Integrated measurements of total ozone, total content and vertical distribution of nitrogen dioxide, and spectral UV irradiance in Buryatiya

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The results of spectrophotometric measurements of total column ozone (TCO), total content and vertical distribution of nitrogen dioxide, and spectral UV irradiance are presented. The measurements were conducted in summer and fall of 1999 and fall of 2000 on the southern coast of Lake Baikal, Buryatiya. A significant negative relation was found between TCO and spectral UV irradiance under clear sky conditions. An appearance of optically thin cirrus caused an increase in the spectral UV irradiance possibly due to transformation of the scattering phase function. No significant correlation between TCO and total nitrogen dioxide was observed likely because of short time series of observations.

Introduction

Climatic-ecological studies become now increasingly intensive in many regions of Russia, including the Lake Baikal territory. This is connected with the actual ecological deterioration of the environment and the current change in the global climate. In particular, one of the tasks of high priority in these studies is estimation of contribution of anthropogenic or natural factors in formation of ecosystems and in the climate change. The correct evaluation of the role of these factors determines, to a high degree, the further social and economic development of regions and safety of their natural resources.

The incoming solar UV radiation at the surface level is among important climatic and ecological parameters of the earth–atmosphere system. It can be characterized by the intensity of the spectral or net flux. The physical-chemical and biological effect of the UV radiation is determined by its possibility to dissociate molecules of atmospheric gases, change the molecular composition of organic substances and inorganic materials, suppress photosynthesis of plants, and even change the structure of the DNA molecule. This leads to transformation or destruction of chemical compounds, materials, or medium of both natural and anthropogenic origin and, in particular, affects the evolution and productivity of flora and fauna. The UV radiation flux coming to the lower atmospheric layers and to the surface is controlled, in its turn, by the stratospheric ozone layer or the total column ozone (TCO). The photochemical balance of the stratospheric ozone O_3 depends significantly on the catalytic cycle of nitrogen, which is responsible, as estimated, for up to 50% of total catalytic destruction of ozone. A very important element of this cycle is such minor atmospheric constituent as nitrogen dioxide NO_2, whose total content can be controlled rather readily with spectrophotometric measuring devices. For correct evaluation of the climatic and ecological state of some ecosystem, in particular, in the Baikal region, a very urgent problem is to study links in the chain NO_2–O_3–UV radiation–ecosystem.

For this purpose, since 1999 the Department of Physical Problems BSC in cooperation with the Institute of Atmospheric Optics has conducted integrated measurements of the total column ozone, total content and vertical distribution of NO_2, as well as the spectral UV irradiance (since 2000) at the observing station in Istomino (52.17°N, 106.33°E). In this paper, we present the results of measurements conducted during two field seasons in summer and fall of 1999 and fall of 2000.

1. Brief description of the instrumentation

To measure the total content (TC) and the vertical distribution (VD) of NO_2, TCO, and the spectral UV irradiance (SUVI), we used a highly sensitive automated spectrophotometer based on MDR-23 monochromator. The technique for measurements of the TC/VD of NO_2 is based on the method of differential absorption of the solar radiation scattered in zenith by NO_2 molecules in the spectral region from 430 to 450 nm. The radiation intensity was measured with the

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spectral resolution of 0.9 nm, the step of mechanical scanning was 0.01 nm, and the scanning time was 40 s. Measurements were conducted in twilight in the morning and evening at the solar zenith angle (SZA) from 83 to 96°. Initially, the content of NO_2 was determined in a slant column. Then the mean content in 5-km layers and the total content in the vertical column from the surface up to the altitude of 50 km were calculated.[1]

The total column ozone was estimated by the multiwave technique[2] based on recording of the solar radiation in the spectral region from 290 to 340 nm. The time of scanning was 1.5 min. The measurements were conducted in daytime with the interval of 30 min at the SZA less than 83°.

For TCO measurements, the M-124 filter ozonometer was used as well. Measurements were conducted by the standard technique[3] in daytime with the interval of one hour from the solar radiation both direct and scattered in zenith at the SZA less than 70° and 85°, respectively.

The SUVI in the region from 290 to 340 nm was measured at minimal values of the SZA in near-midday time. The radiation was measured from the celestial hemisphere; one measurement took about 8 min.

2. Discussion of the measurement results

2.1. Measurements of 1999

The measurements of 1999 (July 29 – October 7) included TCO measurements with M-124 ozonometer No. 29. The results are depicted in Fig. 1.

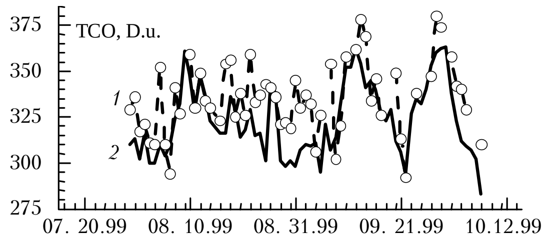

Fig. 1. TCO over the southeastern part of Lake Baikal in July–October 1999 as measured by M-124 ozonometer No. 29 (*1*) and TOMS/EP (*2*).

