The difference in the albedo of underlying surface in Novosibirsk and in the surroundings of Novosibirsk

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Received August 19, 2004

We discuss the measurement data of albedo of the underlying surface made using pyranometers mounted onboard an aircraft-laboratory over the territory of Novosibirsk and surroundings of Novosibirsk. The annual mean albedo for Novosibirsk was demonstrated to be 0.256 and for the surroundings of Novosibirsk – 0.356. The differences in the albedo in the adjacent territories are 33%. In the seasonal behavior the differences are retained, although their amplitude varies. In winter the albedo of the suburb can reach 0.84. In summer the albedo of the urban territory can decrease down to 0.08. Such a behavior of the albedo of the surface defines an additional influx of solar energy to the urban territory from 23.8 W/m^2 to 147.8 W/m^2.

Introduction

The present-day city is characterized, according to data of numerous investigations, by elevated temperatures of the air, as compared with the surroundings, and this phenomenon is known as heat island.[1] The difference in temperatures between the temperature in the urban center and that in the outskirts can reach 12°C and depends on the city scales.[2] Two opinions exist in this relation.

The first opinion is that due to the industrial emissions in the urban atmosphere the radiation regime changes caused by an extra absorption of solar radiation. The second opinion is that the supplementary (to solar) heat is emitted in the atmosphere due to the industrial pollution.[3]

As described in the literature,[4] the total radiation balance for urban conditions can be written in the form:

$$Q_N = Q_I(1 - A) + Q_{L\downarrow} - Q_{L\uparrow} = Q_S + Q_H + Q_E + Q_P,$$

where Q_I is the descending short-wave radiation reaching the Earth's surface (direct solar radiation plus the scattered radiation of sky); A denotes the surface albedo; $Q_{L\downarrow}$ denotes the descending long-wave radiation; $Q_{L\uparrow}$ denotes the ascending long-wave radiation (thermal radiation of the surface); Q_S denotes the heat flux in soil or another medium; Q_H denotes the heat flux between the atmosphere and the ground surface; Q_E denotes the heat losses for evaporation from the Earth's surface (or vegetation) or its accumulation because of the processes of condensation (formation of dew or hoarfrost); Q_P denotes the anthropogenic heat.

The present paper describes the problems connected with the change of the first term of this equation.

According to data, generalized in Ref. 4, when solar radiation passes through the polluted urban atmosphere, the greatest losses of solar energy are observed at maximum relative thickness of the polluted atmospheric layer, through which the solar rays propagate, i.e., at small sun elevation over horizon. The solar radiation losses can amount to 10–20% of the quantity of direct solar radiation. Here the author points out that simultaneously the scattered radiation flux increases sharply (more than twice). Consequently, the total radiation arriving at the Earth's surface must not vary greatly. In this case the magnitude of the albedo has come into importance, which indicates the amount of solar energy absorbed by the ground surface that defines the heat balance of the atmospheric boundary layer.

In the literature there are too little data on the albedo of urban territories and adjoining environs. In the Ref. 4 the data by Kung and coauthors are given, from which it follows that the value of albedo for the rural locality is by 10–30% larger than for the urban territories. Because of this, any supplementary measurements, undoubtedly, are of interest.

Measurement technique

Measurements of the albedo were performed using the AN-30 Optik-E airplane over Novosibirsk and adjoining environs. The onboard pyranometers of M-115M type were used in measurements. These pyranometers were tested at regular intervals at the calibration department of the West-Siberian Department of Rosgidromet. One of the pyranometers was mounted on top of the aircraft fuselage for reception of the total solar radiation $Q_\downarrow$ descending from the hemisphere. Another pyranometer was mounted on the bottom of the fuselage and detected the ascending (reflected) radiation from the lower hemisphere $Q_\uparrow$. In connection with the fact that pyranometers have the radiation shielding in the form of a glass cover, they detect the radiation in the spectral range 0.4–2.3 μm. The value of albedo was

0235-6880/05/03 218-04 $02.00

determined as the ratio between the solar radiation flux reflected by a given surface and the incident radiation flux:

$$A = Q\uparrow/Q\downarrow.$$

Monthly flights started in 1997. The measurements of $Q\downarrow$ and $Q\uparrow$ have been performed since 1998. These measurements have been continued until the present time. Figure 1 shows the schedule of routes. From this figure we notice that the route of the airplane after the flight from the airport "Severnyi" runs over the urban territory and then over the area of measurements. The way back trajectory is different. Thus in each flight the data on $Q\downarrow$ and $Q\uparrow$ are found measured over Novosibirsk and its surroundings. The maximum bulk of data could be 75. However, some flights were realized under cloudy conditions. The failures in the operation of equipment took place also. Therefore for data processing 42 series of measurements were selected.

Measurements results

Data on the annual mean values of albedo for the urban territory and suburban regions are given in Table 1.

Table 1

City	Suburban region	A_{suburb}/A_{city}, %
0.256	0.356	33

From Table 1 we see that the mean value of albedo for the urban territory of Novosibirsk is 0.256 and for the suburban territory the mean value of albedo is 0.356. The reflective characteristics of Novosibirsk surroundings are higher by 33% as compared with the urban area. This is essentially larger than it was obtained in different experiments.[4]

Figure 2 shows the variations of albedo of the urban area and the Novosibirsk surroundings. From the figure one can see that during the whole year the albedo of surroundings is higher than the albedo of the urban area. In winter the reflectivity of both surfaces is much higher. From November to March its value exceeds annual mean values and reaches for suburban regions of 70%. During this period the absolute difference between the urban and suburban values of albedo increases. It is obvious that this is due to the establishment of stable snow cover. It is known that the albedo of fresh snow can exceed 90%.[1]

