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ATMOSPHERIC RADIATION, OPTICAL WEATHER, AND CLIMATE

The Blocking Role of the Ural Mountains in the Transborder Transfer of Impurities from Europe to Asia

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Abstract—Distribution of impurities over the region abutting the Ural Mountains is analyzed with the purpose of searching for traces of western European emissions over the territory of Siberia. It is shown that transborder transfer of impurities from Europe to Asia along direct trajectories (along a circle of latitude) from west to east is possible only in the free troposphere, in a layer higher than 2 km. Within the limits of the atmospheric boundary layer, the transfer of impurities from Europe to Siberia is probable only along trajectories rounding the Urals from north or south.

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INTRODUCTION

Possible negative changes of global climate and environment generate a need to search for sources and runoffs of anthropogenic emissions that can cause such changes; the study of atmospheric propagation of impurities and their transformation during transfer are of great importance. The Russian–French project YAK-AEROSIB is devoted to this problem; the authors of this work are participants of the project. It has been ascertained long ago that an increased anthropogenic-emission background exists in western Europe due to the high agglomeration of industries, and transfer of impurities occurs from west to east in the Northern Hemisphere; in view of this, the aim of the YAK-AEROSIB project is to search for traces of western European emissions over Siberian territory. The control was carried out by greenhouse gases (CO_2 and CH_4), air oxidants (CO, NO_2, and O_3), and aerosols. In addition to measurements, numerical simulation and the back trajectories technique that showed good results in a series of works [1, 2] are used.

However, the experiments carried out in the past within the project with the results published in [3–7] did not reveal direct impurity-transfer paths from western Europe to Siberia along a circle of latitude. If anthropogenic impurities are fixed, they come to Siberia along northern and southern trajectories. The reason for such propagation of impurities seems to be the blocking role of the Urals, which is confirmed by the data received in 2009 and given below. This work is devoted to the analysis of the distribution of impurities over the region abutting the Ural Mountains.

1. DESCRIPTION OF THE EXPERIMENT

The experiments were carried out with the use of the Optik-E An-30 aircraft laboratory [8]. The complex of equipment used in the experiments is described in [9].

Figure 1 shows the Novosibirsk–Ufa–Anapa route pattern and the vertical profile of the flight.

As is seen, the area flight runs first (up to Ufa), along a circle of latitude, and then had a southwestern direction. Several climbs and descents were made within an altitude range from 500 to 6000 m. Such a flight profile allowed the retrieval of cross sections through the atmosphere; this is a peculiarity of this

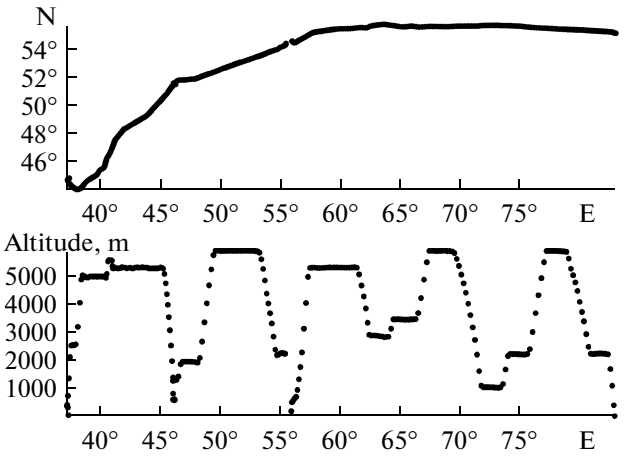

Fig. 1. Flight pattern and vertical profile along the Novosibirsk–Ufa–Anapa route.

