Influence of local circulation processes on the surface ozone dynamics

V.I. Demin and M.I. Beloglazov

Polar Geophysical Institute,
Kola Scientific Center of the Russian Academy of Sciences, Apatity, Murmansk Region

Received January 27, 2004

The influence of microclimatic and landscape features on the results of atmospheric monitoring is considered. As an example we analyze measurement data on the surface ozone concentration (SOC) collected at the atmospheric stations of the Polar Geophysical Institute in the central part of the Kola Peninsula (the city of Apatity and Lovozero settlement). The irregular variations of the SOC up to 15–20 ppb under quiet night conditions have been revealed. It is shown that the causes of these SOC variations are the ascending air flow phenomena and associated with them accumulation processes and the processes of air mass collapse.

At present it is absolutely clear that trace gases play a leading part in the problem of climate changes. In this case the ground-based monitoring network is extended progressively. However, it remains unstudied so far in which ways the secondary gas flows in the atmospheric boundary layer influence the measured data on the trace gases and aerosol at any particular monitoring site. This fact gives rise to significant difficulties when interpreting and comparing the measurement data collected at various stations even if they are located relatively close to each other, but under different microclimate conditions. We believe that the account for these peculiarities is quite necessary in choosing a point for the background observations, which must represent not local but regional processes.

The goal of this study is to show a key role of micro- and mesoclimatic processes in the dynamics of trace gases in the atmospheric boundary layer using as an example the behavior of the surface ozone concentration (SOC) in the central part of the Kola Peninsula. Thus, the long-term observations at the Apatity atmospheric polygon of the Polar Geophysical Institute have revealed essential nighttime variations of SOC (Fig. 1), which are not typical for the PGI observatory Lovozero located 90 km to the north from the city of Apatity.

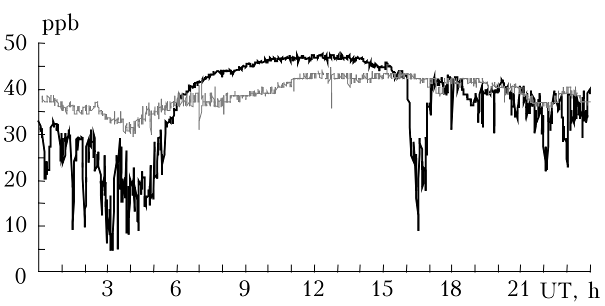

Fig. 1. Daily behavior of the SOC in the city of Apatity and in Lovozero on April 6, 2002.

These variations cannot be the result of the anthropogenic impact of the city located 2 km to the east because the measurements of SOC carried out at the center of the city (Akademgorodok, the PGI building) unambiguously show that at nighttime the ozone concentration does not differ from the regional background values determined by the data of the observatory Lovozero, independent of the meteorological situation. This is due to low concentration of the ozone destructing substances.

This cannot be caused by the diffusion of nitric oxides from a motor-road, which was at a distance of 0.5 to 1.5 km from the measurement site, because the traffic at nighttime was not heavy. The solution of equation of spreading of an impurity from a linear source[1] pointed to this fact, which in a simplified form is written as follows:

$$\frac{q}{M} = \frac{1}{(n+1)k_1 x} \exp\left(-\frac{u_1 z^{n+1}}{(1+n)^2 k_1 x}\right),$$

where q/M is the ratio between the impurity concentrations at an observation point and its value at the source; x is the distance between them; k_1 and u_1 are the turbulence coefficient and the wind speed at 1 m height; $n = 0.15–0.20$.

If we take acceptable values: $x = 500$ m, $k_1 = 0.04$ (the turbulence coefficient typical for nighttime, Ref. 2) and the wind velocity $u_1 = 0.5$ m/s, then the ratio q/M is found to be small (≈0.04). Because a large forest area is located on the way to a possible impurity spreading from the motor vehicles, in practical situation this ratio is found to be much smaller.

Finally, the detected night variations cannot be caused by the wave processes at the upper boundary of the atmospheric boundary layer since in this case the variations were of a general character and they were observed, if only sometimes, both in Apatity

0235-6880/04/04 292-03 $02.00 © 2004 Institute of Atmospheric Optics

and in Lovozero, but this fact was not observed in practical situation.

