DISTRIBUTION MODELS OF AEROSOL AND SOME GASES IN ANTICYCLONES AND CYCLONES

B.D. Belan,[1] G.O. Zadde,[2] T.M. Rasskazchikova,[1] T.K. Sklyadneva,[1] and G.N. Tolmachev[1]

[1] Institute of Atmospheric Optics, Siberian Branch of the Russian Academy of Sciences, Tomsk
[2] Tomsk State University
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Some data on distribution of aerosol, CO, and O_3 in cyclones and anticyclones are presented. It is shown that their concentration may vary two to four times in different parts of these formations and there are some differences in the character of their distribution inside the objects. Stable gradients are observed in cyclones along the line of an atmospheric front from its front to the back. In anticyclones, as a rule, concentration gradients are low in the central part and sharply increase at the south or west periphery.

Information about the dynamics of gaseous and aerosol composition of the atmosphere is important for two principal reasons. The first reason is possible global climate warming due to increasing emissions of greenhouse gases. The second one is the necessity to predict air composition in regions where concentrations of some ingredients above maximum permissible values are observed.

It has long been revealed that most drastic changes of atmospheric parameters originate from the main objects of the general atmospheric circulation, such as fronts, cyclones, and anticyclones.[1] Earlier we have investigated changes in air composition at passage of atmospheric fronts.[2,3] In this paper we consider distribution of aerosol and some gases in cyclones and anticyclones.

Since the gaseous and aerosol composition of the atmosphere is not monitored at the existing network of stations, the problem to obtain distribution of individual air components in the main objects of circulation proves to be rather complicated. So to solve it, the special technique has been developed. It is described in detail in Ref. 4. The technique has been tested against the results of measuring the spectral transparency, and its high efficiency has been proved.[5]

The essence of this technique is that only single-site measurements of air composition are used for the analysis. In our case they are the data obtained at the TOR station near Tomsk.[6] A cyclone or anticyclone coming to the region of observations is divided into eight periphery and one central sectors with some set of data corresponding to every sector. Then values are averaged over each sector using, as a rule, no less than 600 readings. The difference between the mean values is examined by the method described in Ref. 7. Then the distribution of concentration of one or another ingredient in a cyclone or anticyclone is constructed (Figs. 1–5).

At the first sight, dividing into nine sectors seems to be not very detailed. However, the specificity of the synoptic data is so that greater detailing may decrease reliability and quality of results due to error accumulation.[8,9] At the same time, more rough division does not allow structural peculiarities to be revealed in the distribution.[1]

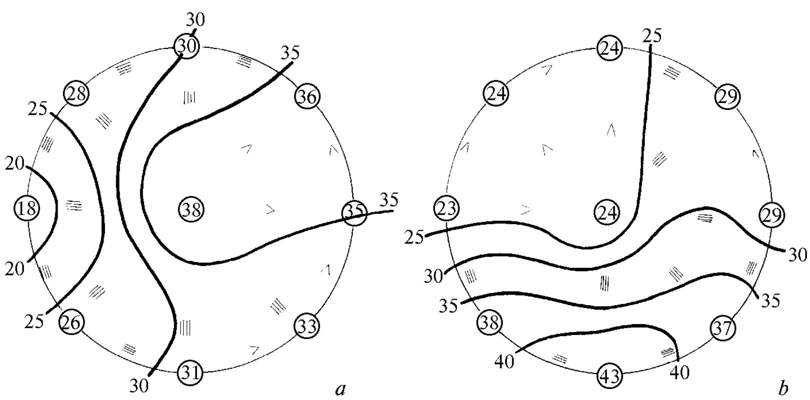

FIG. 1. Ozone distribution in the cyclone (a) and anticyclone (b): circles present the mean values for every sector. Difference between the mean values: less than 0.1% (<)*; at the level of* 0.1% (–)*; at the level of* 0.05%(=)*; at the level of* 0.01%(≡)*, and at the level of* 0.001%(≣).