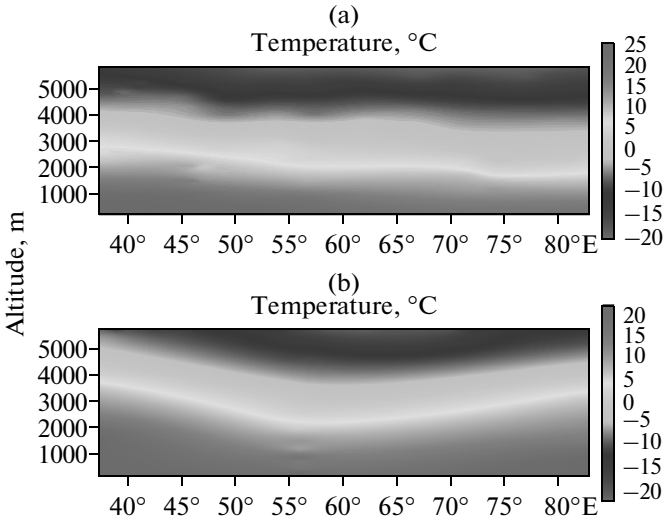

Fig. 2. Vertical distribution of air temperature.

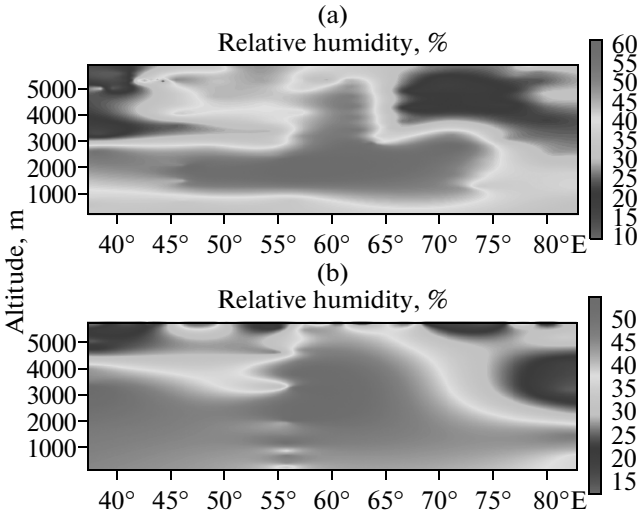

Fig. 3. Vertical distribution of relative humidity.

experiment, as compared with the majority of aircraft experiments.

The aircraft departed for Anapa on July 3 and came back on July 10, 2009. The scheme of altitude separation was similar during the return route.

2. Data processing and interpretation of sensing results

Let us first analyze the vertical distribution of weather parameters along the flight route. The data are given in Fig. 2 (forward (a) and backward (b) directions).

Figure 2a shows the sufficiently homogeneous distribution of air temperature in the first flight. The only differences can be noted in the altitude of the mixing layer over western and eastern regions; it was about 2 km over western regions and 1.5–1.6 km over eastern ones, which reflects the difference in heating of the underlying surface during the experiment [10, 11]. The behavior of the temperature distribution noticeably changes during the week (Fig. 2b). The altitude of the boundary layer increased over the western and eastern regions and reached 3 km. According to the weather analysis, the decrease near Ufa took place in the cold sector of a cyclone, where the altitude of boundary layer was much lower (2 km). In general, the received data reflected the known regularities of air temperature distribution quite well [10, 11].

In contrast to the sufficiently homogeneous temperature field, the relative humidity field was not so monotonic (Fig. 3).

The ingress of wet air from western regions is observed in the layer from 1 to 3 km up to 75°E in the first flight and far beyond 80°E in the second one. In addition, the area of increased humidity is observed near 60°E in both flights. Since they took place in different weather conditions, and the distributions were similar, one may assume that the phenomenon is caused by local factors, such as a high moisture content of the underlying surface of the West Siberia lowland [10, 11].

The west-to-east transfer manifests more contrast in other, more traditional impurities.

Both parts of Fig. 4 clearly show the ingress of air with high CO_2 concentration from western to eastern regions in the free troposphere.

Since the sensing took place in summer, a significant decrease in CO_2 concentration is observed in the Transurals, where there are many processes resulting in its run-off from the atmosphere (vegetation). This reflects the important role of Siberian forests in global

