DYNAMICS OF AEROSOL VARIATIONS DURING PASSAGE OF ATMOSPHERIC FRONTS

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Measurement data on disperse aerosol composition acquired in the vicinity of Tomsk in 1993 and 1994 are used to analyze aerosol variations during the passage of atmospheric fronts. It is shown that in the frontal zone, the aerosol concentration goes through a series of maxima and minima rather than peaking only once. The shape of the curve of aerosol variation within the frontal zone depends on the direction of front propagation (cold or warm) and its origin (arctic, polar, or tropical).

It has long been recognized that all major changes in the atmospheric optical properties are related to the formation, transformation, and decay of the basic objects of general circulation: fronts, cyclones, troughs, ridges, etc. A detailed review of such relations can be found in Ref. 1 where, in addition, it is shown that such a relationship is realized via variations in the aerosol and gaseous composition of air. However, despite of numerous publications about air composition in different physical and geographic locations, the relationship between the air composition and the basic synoptic objects still remains uncertain. The reason seems to be that the measurements of air composition are only occasional, while the variety of specific synoptic conditions occurring in each particular measurement hinders the acquisition of statistically meaningful material for a single synoptic object. Monitoring measurements at the TOR station[2] has enabled us to acquire statistically meaningful data set for a wide range of synoptic conditions.

In this paper, the results of measurements of disperse aerosol composition, acquired at the TOR station in 1993 and 1994, are used to study the dynamics of aerosol content during passage of atmospheric fronts. Such conditions are chosen because, as Khromov[3] showed in 1948, normally the turbidity factor is distributed uniformly over any air mass, and it changes relatively abruptly across the frontal zones. However no detailed characteristics of such a jump-like behavior were presented. So, in this paper we shall try to fill in this gap.

Front location was determined using near-ground maps and maps of baric topography, which were kindly presented by the Tomsk regional hydrometeorological center. Fronts are complex formation consisting of prefrontal and postfrontal cloud fields, precipitation zones, condensation and convergence of wind vector field, and a fairly narrow strip (about 10–20 km) of the near-ground frontal line[4] itself, whereas aerosol was measured at one point and every hour. Therefore, for each case considered the front position was recorded at 5, 4, 3, 2, and 1 h before its appearance at the measurement site, during its passage, and 1, 2, 3, 4, and 5 h after its passage. A total of 304 cases have been analyzed over the period studied, which were classified by the direction of propagation and by the geographic features as: 93 cold fronts (61 arctic and 32 polar), 95 warm fronts (63 arctic and 32 polar), 49 occlusion fronts (5 arctic, 33 polar, and 11 tropical), 51 near-ground cold fronts (including 14 warm upper level fronts).

Aerosol number concentration is known[5,6] to vary diurnally and annually. So, in order to compare the results for different times of a day and different seasons, all values measured 5, 4, 3, 2, and 1 h before and 1, 2, 3, 4, and 5 h after the passage of the frontal line were normalized by the front passage value. Thus, all data on the dynamics of aerosol are in relative units.

Consider first the relative variations of aerosol concentration as a front propagates in a certain direction (Fig. 1).

From Fig. 1 it follows that, as the cold front progresses, the aerosol concentration starts decreasing at 5 h separation from the front line (axis), i.e., at a distance 300–240 km from the front axis assuming 40–60 $km \cdot h^{-1}$ velocity[4] of the front propagation. Just before the front line (40–60 km), the aerosol concentration starts growing and reaches nearly the same values as in a warm air mass 100–180 km after the front line. Then, the aerosol concentration markedly decreases in the cold air mass at a distance 240–300 km into the front back. Such a concentration fall off is caused by the fact that normally there is intense precipitation in the prefrontal zone of a cold front,

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accompanied by an intense turbulence.[4] This leads to the fact that a portion of aerosol is washed out of the atmosphere, and another portion is dispersed in a larger volume. The growth of concentration in the front back is caused by two opposing processes: strengthening of wind velocity near the front line and the associated dynamic turbulence, with the latter bounded above by frontal inversion. As a result, aerosol, lifted again from the underlying surface, is now dispersed in a much smaller volume. After the front has passed, and the perturbations in the lower layer weakened, aerosol reverts to obey the laws of its formation, observed in a homogeneous air mass.

