Complex assessment of the conditions of the air basin over Norilsk industrial region. Part 4. Vertical stratification of contaminants

V.G. Arshinova, B.D. Belan, G.A. Ivlev, T.M. Rasskazchikova, D.V. Simonenkov, G.N. Tolmachev, and A.V. Fofonov

Institute of Atmospheric Optics, Siberian Branch of the Russian Academy of Sciences, Tomsk

Received January 23, 2006

The measurements of vertical distribution of contaminants and air temperature have revealed the presence of a permanent temperature inversion at 1-km height during the entire period of the experiment that does not allow the industrial emissions to travel aloft. The climatic data have shown that such an inversion keeps undestroyed over the whole region, even during daytime, from September until April. Even in summer, in the daytime, there exists the trapping layer at 900 to 1000-m height in this region. Therefore, increasing the height of plant stacks up to 500 m is senseless because the industrial emissions are transported below the inversion layer and their dispersal will hardly improve. In spite of high ozone concentrations, its origin is most likely stratospheric than photochemical. In summer, the vegetation around Norilsk, even at strong anthropogenic emissions, accumulates carbon. The aerosol field over Norilsk is of laminar type, with the concentration maximum in the ground or boundary layers.

Introduction

There exist several approaches to estimation of the vertical stratification of the atmosphere. Some approaches use the gradient method,[1] the other employ all kinds of numerical indices, which are often used in theoretical calculations.[3] In this paper the analysis is carried out based on data of direct measurements. Now we consider the temperature stratification of the atmosphere and its effect on the vertical distribution of contaminants.

It is necessary to assess the function of vegetation in the variation of carbon dioxide vertical distribution and the prediction, made in Ref. 4, of a possible intensification of photochemical processes in summer. As known, one of the purposes of the work[4] was the estimation of vertical stratification of air temperature in the Norilsk area and the feasibility of increasing the heights of plant stacks to improve the dispersal of the contaminants. However, as the climatic data have shown, it is inadvisable because stable temperature stratification is observed in summer in this region.

As can be seen from Fig. 1, the conclusion based on the climatic data proved to be correct. For comparison, on the plot the stratification is shown (by points), which corresponds to dry adiabatic gradient, i.e., convective conditions.[1] The actual stratification was found to be stable both in the beginning of the flight (in the morning) and at landing (in the evening). The same data were obtained during other flights.

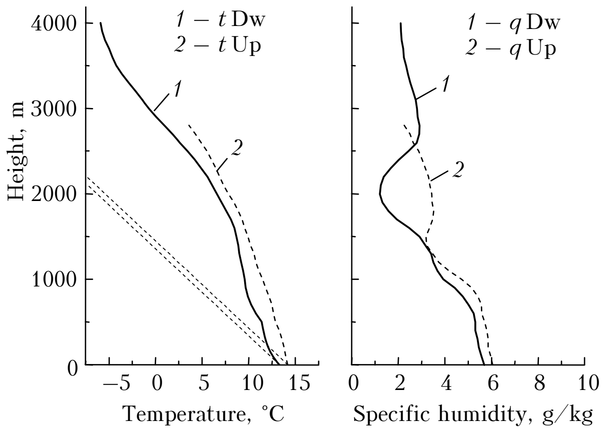

Fig. 1. Vertical distribution of air temperature and specific humidity during one of summer airborne investigations in Norilsk. Here and further the measurement designations: Up – during take-off, Dw – at landing.

We shall make more important "finding" if we compare the vertical profiles of temperature for winter and summer seasons (see Fig. 2).

Figure 2 shows that the slopes of air temperature curves slightly varied from winter to summer. This is explained by the fact that the temperature stratification in Norilsk depends slightly on the season of the year, although, as can be seen from the plot, the air temperature varies during season, increasing its absolute value during warm period.

Evidently, this is a characteristic peculiarity of the atmosphere over high latitudes. The authors of

0235-6880/06/10 814-04 $02.00

Ref. 5 based on the airborne experiment during the entire warm period in Yakutsk confirmed this conclusion.

