CORRELATION BETWEEN THE TOTAL OZONE AND AEROSOL CONTENT IN THE ATMOSPHERE OVER RUSSIA

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The correlation between fine aerosol fraction and monthly variations of the total ozone content is analyzed based on measurement data on total ozone content and spectral transmittance of the atmosphere acquired during the period from 1973 to 1988 at 38 ozonometric stations in Russia and neighboring countries.

Taking into account multiple factors causing the ozone variation in time and space, namely, the effect of gas composition, atmospheric circulation, thermal regime of the atmosphere, the presence of aerosol, and others on the total ozone content, the assessment of correlation between the variation of aerosol in the atmosphere and total ozone is of particular interest. At present a greatest bulk of information on the total ozone has been compiled. The ozone content was measured at 45 stations located in different natural zones of Russia and neighboring countries. The observations of total ozone over a period from 1973 to 1988 were published in the reference book "Total Content of the Atmospheric Ozone."[1]

In contrast to the total ozone measurements, the systematic and regular aerosol measurements at the stations of ozonometric network have not been carried out. In this connection we used, to assess the aerosol characteristics, some indirect methods. From Ref. 12 it follows that the relationship of aerosol optical density (δ_{λ_1} and δ_{λ_2}) at one and the same moment in time, as measured at two wavelengths λ_1 and λ_2, is

$$\frac{\delta_{\lambda_1}}{\delta_{\lambda_2}} = \left(\frac{\lambda_1}{\lambda_2}\right)^{3-n}, \qquad (1)$$

where n is the parameter, that enters into the Junge formula (2) and characterizes the aerosol particle size distribution

$$\frac{dN}{dr} = cr^{-n}, \qquad (2)$$

where N is the total number of aerosol particles with the radius being less than r; c is the constant.

In Ref. 1 one may find the Junge parameter calculated. However, only two wavelengths, 369 and 530 nm, were used to calculate this parameter. The parameter n must not depend on the choice of the wavelength pair; the larger the number of the pairs, the more accurate is the result. From the theory of mathematical statistics it has been known that the calculation error of n depends on the number of pairs and decreases as the factor $\sqrt{N}$ falls off, where N is the number of pairs. Therefore for calculation of n we use six wavelengths, what makes up 15 pairs of wavelengths. In this case the error of the Junge parameter calculation decreases by the factor of $\sqrt{15}$.

The aerosol optical density for each of the six wavelengths is obtained using the following formula:

$$\delta_\lambda = \log T_\lambda - \beta_\lambda \frac{P}{P_0} - \alpha_\lambda X, \qquad (3)$$

where T_λ is the spectral transmittance, β_λ is the Rayleigh optical thickness, α_λ is the ozone spectral absorption coefficient; X is the total ozone content.

Thus we have obtained the time series of the total ozone content and of the Junge parameter. Assuming that the aerosol variations do not affect the annual ozone variation, at the first stage of data processing the annual variation was removed from the data array on the total ozone and parameter n. Then we passed from the absolute values of X and n to their monthly variations. The complete sample was divided into two subarrays. The first subarray involved the data on situations when the decrease (increase) of the Junge parameter was accompanied by a decrease (increase) in the ozone content (variations of same sign). The second subarray involved the data when the opposite-sign variations of the parameter n and ozone were observed. Thus the succession of the first and second situations was obtained when same variations are changing for those in the opposite directions. The series criterion was used to prove that these successions were not random. For all the measurement points considered the statistics of this criterion turned out to be more than the critical one by a factor of three or four. From this it follows that thus obtained successions essentially differ from the random ones and the subdivision of the total array into the two situations is well justified.

We have assumed that the total ozone variations are linearly related to the variation of the fine aerosol fraction. Therefore for each subarray the equations of

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linear regression have been constructed. Using these equations we have assessed monthly variations of the ozone under the effect of Junge parameter variation. The Table I gives the evaluation of the relationship between the fine aerosol and total ozone.