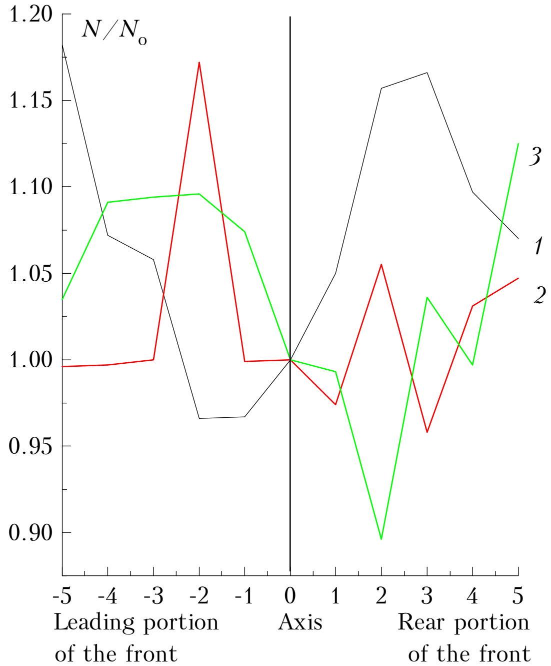

FIG. 1. Variation of aerosol number density ($d \geq 0.4$ μm) during passage of fronts across Tomsk: (1) cold, (2) warm, and (3) occlusion (prefrontal zone, axis, postfrontal zone).

For a warm front, the meteorological quantities generally have inverse distribution and the atmospheric processes are less intense. A consequence is that during warm front passage, aerosol concentration behaves inversely to that in a cold front (Fig. 1, curve *2*); the only exception is the presence of a postfrontal secondary maximum (1–3 h) which is statistically significant at the 99% level. Possibly, this is again caused by an enhanced postfrontal wind and turbulence. This speculation, however, needs a separate study.

In order not to make the statistics poorer, we did not separate the occlusion fronts by the formation features into warm and cold. From Fig. 1 one can conclude that our sample is mainly composed of warm fronts in view of the close resemblance between curves *3* and *2*. The only difference between them is different scales of influence on the aerosol fields, being much larger for occlusion fronts than for warm fronts. Here we also see the prefrontal aerosol "billow" and the secondary maximum, significant at the 95% level but delayed in time. The cause of the difference seems to be that the occlusion fronts are typical for "mature" cyclones, which are less mobile; thus, their slow motion gives us such a temporal effect when the one-point method is used.

The atmospheric fronts differ not only in the direction of propagation and the formation path, but also in the geographical characteristics for they separate air masses of different geographic origin.[3, 4] So, to analyze aerosol concentration as a function of an additional geographical parameter would be desirable.

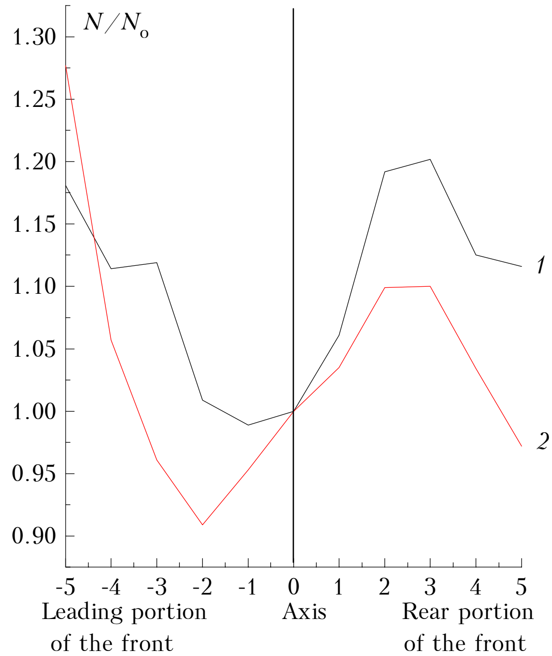

FIG. 2. Variation of aerosol number density ($d \geq 0.4$ μm) during passage of cold fronts across Tomsk: (1) arctic and (2) polar (prefrontal zone, axis, postfrontal zone).

As seen from Fig. 2, after the inclusion of the geographical parameter for cold fronts, the overall temporal dynamics of aerosol during front passage over the measurement site remained unchanged from the combined pattern (cf., Fig. 1). Only a minor difference exists between cold arctic and polar fronts in the amplitude of aerosol variations and in the time of reaching a minimum concentration in the prefrontal zone. So, it can be stated that the aerosol dynamics in the cold fronts does not depend on their geographic origin.