Such stratification affects the accumulation of contaminants in the atmospheric boundary layer. Consider now the profiles of sulfur dioxide shown in Fig. 3.

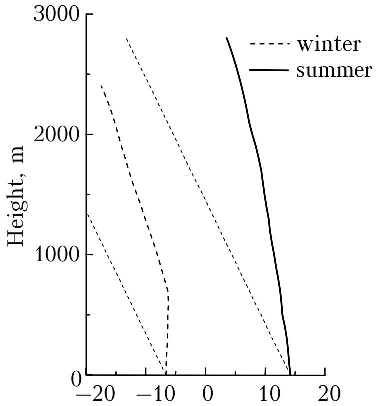

Fig. 2. Vertical distribution of air temperature over Norilsk in winter 2002 and in summer 2004.

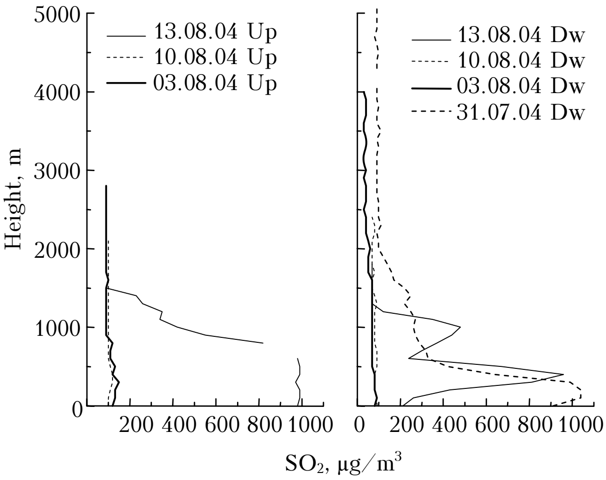

Fig. 3. Vertical distribution of sulfur dioxide in summer over Norilsk.

This figure demonstrates that when the airport is outside the area of the effect of industrial emissions, the stratification of sulfur dioxide is close to the background being neutral with height. If this occurs, it manifests itself only in the atmospheric boundary layer.

As can be seen from Fig. 3, the gas concentration becomes background at an altitude higher than 2000 m. Consequently, stable stratification of the atmosphere over Norilsk area in summer does not permit the pollutants to rise upward. Although, as compared with winter conditions, the mixing layer in summer becomes higher that is natural by physical mechanisms of its formation.[6]

Based on the measurement data for cold period, in Ref. 4 it was assumed that photochemical processes in Norilsk in summer can develop rather intensely. This conclusion was drawn according to data on the relatively high ozone concentration.

If we compare the data of summer and winter experiment (Fig. 4) then at first sight it would seem that this assumption is true.

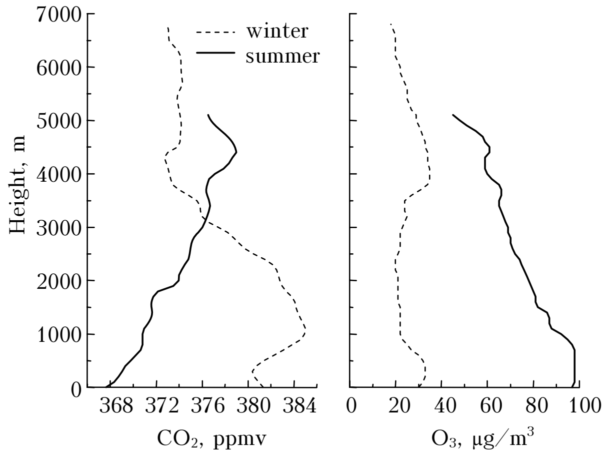

Fig. 4. Vertical distribution of carbon dioxide and ozone in November 2002 and August 2004.