Analysis of the table shows that significant values of the correlation coefficient are characteristic of the observations at practically all stations the data from which have been involved into the above analysis. In the first sample a well pronounced positive correlation was observed at the stations in Tiksi (0.672), Voronezh (0.647), and Krasnoyarsk (0.646). The statistically significant negative correlation was observed at the stations in Kuibyshev (−0.671), Khanty-Mansiisk(−0.655), and Ekaterinburg (−0.640).

TABLE I. Evaluation of the contribution of small-sized aerosol fraction to the monthly variability of ozone.

Station	$r1$	$r2$	$D1$	$D2$	$a1$	$a2$
Dickson Island	0.524	−0.507	403.34	572.5	10.515	12.122
Kotelnyi Island	0.617	−550	259.83	332.01	9.953	10.028
Tiksi	0.672	−0.459	271.82	373.23	11.080	8.863
Murmansk	0.469	−0.401	668.74	681.19	122.126	10.477
Arkhangelsk	0.464	−0.517	811.19	506.41	13.202	11.625
Igarka	0.520	−0.518	547.37	559.08	12.173	12.242
Pechora	0.488	−0.606	714.71	721.27	13.057	16.285
Khanty-Mansiisk	0.436	−0.655	535.40	411.33	10.096	13.292
Olenek	0.534	−0.453	366.74	324.19	10.221	8.165
Tura	0.559	−0.415	618.34	656.52	13.892	10.644
Yakutsk	0.605	−0.475	434.58	381.28	12.614	9.275
Markovo	0.488	−0.492	542.66	538.65	11.372	11.416
Nagaevo	0.550	−0.520	584.76	569.80	13.299	12.423
St. Petersburg	0.616	−0.467	342.07	674.78	11.391	12.132
Riga	0.554	−0.444	345.52	362.39	10.292	8.461
Moscow	0.587	−0.600	344.73	422.48	10.898	12.338
Kuibyshev	0.628	−0.671	486.98	506.86	13.859	15.109
Ekaterinburg	0.560	−0.640	433.59	379.92	11.664	12.466
Omsk	0.533	−0.492	506.28	460.27	11.990	10.546
Krasnoyarsk	0.646	−0.529	347.57	786.90	12.044	14.840
Skovorodino	0.633	−0.527	236.86	233.70	9.739	8.054
Irkutsk	0.591	−0.534	444.41	467.05	12.453	11.534
Nikolaevsk-na-Amure	0.632	−0.578	399.89	429.39	12.646	11.986
Vladivostok	0.609	−0.533	292.88	337.41	10.428	9.795
Petropavlovsk-Kamchatskii	0.513	−0.593	386.88	393.45	10.083	11.760
Kiev	0.543	−0.489	437.20	403.49	11.359	9.814
L'vov	0.576	−0.494	354.66	364.24	10.848	9.429
Odessa	0.531	−0.590	372.23	377.51	10.251	11.459
Voronezh	0.647	−0.481	357.85	397.30	12.248	9.589
Karaganda	0.609	−0.594	306.23	285.56	10.660	10.035
Gur'ev	0.492	−0.505	302.45	265.55	8.550	8.237
Aral Sea	0.552	−0.538	337.45	202.24	10.146	7.658
Semipalatinsk	0.531	−0.481	192.13	284.58	7.355	8.118
Alma-Ata	0.574	−0.513	274.75	236.39	9.512	7.8877
Tbilisi	0.531	−0.508	291.99	264.29	9.076	8.258
Chardjou	0.573	−0.636	200.69	177.76	8.116	8.476
Dushanbe	0.599	−0.635	187.68	224.14	8.205	9.507
Ashkhabad	0.563	−0.441	293.92	203.96	9.655	6.304

Note: $r1$ and $r2$ are the correlation coefficients of the Junge parameter variability and the net ozone variability based on the first and second samples; $D1$, $D2$ are the total variance of the parameter variability based on the first and the second samples; $a1$ and $a2$ are the values of rms deviation of ozone due to the variation of small-sized aerosol fraction.