Comparison of our measurements with the satellite data (TOMS/Earth Probe) revealed both systematic and random discrepancies. The mean discrepancy is 14 D.u., which is smaller than the natural variability of the daily mean TCO (±50 D.u.) and than the 5-% error of the M-124 ozonometer (±10–25 D.u.). Our analysis has shown that the observed discrepancy is caused by different methods used in TCO measurements by M-124 and TOMS mostly under conditions of cloudy atmosphere. After smoothing by a 10-day moving average, which decreased the small-scale variability due to the measurement error and day-to-day fluctuations of ozone, the correlation between the time series was equal to 0.8.

The data of TCO measurements were analyzed in comparison with the data of aerological probing. For this purpose, the correlation between TCO, temperature, geopotential altitude, and wind speed and direction at the isobaric levels of 300, 200, and 100 hPa was calculated. All time series were pre-smoothed by the 10-day moving average. The calculated results are given in the Table. Except for statistically insignificant correlation coefficients between the TCO and temperature at the 200-hPa level, as well as the TCO and the wind direction at all levels, all correlation coefficients are statistically significant at the level of less than 0.05.

Isobaric level, hPa	Coefficient of correlation between TCO and		
	temperature	geopotential altitude	wind direction
100	0.73	−0.68	−0.25
200	−0.24	−0.68	−0.26
300	−0.67	−0.76	−0.18

Comparison of variations of atmospheric circulation in the upper troposphere and lower stratosphere and TCO fluctuations has shown that in the first half of July and in August, when the circulation was mostly anticyclonic, the TCO values were lower than the norm. In September, when cyclonic circulation prevailed, the TCO values were relatively high.

As known, high baric formations, among which are central cyclones and blocking anticyclones, cover atmospheric layers down to the lower stratosphere. Horizontal–vertical air motions connected with these formations (large-scale quasi-horizontal advection) cause re-distribution of both the TCO and the vertical distribution of ozone. (Local break occurs in the quasi-latitude distribution of ozone.) Due to this process in the warm half-year, the growth (or drop) of TCO is accompanied by the simultaneous growth (or drop) of temperature in the lower stratosphere. In the troposphere, the drop (or growth) of the geopotential altitude and temperature, that is, intensification of cyclonicity (or anticyclonicity) of atmospheric circulation is usually observed at this time.

2.2. Measurements of 2000

In 2000 (September 7–20), TCO measurements with M-124 ozonometer No. 29 were complemented with measurements of TCO, TC/VD of NO_2, and SUVI using an automated spectrophotometer. The comparison of these measurements has shown that the discrepancies between TCO values did not exceed 4–5%. The results are presented and discussed below.

Figure 2 depicts fluctuations of VD of NO_2 as judged from the data of morning measurements. A pronounced day-to-day variability is clearly seen in the region of climatic maximum (30–35 km). Fluctuations of the NO_2 concentration made up about $2–3 \cdot 10^{14}$ mol $\cdot$ cm^{-2}.

This value does not exceed the natural small-scale variability of NO_2 due to atmospheric circulation of air masses in the stratosphere.

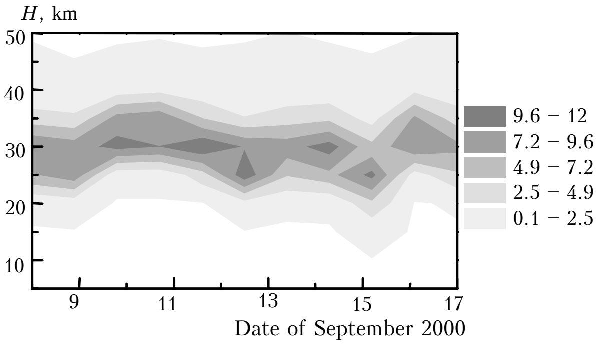

Fig. 2. VD of NO_2 over the southeastern part of Baikal in September 2000 as judged from morning spectrophotometric measurements (10^{15} mol/cm^2).

Figure 3 depicts fluctuations of TCO and TC of NO_2. The correlation analysis has shown that in the series of daytime TCO measurements, being one day shifted with respect to the series of evening measurements of TC of NO_2, the negative correlation with the coefficient of -0.50 ± 0.22 can be found. The series of daytime TCO measurements and morning measurements of TC of NO_2 (without time shift) are positively correlated (0.58 ± 0.17). At the same time, no correlation is observed between TCO and averaged TC of NO_2 (0.20 ± 0.17). As is seen, all values of the correlation coefficient are insignificant, what is likely due to the short length of the time series. Therefore, we still cannot draw a conclusion on the correlation between TCO and TC of NO_2.