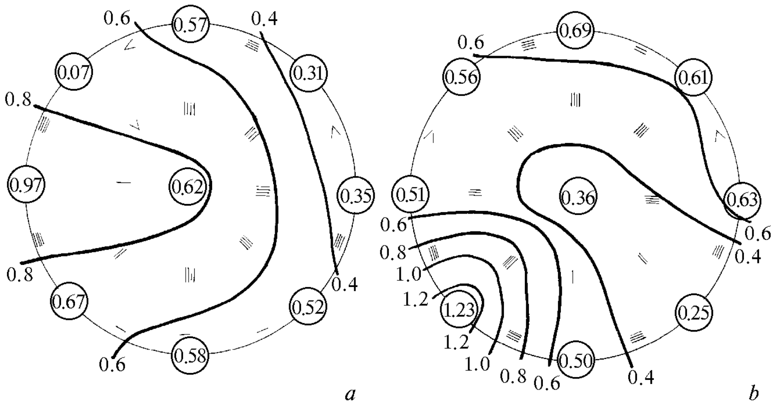

FIG. 2. Carbon oxide distribution in the cyclone (a) and anticyclone (b). Designations are the same as in Fig. 1.

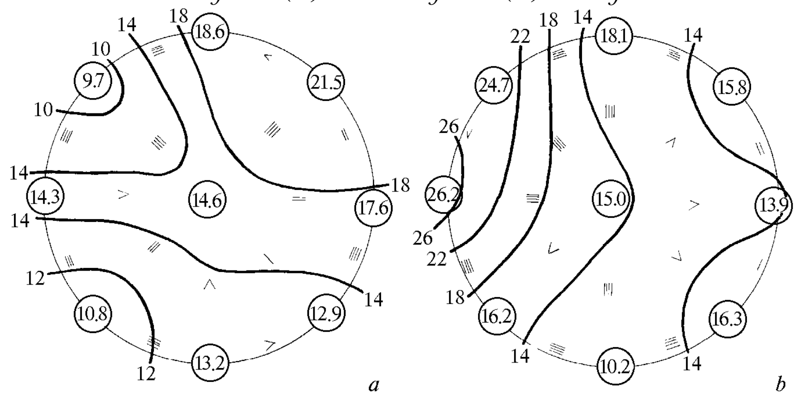

FIG. 3. Number density distribution of aerosol (d ≥ 0.4 μm) in the cyclone (a) and anticyclone (b). Designations are the same as in Fig. 1.

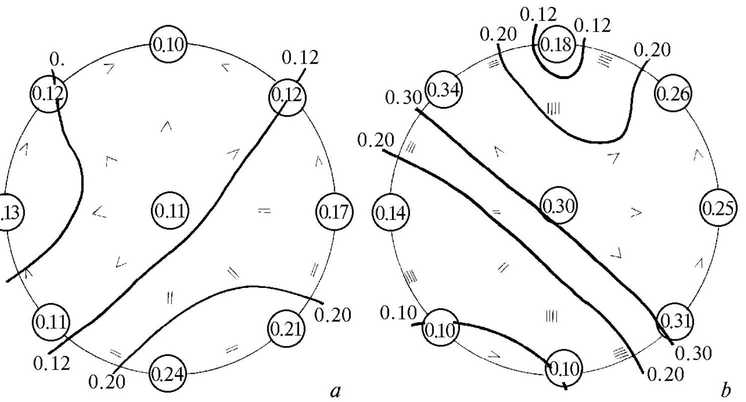

FIG. 4. Number density distribution of aerosol (d ≥ 1.5 μm) in the cyclone (a) and anticyclone (b). Designations are the same as in Fig. 1.

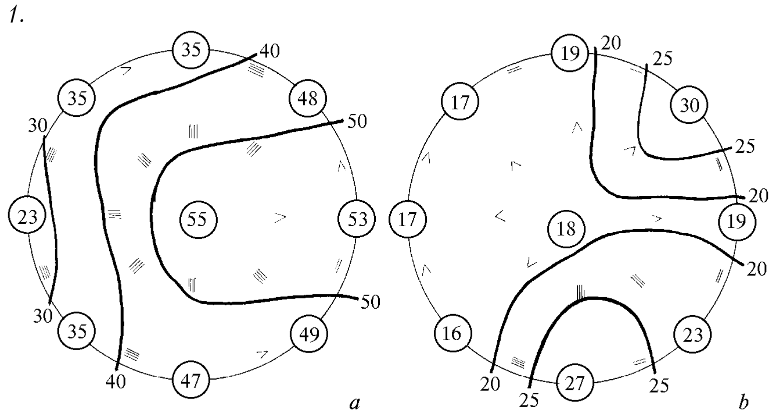

FIG. 5. Ozone distribution in the warm season in the cyclone (a) and in the cold season in the anticyclone (b). Designations are the same as in Fig. 1.