The analysis of synoptic situations has shown that the appearance of the described variations is preceded by a strong clear sky radiation cooling of the boundary layer under practically calm weather conditions. This points to a possibility that there existed a microscale dynamic process owing to the landscape peculiarities at the measurement site of the Apatity atmospheric polygon.

The first peculiarity is that the polygon is located on a big meadow in the forest. Therefore, according to known mechanisms,[3–8] the ozone concentration at nighttime should be low there, because of a weaker turbulent exchange, as compared with that over an open smooth land. The second peculiarity is that the measurement site is on a slope of a hill (Fig. 2*a*). The height drop at a distance of 500 m was found to be no less than 8 m, i.e., almost 3° that is sufficient for the appearance of a descending flow phenomena.

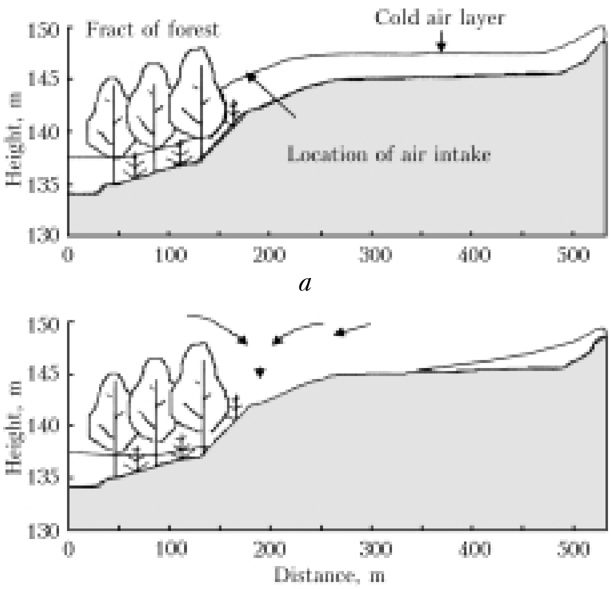

Fig. 2. Vertical profile of the locality based on the line of sink of cold air at the polygon of PGI in Apatity; the formation of "the lake of cold" at the meadow (*a*); breaching of cold air downwards (*b*).

For their appearance it is required, first, to have significant vertical stratification owing to strong radiation cooling, and, second, the dynamical stability of the atmosphere since any synoptic processes proceeding at a velocity of 3–5 m/s can fully wash out the microscale processes. The direction of the descending wind is perpendicular to isohypses, and its intensity depends both on the difference of air density along the vertical and on the orographic characteristics of the site. In most cases, however, the wind speed does not exceed 1 m/s, and it often appears to be less than the threshold of sensitivity of the instruments. In this case the down flow of cold air can occur both continuously, sometimes at fast varying velocity and as occasional collapses – air avalanches.[9] The latter is most probable when there are dense trees and bushes on the way, creating an obstacle. As a result, the down flowing cold air is accumulated and becomes stagnant at distances among trees and it does not come to the low ground.[7,8]

The combination of the above-mentioned specific features of the measurement site enables one to describe the process of appearance of night variations of SOC as follows. Before sunset the inversion is formed in the atmospheric boundary layer. Due to a strong decrease of the turbulent exchange directly over the forest meadow the ozone concentration decreases. The occurrence of the down flow wind results in accumulation of cold air because the wood prevents the air to move down the slope. The situation is more complicated as the building of the polygon with a measurement instrumentation is located at the edge of the meadow and at the mouth to the valley, in which the down flow of air took place, i.e., directly in the deepest part of the lake of cold air. If the radiation cooling continues then the influx of cold air results in an increase of potential energy of the system and at a certain moment – due to the violation of conditions of an equilibrium – in throwing down the accumulated air mass. The air mass deficit is quickly compensated for by the counterflow – at this moment the turbulence increases sharply, because the barrier layer, created by the forest meadow, disappears (Fig. 2*b*), and the ozone concentration increases up to the values typical for the air over the upper forest boundary. The character of variations of ozone concentration, which is "broken" and typical for unsteady turbulent regime, is indicative of a significant increase of turbulence as well as sharp, without predominant direction and fast attenuated, pulsations of wind velocity (Fig. 3).

