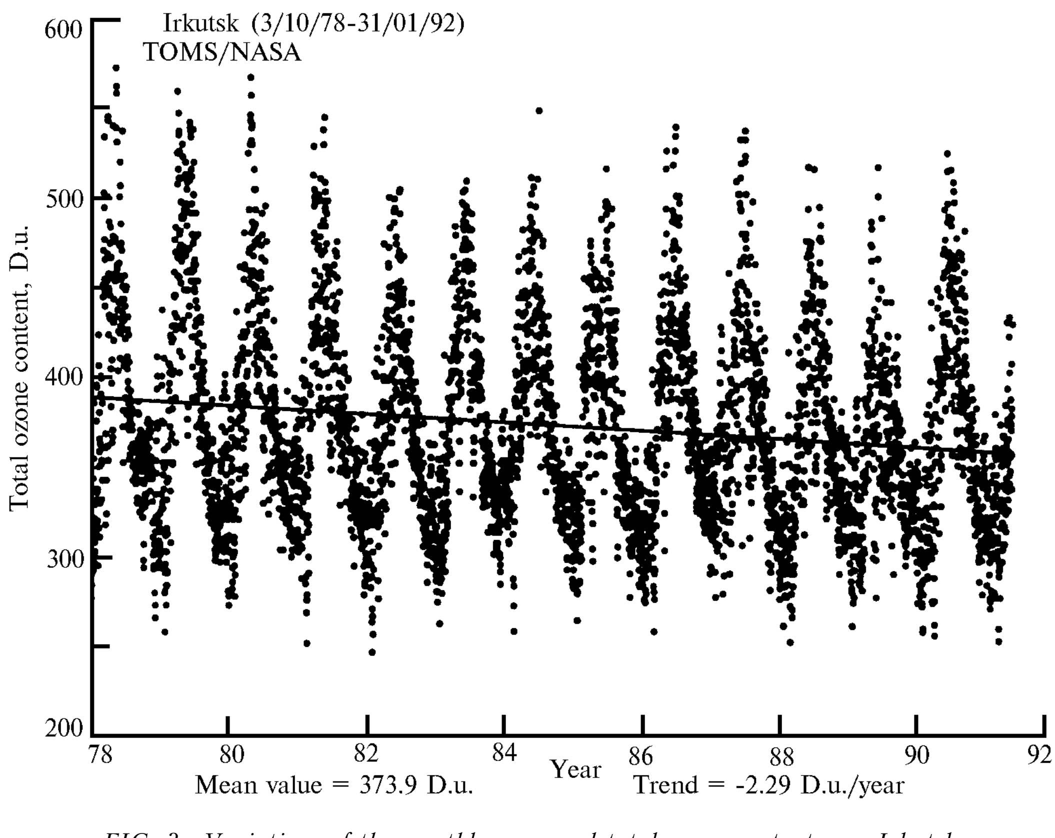

FIG. 3. Variations of the monthly averaged total ozone content over Irkutsk.

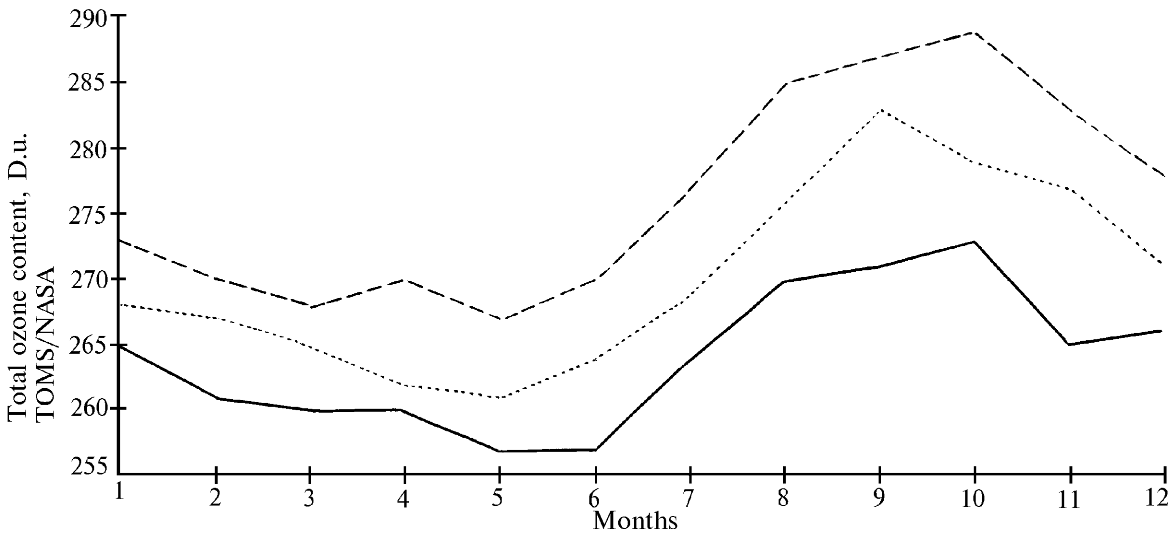

FIG. 4. Average annual behavior of the total ozone content over the Andes and neighbouring flat areas: 16.5°S, 78.1°E *(dashed curve), the Andes,* 16.5°S, 68.1°E *(solid curve),* 16.5°S, 58.1°E *(dotted curve).*

2. OROGRAPHIC EFFECTS

It was noticed in a number of papers that over mountains the TOC value is systematically lower than over flat areas surrounding them, and this difference is much higher than that explained by the subtraction of ozone from the part of the troposphere occupied by mountain ridges. We checked this situation by the variations of monthly averaged TOC in the period 1979–1992 for Pamir in the eastern hemisphere and the Andes in the western hemisphere.[5] The data were taken from the NASA database.[4] Really, the systematic decrease of TOC over mountains as compared to the flat areas lying to the west of them is observed for Pamir and even more clearly for the Andes mountain chain extended along the meridian. Figure 4 demonstrates the TOC annual behavior, averaged for the whole period of observations, for three points: 16.5°S, 68.1°W – mountains; 16.5°S, 78.1°W – ocean to the west; 16.5°S, 58.1°W – plain to the east. The effect is obvious.