It is seen from Fig. 1*a* that the ozone distribution in the cyclone is rather inhomogeneous and its values in different parts can differ more than twice. The ozone concentration is maximum in the front part of the cyclone and minimum in its back part. Such a distribution can be easily explained if we recall where the frontal zone is situated in the cyclone[1] and how the ozone content changes in the frontal zone.[2]

Gradients of the ozone concentration in the anticyclone are somewhat less than that in the cyclone (Fig. 1*b*), although its distribution shows greater inhomogeneity. It follows from Fig. 1*b* that the ozone concentration in the Tomsk region is almost constant in the northern and central parts of the anticyclone and sharply increases at its SW, S, and SE peripheries. Such a distribution likely represents peculiarities of arrival of ozone producing substances in the region of observations, that is, a position of the station about the city.

The carbon oxide distribution in the cyclone (Fig. 2*a*) is exactly the opposite of the ozone distribution (Fig. 1*a*). The concentration gradient from the front to the back is also observed here, but with the maximum in the back part and the minimum in the front part. The maximum and minimum values differ almost three times. Taking into account peculiarities of the ozone formation in the atmosphere and the mechanism of CO emission, such differences seem to be regular.

The presence of a large single-pole area with small gradients in the central part and the increase of gradients at the periphery (Fig. 2*b*) is characteristic of the CO distribution in the anticyclone, as well as the ozone distribution. The difference in CO concentrations in the anticyclone is even greater than in the cyclone and reaches almost four. Its value is maximum at the SW and S peripheries, what represents the effect of the city on the measurement site under conditions of the anticyclone, as in the case of ozone.

It is seen from Fig. 3 that the pattern of aerosol distribution in the cyclone and anticyclone is more complex than for gases. In the cyclone, one zone with maximum values and two zones with minimum values (one in SW part and another in NE part) can be distinguished. Differences between mean values in these sectors are large. Such a distribution is likely representative of earlier revealed aerosol wash-out by precipitation in the zone of atmospheric fronts.[3] Then the zones of minimum concentrations represent passage of cold fronts: the main and secondary ones. The zone of maximum values is representative of "aged" aerosol accumulation in the prefrontal zone of the warm front. The aerosol number density gradient in the cyclone is less than that of gases, and its maximum exceeds minimum a little greater than twice.

The aerosol number density distribution in the anticyclone (Fig. 3*b*) is similar to that of gases. Small gradients mostly observed in it increase sharply at the periphery. The difference from the case of gases is that the maximum aerosol content is observed at the west periphery of the anticyclone, while the maximum concentrations of CO and O_3 were observed in the south sector.

Comparison of the absolute number density values in the cyclone and the anticyclone (Fig. 3) shows that in the anticyclone they are greater than in the cyclone. This once more confirms the conclusion, drawn on the basis of the atmospheric spectral transparency analysis, that air turbidity in the anticyclone is greater than in the cyclone,[11] and it is principally determined by the aerosol extinction.

It is well known that atmospheric aerosol has the very wide particle size spectrum, which is governed by different generation mechanisms. So it would be expedient to analyze the distribution of coarse-disperse particles in the main synoptic objects. Contrary to submicron particles (see Fig. 3), they are mostly formed due to the dispersion process.[12]

It is seen from Fig. 4*a* that the number density of coarse-disperse particles in the cyclone can change twice. However, the distribution of aerosol of this fraction inside the most part of the synoptic object is quite homogeneous, and no marked differences between six sectors are observed. Significant number density gradients are found only in the zone, where frontal interfaces are usually observed, and in the warm sector of the synoptic object. Evidently, the increase of the number density of the coarse-disperse particles in this part of the cyclone is caused by the increase of the wind velocity near frontal interfaces and by the condensation growth of particles due to increase in relative humidity.[13] The difference between the mean number density values in the cyclone sectors does not exceed 0.01%. Most likely, this represents variability of the coarse-disperse fraction itself, because averaging over sectors was performed using more than 600 readings, what is sufficient for statistical confidence of the estimates.