The situation is different for warm fronts. From Fig. 3 it follows that, whereas in the warm polar front the aerosol behavior follows that observed in the Fig. 1 for a geographically unseparated sample, the warm arctic front shows quite different behavior from this same sample. It is also important to note that, of the total warm front statistics (95 cases), arctic fronts make up a sample of 63 and polar 32. Peaks in curve *1* are insignificant even at the 95% level and they can be smoothed out. The result of averaging, the curve *3*, reveals only the presence of gradient between arctic and midlatitude air masses, which is not a new fact.[7] Possibly, such an aerosol behavior in the warm arctic fronts is because the latter are weakly reflected in the meteorological parameters, as reported in Ref. 8. Furthermore, recent data on wind conditions, obtained at TOR station,[9] indicate that the atmospheric dynamic component in the vicinity of Tomsk has decreased relative to its value published in Ref. 8 and, on the whole, relative to climatic data for Tomsk.[10]

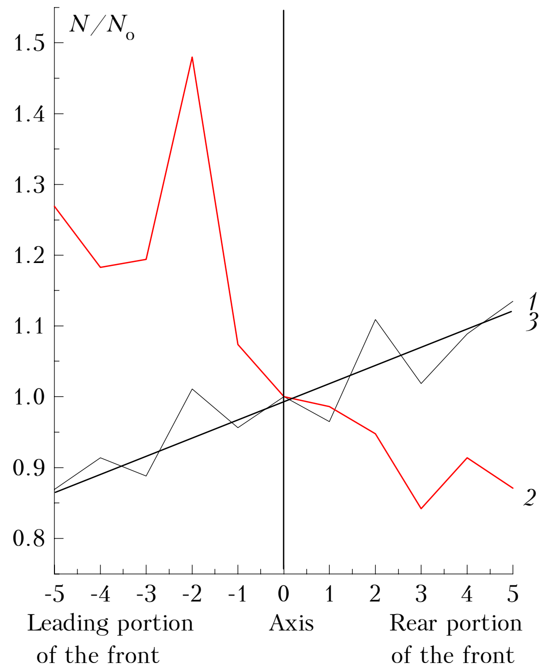

FIG. 3. Variation of aerosol number density ($d \geq 0.4$ μm) *during passage of warm fronts across Tomsk: (1) arctic, (2) polar, and (3) polar after smoothing (prefrontal zone, axis, postfrontal zone).*

The occlusion fronts have poor statistics, so we will not separate them by geographical characteristics in the present paper. We only note that, in view of the complexity of the phenomenon of occlusion fronts itself, the character of aerosol variations within them is highly complicated and is difficult to interpret reliably without additional data which we continue to collect now.

Of quite frequent occurrence around Tomsk are fronts which are secondary: near-ground cold front at the back of stationarizing central cyclones and upper warm front in anticyclones.[8] Generally, such fronts are weakly reflected in the contrast of meteorological parameters and phenomena.[3,4] So of interest would be to examine if they affect the aerosol field in the near-ground air. The data on aerosol number density variations in these fronts are presented in Fig. 4.

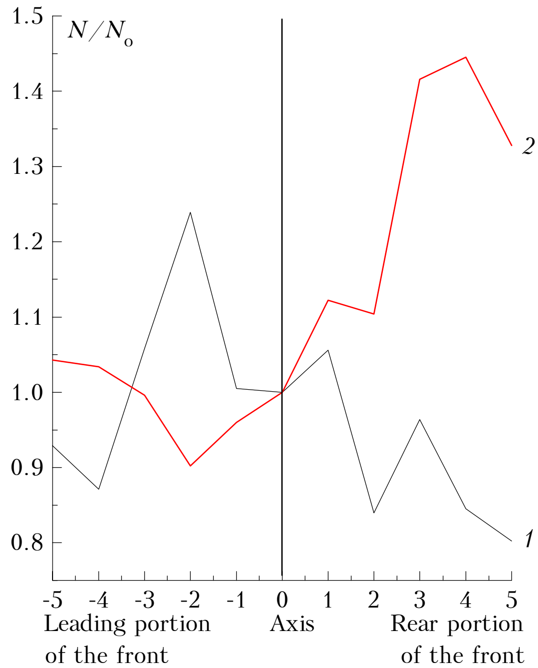

FIG. 4. Variation of aerosol number density ($d \geq 0.4$ μm) *during passage of (1) warm upper fronts and (2) cold near-ground fronts across Tomsk (prefrontal zone, axis, postfrontal zone).*

From Fig. 4 we see that both fronts influence aerosol field and, on the whole, preserve respective tendencies for cold and warm fronts. At the same time, in the prefrontal zone of a near-ground cold front, which is characterized by less precipitation,[3,4] the effect of washing out of aerosol is less pronounced. Conversely, postfrontal increase of aerosol concentration is larger there, probably reflecting the fact that more secondary aerosol can be lifted from less moistened surface. At the moment, we refrain from making comments about the differences between warm air masses, because the sample volume is only 14 cases of the upper fronts. We only note their influence on the near-ground aerosol and will recall this in the future analysis of a larger front sample.