The effects observed may be connected with the vertical propagation of the internal gravitational waves (IGWs), appearing at the interaction of horizontal air flow (general circulation directed from west to east) with an obstacle such as a mountain area. The fact that at upward motions total ozone content decreases is well known. IGWs can transfer energy into the stratosphere and even the mesosphere and dissipate at these altitudes thus heating the atmosphere. Temperature changes, in their turn, can become the reason for change in the rate of ozone cycle reaction. It is also known that IGWs appearing in the stably stratified atmosphere, when wind is normal to orography, can propagate into the middle atmosphere and even affect the formation of the so-called polar stratospheric clouds, playing significant part in chemistry and dynamics of the high-latitude ozone.

It is clear, however, that one cannot yet draw some particular conclusions. For a more complete analysis, careful study of meteorological situation in the regions under study and comparison of the altitude profiles of wind, temperature and ozone concentration measured at the same time are required. It is also necessary to analyze data for different regions.

3. ON THE POSSIBLE RELATION OF THE STRATOSPHERE WITH THE LOWER IONOSPHERE

Intense studies are presently conducted of the interaction between different layers of the earth's atmosphere including the interaction of its ionized areas (ionosphere) with the lower neutral atmosphere.

The literature on meteorological effects in ionospheric processes is quite voluminous.[6,7] One of the methods to estimate the physical parameters of the lowest ionosphere, the region D (60–100 km), is to measure the absorption of short and medium radio waves during their propagation in the ionosphere. The correlation was noticed between the quasiperiodic variations of the radio waves absorption and TOC in mid-latitudes, as well as an increase in TOC in the periods of anomalously high absorption of radio waves. We had at our disposal the data array on radio waves absorption and TOC for several mid-latitude radio routes in central, eastern, and south-western Europe. Using monthly averaged values of both parameters for 27 months in the period of minimum solar activity (January 1984–March 1986), we have discovered the statistically significant correlation between the variations of TOC, as the indicator of stratospheric processes, and absorption of radiowaves, as the indicator of the ionospheric processes (electronic concentration, first of all), and that the changes in the ionosphere are 20–40 days ahead of the changes in ozone.[8] We tried to interpret the correlation observed as a consequence of vertical dispersal of long-lived minor gaseous constituents and, first of all, NO_x from the lower ionosphere down to the stratosphere. No_x compounds play a significant part both in the chemistry of the *D* region and in the chemistry of the atmospheric ozone. Time lags well agree with the known values of vertical wind speed (several centimeters per second). Certainly, these results also should be considered as tentative, requiring a check based on a more vast material and further investigations.

4. SATELLITE MONITORING

At the Institute of Solar-Terrestrial Physics recently the instrumental and software complex has been created for reception and processing the data of remote sensing of the atmosphere and the earth's surface from satellites of NOAA series (USA).[9] Satellites orbit along practically circular orbits at altitude of 850 km, at 98° orbit inclination. Since two satellites are now orbiting, we, in Irkutsk, can receive information in different spectral ranges four times a day.

The instrumentation installed on the satellites: AVHRR (Advanced Very High Resolution Radiometer) and TOVS (TIROS Operational Vertical Sounder) give information on albedo; temperature of the earth's surface, water and clouds; vertical profiles of temperature and humidity for altitude interval 0–50 km; fields of the atmospheric pressure; velocity of geostrophic wind; as well as on total ozone content.

The use of the monitoring system in combination with the already existing instrumentation opens new possibilities for a complex study of physics of the lower and upper atmosphere.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to NASA Goddard Space Flight Center (the USA) for the possibility of using the Nimbus-TOMS data as well as their colleagues from the Institute of Solar-Terrstrial Physics N.N. Kolpakidi, G.V. Vergasova, and G.K. Matafonov for help in preparing this paper for publication.

REFERENCES

1. R.D. Bozhkov, V.E. Fioletov, T.V. Kadygrova, et al., Meteorol. Gidrol., No. 9, 30–39 (1995).

2. N.N. Kolpakidi, V.V. Koshelev, G.K. Matafonov, et al., *Variation of the Total Ozone Content over East Siberia from the Data of the Network of Ozopnometric Stations,* Preprint No. 3–95, Institute of Solar-Terrestrial Physics, Irkutsk (1995), 28 pp.

3. J.R. Holton, *An Introduction to Dynamic Meteorology* (Academic Press, New York, 1972), 319 pp.

4. *The Nimbus–7 User's Guide* (NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, 1991), 35 pp.

5. A.D. Danilov, E.S. Kazimirovskii, B.A. de la Morena, et al., Geomagn. Aeron. **35**, No. 3, 108–115 (1995).

6. E.S. Kazimirovskii, G.V. Vergasova, G.Ya. Khachikjan, et al., J. Atmos. Terr. Phys. **44**, No. 11, 913–925 (1982).

7. E.S. Kazimirovskii and V.D. Kokourov, Geomagn. Aeron. **35**, No. 3, 1–23 (1995).

8. L. Alberca, M. Gil, E. Kazimirovsky, et al., Adv. Space Res. **18**, No. 3, 141–144 (1996).

9. G.A. Zherebtsov, V.D. Kokourov, V.V. Koshelev, and N.P. Min'ko, Issled. Zemli iz Kosmosa, No. 5, 74–77 (1995).