The coarse-disperse aerosol distribution in the anticyclone differs essentially from the distributions of the submicron aerosol fraction and gases (Fig. 4*b*). The dissimilarity is in the fact that maxima of its number density are not only localized at the anticyclone peripheries, but are also distributed over its central part. Such a distribution is likely determined by the wind field in the anticyclone,[14] strengthening of which favors additional generation of coarse-disperse particles.

The aforementioned models are constructed for the mean conditions independently of season, type of air masses, etc. So the question arises as to whether the obtained distributions are stable at least in time. To check the reliability of the models, the aerosol and gases distributions in the cyclone and anticyclone in the warm and cold seasons have been computed and constructed. They have shown the sufficient but, of course, not absolute temporal stability. One of such models is exemplified in Fig. 5, which shows the ozone distribution in the cyclone in the warm season (Fig. 5*a*) and in the anticyclone in the cold season (Fig. 5*b*).

Upon comparison of Fig. 1*a* and Fig. 5*a* one can see that the annual mean ozone concentration field is somewhat different from that in the warm season. However, the general tendency keeps the same, as well as the level of difference between mean values in each sector.

The same conclusion can be made for the anticyclone upon comparison of Figs. 1*b* and 5*b*.

Therefore, the proposed mean models of the aerosol and gas distribution in the cyclone and anticyclone are sufficiently stable, at least for the Tomsk region, because they have been constructed from the data recorded here.

Summing up the results, note that the aerosol and gas distribution inside the cyclone and anticyclone is quite inhomogeneous. Concentration of gases and aerosol number density can differ two to four times in different parts of the synoptic objects. There are also some differences in the structure of the distributions. As a rule, the most part of the anticyclone is characterized by small gradients, increasing sharply at the south or west periphery. The concentration gradient in the cyclone is, as a rule, directed from the front to the back along the atmospheric front line.

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REFERENCES

1. S.P. Khromov, *Principles of Synoptic Meteorology* (Gidrometeoizdat, Leningrad, 1948), 700 pp.

2. V.G. Arshinova, B.D. Belan, T.M. Rasskazchikova, et al., Atmos. Oceanic Optics **8**, No. 4, 326–328 (1995).

3. V.G. Arshinova, B.D. Belan, E.V. Vorontsova, et al., Atmos. Oceanic Optics **10**, No. 7, 507–511 (1997).

4. B.D. Belan, G.O. Zadde, and T.M. Rasskazchikova, in: *Prediction and Monitoring of the Optical-Meteorological State of the Atmosphere* (Tomsk Affiliate of the Siberian Branch of the Academy of Sciences of USSR, Tomsk, 1982), pp. 21–25.

5. B.D. Belan, G.O. Zadde, and A.I. Kuskov, Atmos. Oceanic Optics **7**, No. 10, 770–771 (1994).

6. M.Yu. Arshinov, B.D. Belan, V.V. Zuev, et al., Atmos. Oceanic Optics **7**, No. 8, 580–584 (1994).

7. G.A. Panovskii and G.V. Braier, *Statistical Methods in Meteorology* (Gidrometeoizdat, Leningrad, 1972), 209 pp.

8. N.P. Shakina, G.Yu. Kalugina, E.N. Skriptunova, and A.P. Ivanova, Meteorol. Gidrol., No. 7, 19–30 (1998).

9. N.P. Shakina, E.N. Skriptunova, A.P. Ivanova, and G.Yu. Kalugina, Meteorol. Gidrol., No. 8, 5–15 (1998).

10. G.P. O'hare and R. Wilby, Geographical Journal **161**, Pt. 1, 1–20, (1995).

11. B.D. Belan and G.O. Zadde, *Spectral Transparency and Aerosol Extinction over USSR* (Tomsk Affiliate of the Siberian Branch of the Academy of Sciences of the USSR, Tomsk, 1987), 180 pp.

12. N.A. Fuks, *Mechanics of Aerosols* (Academy of Sciences, Moscow, 1955), 352 pp.

13. M.V. Kabanov and M.V. Panchenko, *Atmospheric Aerosol* (Tomsk Affiliate of the Siberian Branch of the Academy of Sciences of the USSR, Tomsk, 1984), 189 pp.

14. V.I. Vorobjev, *Synoptic Meteorology* (Gidrometeoizdat, Leningrad, 1991), 616 pp.