Different aerosol fractions behave differently during the atmospheric front passage (Fig. 5). For instance, the submicron fraction ($d = 0.4$–0.5 μm) in general follows the variations in the total aerosol number density we revealed earlier. This as expected, for this fraction, makes the major contribution to the total concentration. Particles with diameters $d = 0.9$–1.0 μm, which are intermediate between two fractions, submicron and moderately dispersed, and normally have neutral behavior,[5] follow the behavior of the total concentration, though with a higher amplitude. The moderately dispersed fraction ($d = 1.5$–2.0 μm), though preserving general tendencies, shows certain distinctions. Its typical feature is the growth of amplitude of the number density variations during cold front passage and the appearance of secondary maximum at a distance 120–180 km into the prefrontal zone, where precipitation and intense washing out of the total aerosol concentration usually occur. This maximum becomes primary for the coarse dispersed fraction (d = 2–4 μm), increasing in amplitude by a factor up to 14, as compared to others increasing by no more than several tens of percent. Possibly, this is finely-dispersed fraction of precipitable water, which can amount to 10% of the total precipitation.[11] However, like several speculations above, this one also needs for an experimental validation.

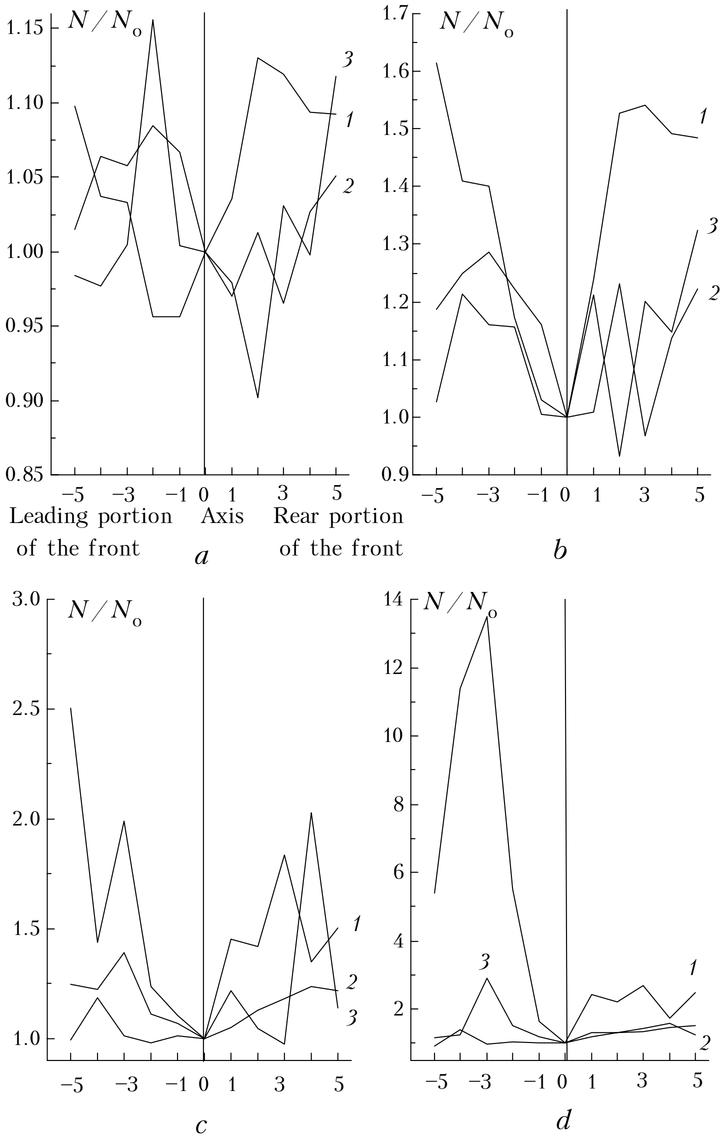

FIG. 5. Variation of aerosol disperse composition during passage of fronts across Tomsk: (1) cold, (2) warm, and (3) occlusion; (a) d = 0.4–0.5 μm, *(b)* 0.9–1.0 μm, *(c)* 1.5–2.0 μm, *and (d)* 2–4 μm *(prefrontal zone, axis, postfrontal zone).*

In the literature we found no such a detailed study of aerosol dynamics in atmospheric fronts, although a number of papers concerned this issue and noted considerable perturbation of aerosol fields during a front passage. Comparison with the dynamics of ozone in the frontal zone, studied recently with the use of the same method,[12] shows that for most fronts the variations of ozone concentration in the near-ground layer have just the opposite character except for the warm arctic fronts. Having in mind that sometimes aerosol serves as a sink for ozone, these differences could have been quite reasonable.

ACKNOWLEDGMENT

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