Figure 4 shows that the ozone concentration increased in summer by a factor of more than three. But, as follows from the ground-based measurements, the ozone concentration in the city is low (20–40 μg/m^3). There is one more circumstance, which casts some doubt upon dominating of the photochemical mechanism of ozone formation in the area. It is just the neutral height behavior of its vertical distribution, which does not reflect the level of mixing layer and slight slope of the straight line that is not typical in case of the photochemical generation.[7] The proximity of the area to the polar latitudes most likely results in significant ozone inflow from the stratosphere,[8] on which small generation superposes in the atmospheric boundary layer. As a result, the combination of these two factors makes the ozone concentration to increase.

In addition, one more fact should be considered, i.e., the distinctions in the vertical CO_2 distribution in winter and summer (Fig. 4). It can be seen that in winter the CO_2 concentration is 382 ppm and in the summer period it is 368 ppm. Because the main CO_2 absorber in this area can be only the vegetation, it is clear that in spite of negative estimation of the condition of vegetation in Norilsk, which was done in Ref. 9, the vegetation continues to fulfill its function, namely, to accumulate carbon.

Consider now analysis of vertical distribution of aerosol chemical composition. For this purpose, all the selected samples will be used in two combinations, with and without the account of plumes.

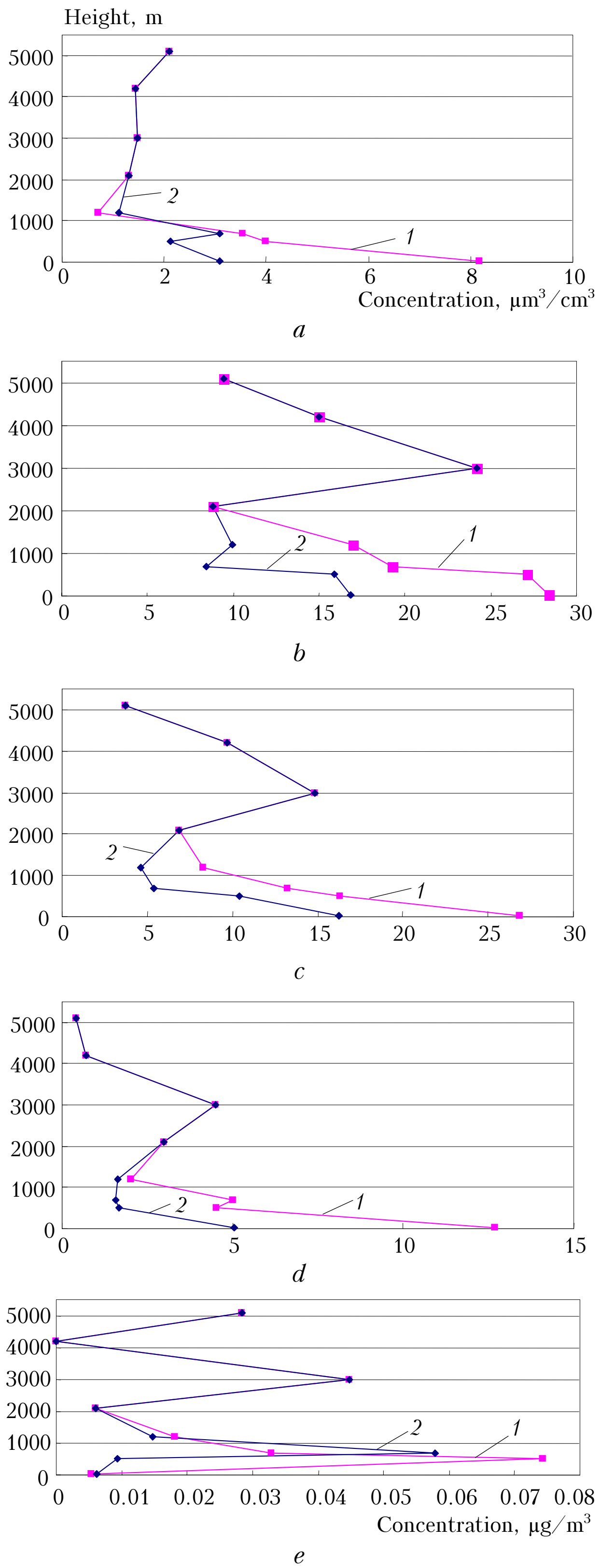

Fig. 5. Vertical distribution of the volume aerosol concentration (*a*); vertical distribution of identified aerosol (*b*); vertical distribution of ions (*c*) and SO_4^{2-} ions (*d*); vertical distribution of lead containing compounds (*e*): all samples (curve *1*), out of plume (*2*).