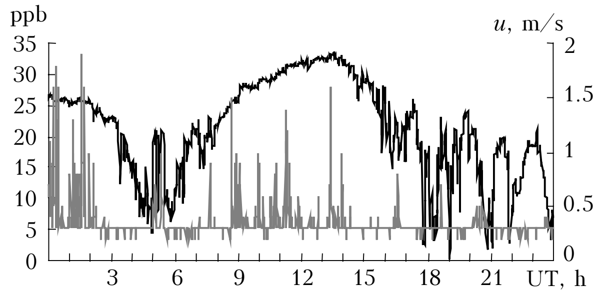

Fig. 3. Daily behavior of SOC and the wind velocity at the polygon of PGI in Apatity on March 4, 2002.

If during the nighttime the synoptic conditions do not change, the described process can be repeat from time to time. The synoptic conditions can vary in the case of a change of synoptic situation and in the case of wind intensification or the cloud thickening. The morning termination of night variations coincides with the sunrise, while their occurrence at night is characterized by a considerable variety. This corresponds to the generally accepted in meteorology concepts, according to which the beginning of destruction (weakening) of the inversion (vertical stratification of the air and descending wind) coincides with the sunrise, and the evening collapse of the atmospheric boundary layer is closely connected with the turbulent state of the atmosphere, i.e., with its previous history, which can be rather different on different days.

Thus, the above-mentioned statement enables us to draw the following conclusions:

– the measurement results on the surface ozone concentration, obtained on Kola peninsula, have shown that under definite conditions the local microclimatic circulations in the surface layer can affect considerably the character of daily variations of SOC;

– it is shown that the source of irregular night variations of SOC with the amplitude up to 15–20 ppb observed at the measurement site over a small area of the Apatity polygon over the period from February to April, are the specific landscape features of the measurement site on the slope of a large forest meadow. As a result, the down flow wind appears, which gives rise to the accumulation of cold air mass, that – after the achieving some critical value – falls across the barrier of the forest region down the slope, and this results in a short-duration increase of the turbulence in the surface layer and in the SOC increase; during nighttime this process can be repeated several times.

Acknowledgments

This work was supported by the Russian Foundation for Basic Research (grants No. 02–05–64114, 04–0579085 and 02–05–79146), INTAS (grant No. 01-0016), INCO-COPERNICUS (grant No. 1CA2–CT–2000–10038), as well as by the Program of Basic Research of DPS RAS “Atmospheric Physics: Electrical Processes, Radiophysical Methods of Investigations” (State contract No. 10002–251/OFN–12/059–063/060603–547).

References

1. M.E. Berlyand, *Prediction and Control of Atmospheric Pollution* (Gidrometeoizdat, Leningrad, 1986), 272 pp.

2. *Climatic Conditions of Impurity Propagation in the Atmosphere.* Reference Book. E.Yu. Bezuglaya and M.E. Berlyand, eds., (Gidrometeoizdat, Leningrad, 1983), 328 pp.

3. R. Geiger, *Climate of the Atmospheric Boundary Layer* (Inostrannaya Literatura, Moscow, 1960), 486 pp.

4. *Microclimate of the USSR* (Gidrometeoizdat, Leningrad, 1967), 286 pp.

5. Z.A. Mishchenko, *Bioclimate of Daytime and Nighttime* (Gidrometeoizdat, Leningrad, 1984), 280 pp.

6. S.A. Sapozhnikova, *Local Climate* (Gidrometeoizdat, Leningrad,1950), 242 pp.

7. I.M. Yaroslavtsev, *Frosts* (Gidrometeorologicheskoe Izd., Leningrad, 1948), 26 pp.

8. B.P. Alisov, O.A. Drozdov, and E.S. Rubinshtein, *Course of Climatology*, (Gidrometeorologicheskoe Izd., Leningrad, 1952), Parts 1 and 2, 488 pp.

9. *Microclimate of the Northern Part of Kazakh Small Hills* (Gidrometeoizdat, Leningrad, 1958), 208 pp.