VARIATION OF THE OZONE CONCENTRATION IN THE GROUND ATMOSPHERIC LAYER BY THE PASSAGE OF ATMOSPHERIC FRONTS

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In this paper we analyze the dynamics of the ozone concentration in the ground atmospheric layer by the passage of atmospheric fronts in the region of Tomsk. Atmospheric fronts are demonstrated to affect considerably the ozone field. In this case the effect depends strongly on the front type and direction of its motion.

Intensive studies of atmospheric ozone conducted in the last decades have made it possible to investigate many aspects of ozone spatiotemporal variability generalized in detail in the monograph by A.Kh. Khrgian.[1] However, it should be noted that a stage of investigation of ozone behavior in the atmosphere is different for different altitude levels. At present we have more data on the dynamics of stratospheric ozone and its total content than the data on ozone variations in the ground layer. Taking into account the fact that the high ozone content in the ground atmospheric layer is undesirable, the problem of ozone investigation in this layer is urgent as before. The present paper is devoted to the study of dynamics of the ground ozone layer in the region of Tomsk.

Regular measurements of the ozone concentration in the ground atmospheric layer in Tomsk have been started since 1989. Measurements have been performed at the High–Altitude Lidar Sensing Station of the Institute of Atmospheric Optics of the SB of the RAS located on the north–east periphery of Tomsk Akademgorodok. Akademgorodok is to the east of the city so that it is affected by the west air mass transfer.

To make measurements, we used a portable chemiluminescent gas analyzer of 3–02P type developed and produced at the Laboratory of Ecotechnology (St. Petersburg). The gas analyzer was capable of measuring the ozone concentration in the range from 1 to 1000 $\mu g/m^3$ with a 15% error. The device contained a built–in calibrator (at a level of 18.5 $\mu g/m^3$) for periodic checking. The air was taken in through a teflon tube at a 6 m height.

The ozone measurements were conducted continuously. Up to December of 1992, signals were recorded by means of a recording instrument. Readings were taken every 10 minutes with subsequent averaging over every hour. The gas analyzer was calibrated twice, in the morning and in the evening. Since December of 1992 the ozonometer was connected with a computer. In this case the procedure of taking readings somewhat changed. Recording was made every hour but the measurements continued 10 minutes with a data sampling frequency of 1 Hz. The average ozone concentration was derived from 600 readings, and the rms deviation was calculated. The latter enabled us to control the stability of the ozonometer operation.

The material gained allowed us not only to assess the climatic variability of ozone in the region of Tomsk[3] but also to analyze its variations in some synoptic situations, in particular, during the passage of atmospheric fronts.

It should be noted that the ozone in the zones of atmospheric fronts was investigated previously (see, for example, Refs. 1, 2, and 4). However, as a rule, these studies were unrealistic since they were mainly based on the data on the total ozone content and encompassed only a few situations. The present paper describes solely the data on the ground layer obtained using the above–mentioned methods. Due to the fact that the data were obtained only at one point and the ozone concentration exhibited the annual and daily variations, the following procedure was used in data processing. For every case of atmospheric front passage through the observation point, we selected 11 hourly values of the ozone concentration: 5 before the front line, 5 after it, and one value in the front line. To exclude the effect of annual and partly daily variations of concentration, all 11 values of concentration were normalized to its value in the front line. Thus, all the data given below are presented in relative units.

Over the period since 1989 till 1993, 372 atmospheric fronts passed through Tomsk. The fronts were of the following types[5,6]: *cold*, namely, arctic (87), polar (38), and tropical (1); *warm*, namely, arctic (74) and polar (26); *occlusions*, namely, arctic (11), polar (56), and tropical (5); *ground cold* (49); and, *upper warm* (25).

First we give a qualitative pattern of variation of the ozone concentration by the passage of atmospheric fronts from the data presented in Table I.

Table I shows that the ground ozone field is strongly affected by the passage of atmospheric fronts. If we consider all the cases of front passage independent of their type, it should be noted that in 49% of cases the atmospheric fronts caused the increase of the ozone concentration, in 40% of cases they caused the decrease of the ozone concentration, and only in 11% of cases the ozone concentration remained unchanged. This proportion may vary depending on the front type and direction of its motion.

TABLE I. Recurrence of the variation of the ground ozone concentration by the passage of atmospheric fronts.

Type of the front	Decrease, %	Increase, %	Without change, %
Independent of the type	49	40	11
Cold	70	24	6
Warm	43	53	4
Occlusions	35	48	17
Ground cold	47	37	16
Upper warm	12	56	32

When cold fronts passed through the observation point, the decrease of the ozone concentration was observed in 70% of cases, the increase of the ozone concentration – in 24% of cases, and only in 6% of cases the ozone concentration remained unchanged.