As was shown earlier[10] the layered vertical structure is typical for the atmospheric aerosol. The presence of urban columns indicates that the particles of the industrial emissions do finally deposit on the underlying surface. This also takes place in Norilsk (Fig. 5) no matter what characteristic is considered: the combined characteristic or characteristic of separate compound or element.

As can be seen from Fig. 5, the greatest concentration of aerosol and its components can be detected in the ground or boundary layer. At higher altitudes, as a rule, the aerosol concentration decreases. At the same time, special attention must be given to the level of 3000 m where the secondary maximum can be observed. Because the atmospheric stratification in Norilsk is stable, it is hardly probable that the local emissions can reach this altitude.

This will most likely be the transboundary transport from the neighbor regions.

Conclusion

The measurements of vertical distribution of impurities and air temperature have revealed permanently existing, during the whole year, temperature inversion at about 1-km height, which does not permit the industrial emissions to rise upward. Climatic data show that such an inversion keeps undestroyed even during daytime from September until April in the whole region. Even in summer, in the daytime, in the region there is a trapping layer at 900–1000-m height. Therefore, increasing the height of the factory stacks up to 500 m is meaningless because the industrial emissions are transported under the layer of inversion and their dispersal will hardly improve.

In spite of high ozone concentrations, the ozone origin is not photochemical but stratospheric.

The vegetation around Norilsk, even under the effect of strong anthropogenic pollution accumulates carbon in summer.

The aerosol field over Norilsk has layered height structure with maximum concentration in the ground or boundary layers.

Acknowledgments

The work has been performed by the Program of the Siberian Branch 24.3, supported by the Interdisciplinary Project of the Siberian Branch No. 130, the Program of the Presidium of RAS No. 13, grants of Russian Foundation for Basic Research No. 04-05-64559 and No.04-05-08010.

References

1. L.T. Matveev, *Atmospheric Physics* (Gidrometeoizdat, St. Petersburg, 2000), 780 pp.

2. K.S.M. Essa, S.M. Etman, and M. Embaby, Atmos. Phys. **83**, Nos. 3–4, 123–129 (2003).
3. F.T.M. Nieuwstadt and H. Van Dop, eds., *Atmospheric Turbulence and Air Pollution Modelling* (Reidel Publishing Company, Dordrecht, 1982).
4. *Complex Estimation of the Condition of Air Basin of the Norilsk Industrial Region in 2002–2003. Scientific Research Work Report* (IAO SB RAS, Tomsk, 2003), No. of state registration 0120.0301390, 174 pp.
5. M.A. Strunin and T. Khiyama, Izv. Ros. Akad. Nauk, Fiz. Atmos. Okeana **41**, No. 2, 178–200 (2005).
6. B.D. Belan, Atmos. Oceanic Opt. **7**, No. 8, 558–562 (1994).
7. B.D. Belan, Atmos. Oceanic Opt. **9**, No. 9, 754–773 (1996).
8. S.P. Perov and A.Kh. Khrgian, *Modern Problems of Atmospheric Ozone* (Gidrometeoizdat, Leningrad, 1980), 288 pp.
9. V.A. Savchenko and M.A. Novitskii, *Present Day Climate of Norilsk* (IPF "Gart", Moscow, 2003), 168 pp.
10. B.D. Belan, A.I. Grishin, G.G. Matvienko, and I.V. Samokhvalov, *Space Variability of Atmospheric Aerosol Characteristics* (Nauka, Novosibirsk, 1989), 152 pp.
11. A.M. Obukhov, *Turbulence and Dynamics of the Atmosphere* (Gidrometeoizdat, Leningrad, 1988), 415 pp.