The spatial structure of the parameter $a1$, indicating the positive correlation between the total ozone variations and variations of fine aerosol fraction, is given in the Figure 1. Isolines show the values of rms deviation. The cells of maxima observed at a given territory show that the total ozone variations are due to a large amount of fine aerosol there.

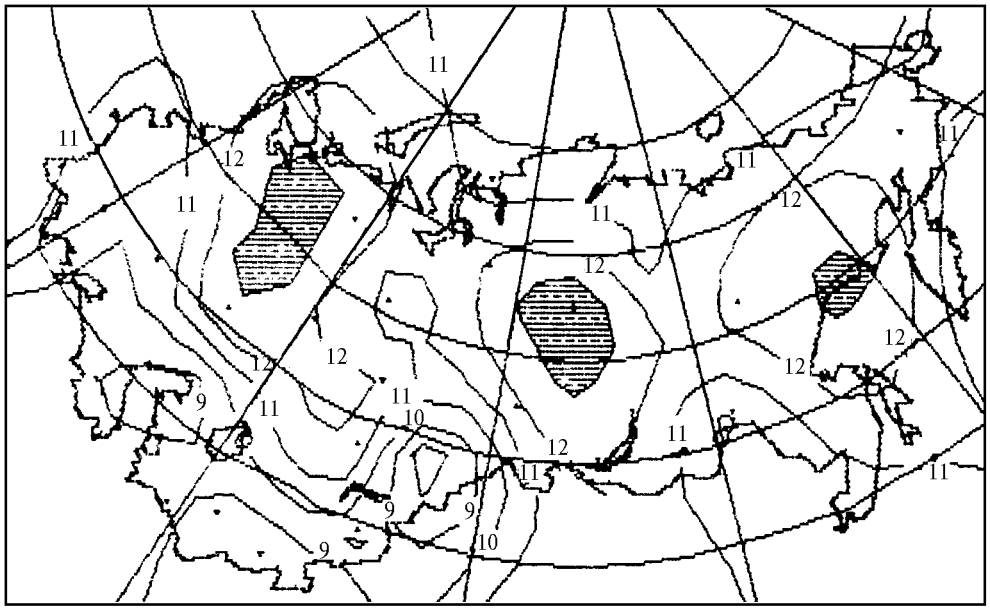

FIG. 1. The net ozone variability caused by the monthly aerosol variations in the lower troposphere (the first sample).

The variations depend also on the aerosol number density, but we have considered the Junge parameter to be an indicator of only the fine aerosol fraction.

Besides the statistically proved dependence of the ozone variations on the variations in fine aerosol fraction, the correlation between them can be explained physically.

Aerosols mainly reside in the atmospheric boundary layer.[3,4] In this relation the aerosols are a protective shield against the substances of anthropogenic origin that cause the ozone destruction. At the same time an increase in the content of fine aerosol fraction in the stratosphere contributes to the ozone destruction. Therefore the situation when variations of ozone have same sign with those of the Junge parameter can be physically explained by the presence of fine aerosol in the atmospheric boundary layer, which manifests itself as a catalyst of chemical reactions involving Cl^-, Br^-, F^-, C^- containing substances. These substances are the gases penetrating into the stratosphere and contributing to the ozone destruction. Thus, the first sample is characterized by small aerosol content in the stratosphere and ozone variations are determined only by the aerosol oscillations in the lower troposphere (boundary layer).

The different-sign variations of X and n can be explained by an increase in the fine aerosol fraction in the stratosphere and its decrease in the atmospheric boundary layer.

Thus, the above investigations have shown that there exists nonrandom relationship between variations of total ozone and aerosol size spectrum. In this case the highest correlation has been observed at mid-latitude territories considered.

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