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Only in 4% of cases the warm fronts did not affect the ground field of ozone. The dependence of concentration by the passage of warm fronts (as compared with cold fronts) was reverse (in 43% the concentration decreased, and in 53% the concentration increased), but it was less pronounced.

The occlusion fronts preserved the tendency of the warm ones. However, the recurrence of cases with unchanged ground ozone concentration was rather high for the occlusion fronts. The ground cold front, formed usually inside one and the same air mass,[5,6] similar to the principal cold one, in 47% of cases caused the ozone concentration decrease and in 37% of cases – the ozone concentration increase. At the same time, during its passage, in 16% of cases the ozone content in the ground layer remained unchanged.

On the one hand, the passage of the upper warm front through the Tomsk region had almost unique impact, namely, in 56% of cases the increase of the ozone concentration was found, and only in 12% the decrease of the ozone concentration was observed. On the other hand, in 32% of cases (maximum recurrence among the considered front types) the ozone field remained unchanged in this situation.

The data in Table I hardly can be explained by sink and influx of ozone from the upper layers due to ascending and descending air flows developed along anafronts and katafronts,[5,6] since the results of vertical sounding of ozone, obtained using an aircraft–laboratory in background and polluted regions,[7–9] have shown that the ozone is redistributed, if at all, only within the mixing layer. The value of the ozone concentration is much less above the mixing layer.

Let us turn to the analysis of the behavior of the ozone concentration by the passage of atmospheric fronts shown in Fig. 1. Here the numbers adjacent to the front types denote the number of cases being processed.

Figure 1*a* shows that the ozone concentration decreases especially sharply in a 100 km region before and after the front line by the passage of cold front. Transforming to the spatial scale is based on the well–known fact that the average velocity of the cold front motion is 40 to 60 km/h (see Refs. 5 and 6). So, the gradients of the ground ozone are mainly localized near the front line. The degree of correspondence of the average pattern to the specific situation is seen from Fig. 1*f*, where an example of the passage of cold arctic front on October 2, 1991 is illustrated. The ozone concentration variation is shown in absolute units.

In case of passage of the warm front, the ozone concentration increases in the prefrontal zone (Fig. 1*a*). At a 100 km distance before the front line, the concentration increase terminates, and the ozone concentration remains practically unchanged in the front line and in the rear.

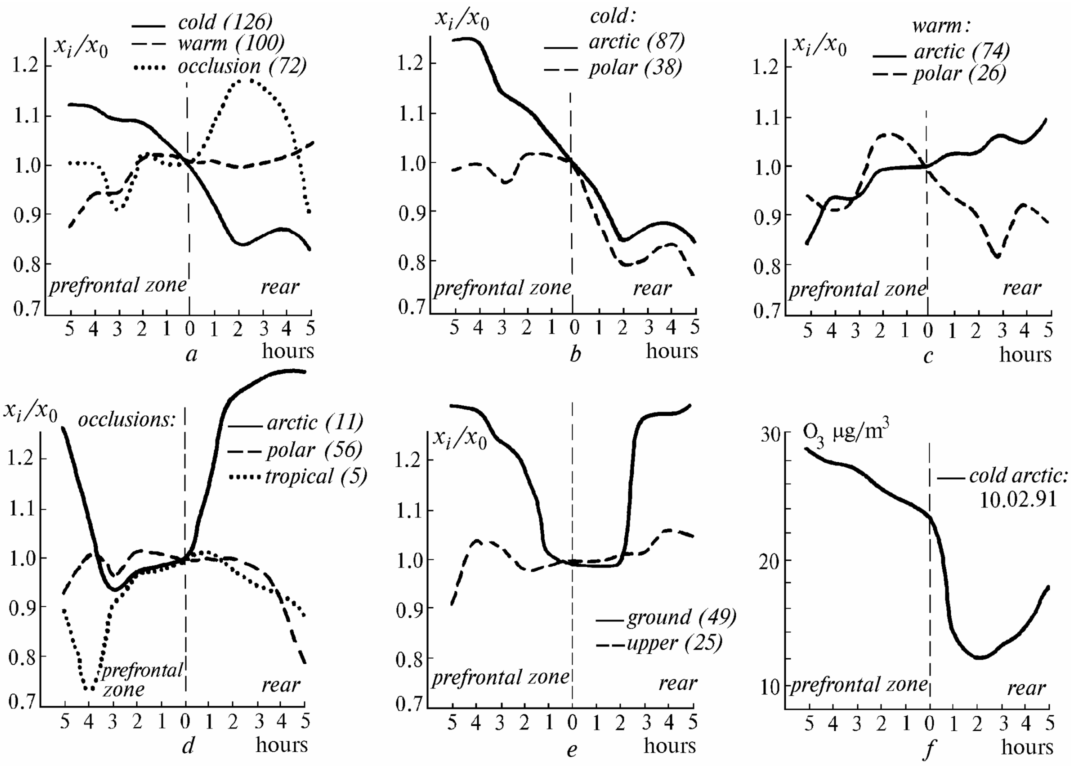

FIG. 1. Variations of the ozone concentration (in relative units) in different front types.