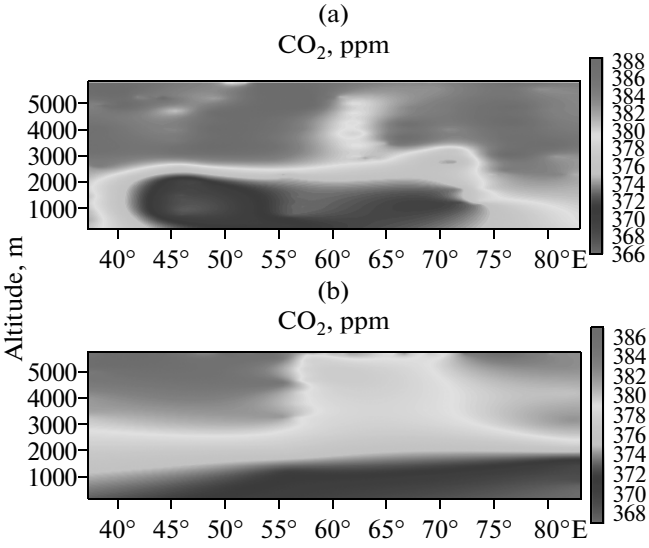

Fig. 4. Vertical distribution of hydrocarbon dioxide.

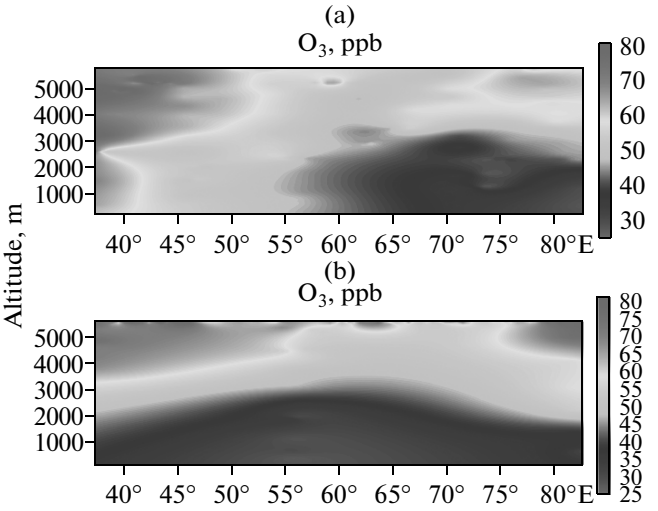

Fig. 5. Vertical distribution of ozone.

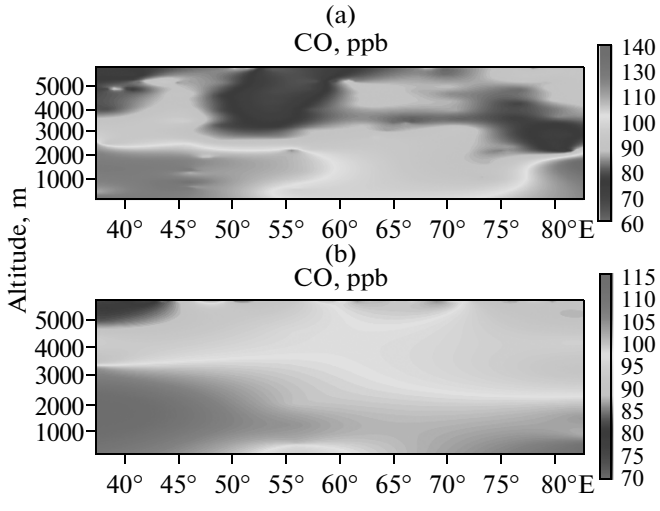

Fig. 6. Distribution of hydrocarbon oxide along the flight route.

CO_2 absorption from the atmosphere [12]. As follows from Fig. 4b, the process goes beyond the limits of the boundary layer to the free atmosphere.

The ozone field, shown in Fig. 5, is inhomogeneous as well.

The cross section through the atmosphere reflects the well-known fact about an increase in ozone content with altitude, which is determined by location of its source in the stratosphere [13]. In addition, the concentration gradient directed from west to east is seen in the boundary layer, which reflects the photochemical ozone generation in regions enriched with gas precursors and its transfer within the system of west-to-east transfer.

One of the gas precursors of ozone is carbon oxide, which follows from the brutto equation [14]:

$$CO + CH_4 + RH + NO \xrightarrow{h\nu,\ H_2O,\ O_2} fH_2CO + kO_3 + NO_2 + P,$$

where f is the stoichiometric coefficient of hydrocarbon transformation; k is the ozone output ratio depending on concentration of nitrogen oxides, which switches its generation chains; and P are the products of photochemical reactions, which are aerosol particles originating in gas component interaction.