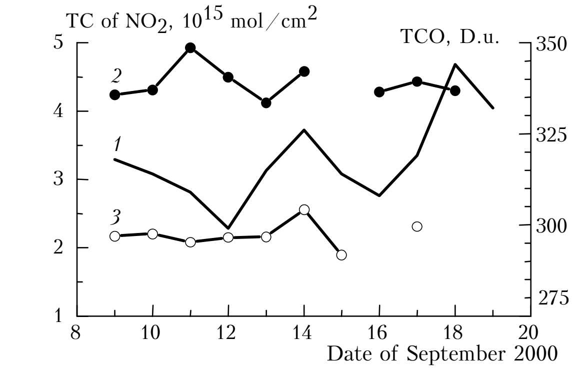

Fig. 3. Spectrophotometric measurements of TCO (*1*) and TC of NO_2 in evening (*2*) and morning (*3*) over the southeastern part of Lake Baikal in September 2000.

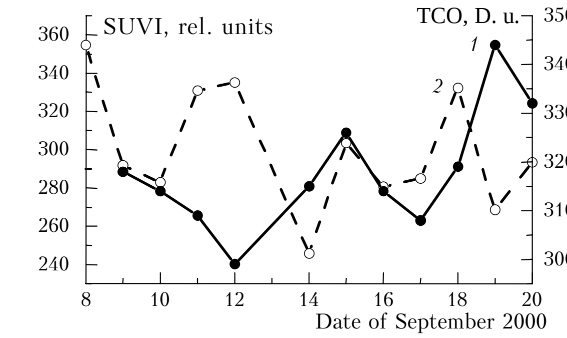

Fig. 4. Spectrophotometric measurements of TCO (*1*) and SUVI in the region of 290–340 nm (*2*) over the southeastern part of Lake Baikal in September 2000.

Figure 4 depicts the curves corresponding to the behavior of SUVI and TCO. In fine days, the pronounced inverse dependence was observed between TCO and UV radiation. At appearance of thin cirrus or stratus clouds, SUVI increased. In our opinion, this increase is caused by the increase of the forward scattered radiation due to the increase of the forward peak of the scattering phase function at scattering by cloud particles.

Using the data of spectrophotometric measurements of TCO in Istomino and Tomsk in fall 2000, we have compared TCO behavior at these two sites. Figure 5 demonstrates the similar pattern of the ozone field evolution for the both sites, but changes in Tomsk were observed two to three days earlier than in Istomino. Such TCO fluctuations are indicative of a certain spatial stability of the ozone field over the vast territory of Siberia in the period of observations. The synoptic analysis has shown that the stability was caused by formation of a high extensive blocking anticyclone coupled with a central slow-moving cyclone in the troposphere and the lower stratosphere. The anticyclone formed in late August – early September in the Middle Ural moved slowly to the east and was broken in the Baikal Region in late September. The cyclone formed over Western Siberia in the second decade of September also moved to the east, following the anticyclone, and lived until late September.

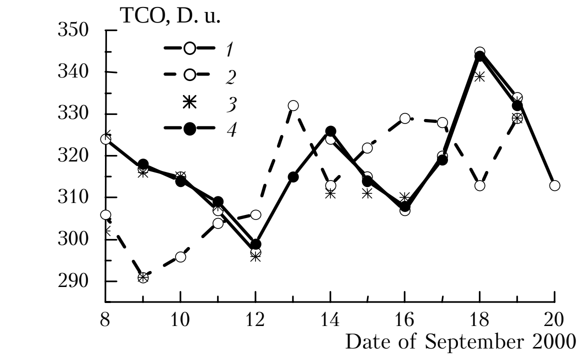

Fig. 5. Evolution of TCO field over the southeastern part of Lake Baikal in September 2000 as measured by M-124 and automated spectrophotometer: M-124 No. 29, zenith, Istomino (*1*), M-124 No. 398, zenith, Tomsk (*2*), M-124, Sun (*3*), automated spectrophotometer, zenith, Istomino (*4*).

Conclusion

The presented results of spectrophotometric observations over the southeastern part of Lake Baikal are only the first step in long-term investigations of atmospheric ozone, nitrogen dioxide, and UV radiation that were started in Buryatiya Scientific Center SB RAS.

Some conclusions can be drawn based on the obtained results and their analysis.

1) The presence of the positive correlation between the TCO and the temperature in the lower stratosphere and the negative correlation between the TCO and the geopotential altitude and temperature in the upper troposphere in warm half-year is confirmed.

2) The pronounced negative correlation between TCO and SUVI is observed under clear-sky conditions.

3) At appearance of optically thin cirrus clouds, SUVI increases likely due to the change in the scattering phase function.

Acknowledgments

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References

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