The behavior of the ozone concentration is more complicated when the occlusion front is formed (Fig. 1*a*). Recall that in this case three rather than two air masses interact.5,6 For this type of fronts the dependence of the ozone concentration, as a whole, is reverse to that observed in cold fronts. At the same time, the concentration behavior is nonmonotonic. The well–defined minimum in the prefrontal zone and the well–defined maximum in the rear can be identified.

Depending on the geographic front type, the above–indicated regularities somewhat change.

So, in cold fronts the variation of the ozone concentration, illustrated by Fig. 1*a*, remains for the arctic front type (Fig. 1*b*). The variations of the ozone concentration in the prefrontal zone are hardly ever observed by the passage of cold arctic fronts, and sharp decrease of concentration starts immediately after the front line.

In warm arctic fronts, the behavior of the ozone concentration is exactly revers to that observed in arctic cold fronts (Fig. 1*b*). In the warm arctic front, the pattern follows that of the cold arctic one (Fig. 1*c*), what is somewhat unexpected. A distinctive feature is the concentration maximum within a 100 km prefrontal zone.

Considerably different behavior of the ozone concentration by the passage of occlusion fronts are observed in the Tomsk region (Fig. 1*d*). Note that it depends on the type of the occlusion front. Thus, the arctic occlusion front is characterized by the sharp decrease of the ozone concentration within a 150 km prefrontal zone and by its drastic increase after the front line. The ozone content varies insignificantly by the passage of the polar occlusion front, although the decrease of the ozone concentration in its rear may be noted. The statistics of the tropical occlusion front are insufficient. It seems as if this front combines the impacts of the two preceding types of fronts. On the one hand, the decrease of the ozone concentration in the prefrontal zone, and on the other hand its neutral behavior in the front line and its decrease in the rear are found to occur.

And finally, Fig. 1*e* shows the results of data processing for nondominant fronts. As one can see from Fig. 1*e*, though the cold ground front affects strongly the field of ground ozone, the spatial scale of manifestation of this effect is small and is limited by a 150 km zone near the front line. The variation of the ozone concentration by the passage of the upper warm front is insignificant. A slight increase of the ozone concentration from prefrontal to rear zone of the front may be noted. In our opinion, the latter underlines once more the fact that in atmospheric fronts the dynamics of the ozone concentration in the ground layer is governed not by the influx and sink of ozone from the upper layers but by other factors.

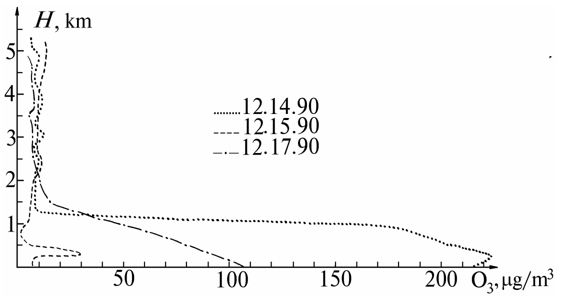

FIG. 2. Vertical profiles of the ozone concentration in Khabarovsk.

This is illustrated by Fig. 2 in which the results of airborne sounding of ozone vertical distribution in the Khabarovsk region during the passage of a front are shown. Measurements were carried out using the 3–02P device analogous to that used for ground measurements.

Figure 2 shows that on December 14, 1990 the ozone profile was characterized by very high ozone content in the boundary and ground layers. In the morning of December 15 the cold arctic front accompanied by snowfalls passed through the region of measurements.

Sounding of the vertical profile of the ozone concentration in the evening indicated that the ozone concentration in the free atmosphere remained practically unchanged, whereas in the boundary and ground layers the concentration decreases down to its background value. Weak maximum observed at a 300 m altitude is indicative of the beginning of ozone generation. The vertical ozone profile recorded on December 17, 1990 shows that the ozone generation in the boundary and ground layers proceeded rapidly. As a result, the ozone concentration was restored to half its original value in two days. As Fig. 2 shows, the variations of the ozone content in the boundary layer and in the free atmosphere are devoced from each other.

The present paper gives no complete interpretation of the data obtained since they do not fall into any known pattern. Evidently, the ozone field varies by the passage of atmospheric fronts due to superposition of a number of factors, namely, different dynamics of atmospheric fronts, prehistory of air masses that enter the region of measurements with different values of the ozone concentration, the effect of industrial emissions of Tomsk located to the west of the observation point, and spread of meteorological parameters in the same type of fronts.

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