The physical sense of the brutto equation is clear; the primary impurities (hydrocarbon oxide CO, methane CH_4, nonmethane hydrocarbons RH, nitrogen oxides NO) are emitted to the real atmosphere, where there are water vapor H_2O and oxygen O_2, and transformed into more toxic compounds under the action of UV solar radiation $h\nu$ (formaldehyde H_2CO, ozone O_3, nitrogen dioxide NO_2, and aerosol P, often containing such toxic compounds as peroxyacetyl nitrates (PAN) and so on). The equation does not reflect intermediate compounds, i.e., hydroxyl groups HO_x and the switching role of nitrogen oxides, but shows precursors of tropospheric ozone and factors determining its formation. The ozone output evidently depends on two factors: the concentration of initial compounds, gas precursors, and the solar radiation intensity and spectrum.

As is evident from Fig. 5, the ozone concentration is noticeably higher to the west of the Urals, where there are powerful sources of gas precursors, in comparison with eastern regions. A barrier is also seen, represented by the mountains, spreading perpendicular to the air stream. The ozone-enriched air transfer from Europe to Asia is observed above the 3-km level in the free troposphere.

Hydrocarbon oxide is one of the gases that acts as an ozone precursor, and is then transformed to the greenhouse gas CO_2. Its distribution along the flight route is shown in Fig. 6.

It is seen that the hydrocarbon oxide concentrations over the region are very low, which is characteristic for background regions [15–18]. Hence, ozone generation is minimum in lower air layers. A very clear concentration gradient is observed, directed from western to eastern regions. This can reflect the presence of a powerful anthropogenic source, i.e., western Europe.

Atmospheric aerosol is a good indicator of impurity transfer. Figure 7 clearly shows the ingress of air with high aerosol concentrations within the boundary layer from western to eastern regions. The blocking role of the Urals manifests in the lower 2-km air layer. The concentration maximum near Novosibirsk is rather caused by the anthropogenic contribution, since the altitude of this region does not exceed the level of the inner mixing layer [19].

The data in Fig. 7 also point to the fact that direct trajectories of impurity transfer from Europe to Asia

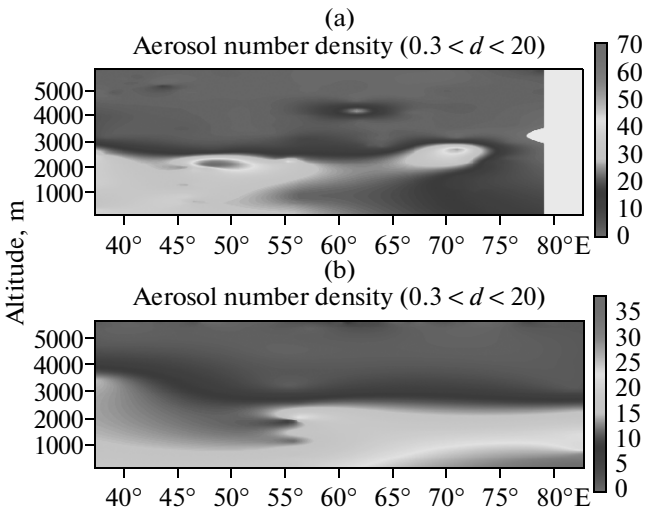

Fig. 7. Vertical distribution of aerosol number density ($0.3 < d < 20$ μm).

are possible only higher than the boundary air layer, in the free troposphere.

CONCLUSIONS

The disturbing effect of mountains on an air stream incoming on a perpendicularly situated ridge is studied in many theoretical works (see, e.g., [20–23]), where vortex formations behind an obstacle are usually considered. The transfer of impurities behind a mechanical obstacle (mountains) is not analyzed. The process of an air stream containing impurities rounding an obstacle is considered in [24] more or less qualitatively. We did not found experimental works, except for episodic sensing [25].

The above data point to the fact that transborder transfer of impurities from Europe to Asia along direct trajectories (circle of latitude) from west to east is possible only in the free troposphere above 2 km. Within the boundary air layer, the transfer of impurities from Europe to Siberia is possible only along trajectories skirting the Urals to the north or south.

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