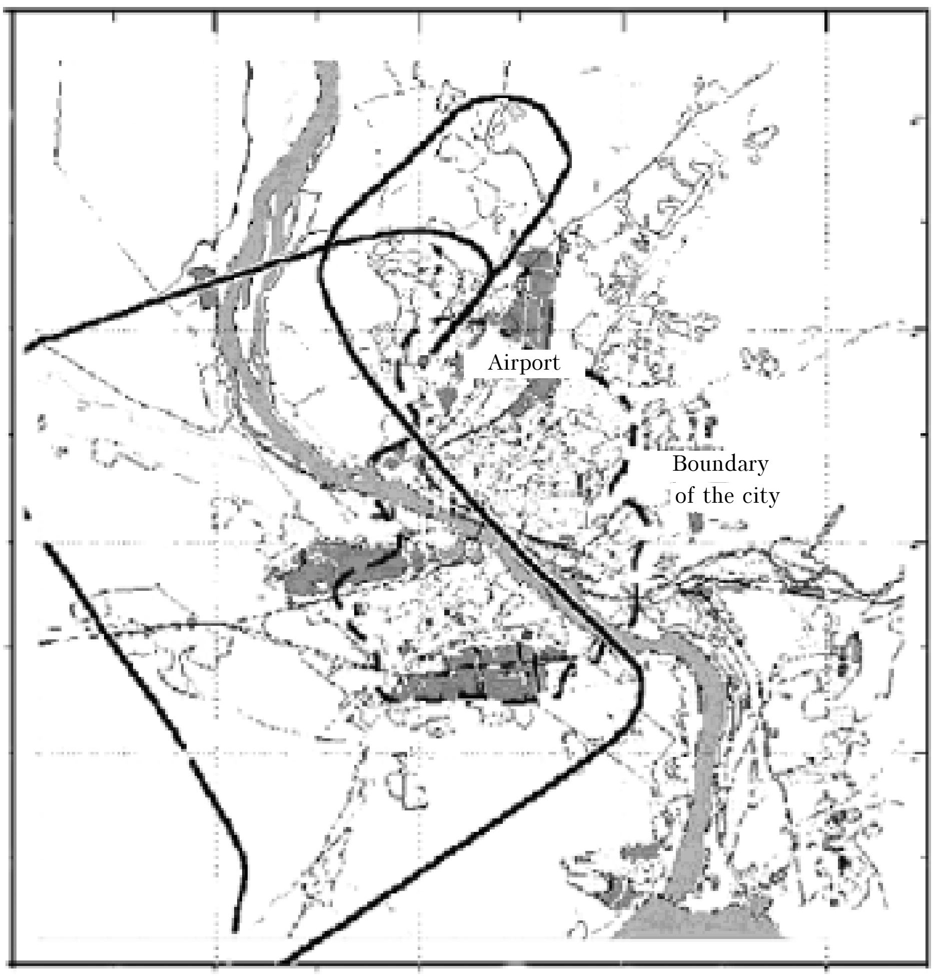

Fig. 1. Diagram of the aircraft-laboratory flights over the city of Novosibirsk and its surroundings.

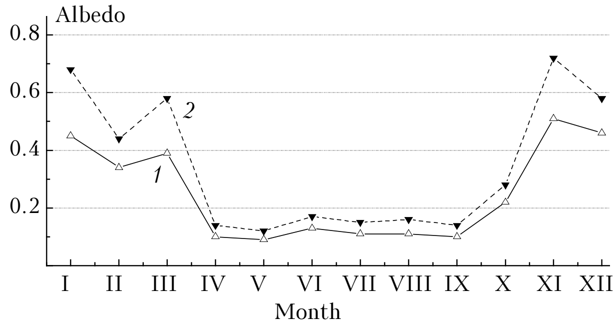

Fig. 2. Seasonal variation of albedo of the Novosibirsk territory and its environs: city (*1*), environs (*2*).

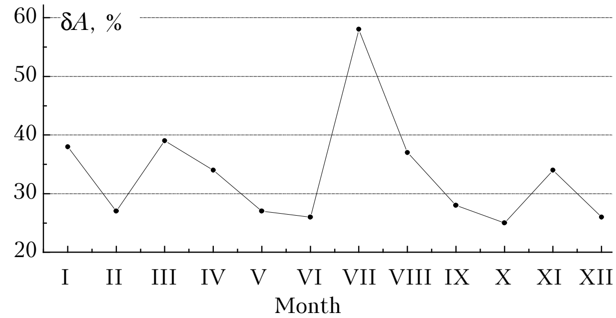

Fig. 3. Seasonal variation of the ratio between the difference of suburb and urban albedos and their mean value.

The decrease of albedo of both territories in February has attracted our attention, although the statistics of measurements for January, February, and March is the same. Most likely the February measurements were performed after long intervals between snowfalls when the ground surface could darken under the effect of industrial emissions.

Figure 3 shows the seasonal behavior of the ratio between the albedo of suburban regions and that of the urban regions found as the difference related to the mean:

$$A = (A_{\text{suburb}} - A_{\text{city}})/(A_{\text{suburb}} + A_{\text{city}})/2.$$

From Fig. 3 it follows that the ratio between the difference and the mean value can vary from 25% to 60%. In this case the greatest variations are detected (July) when the albedo of both surfaces is minimum (Fig. 2).

Weather conditions are different not only within a year, but also have the interannual variability. Figure 4 shows the albedo variations for the city and suburban territories during the period from 1998 to 2004. We notice that during the snowless period the variations of absolute values are small both in the city and in the suburb. These values are 0.08–0.14 and 0.10–0.24, respectively. During winter the amplitude of albedo variations increases greatly, namely, in the city – from 0.25 to 0.55, and in the suburb – from 0.32 to 0.84. It should be noted that these data do not relate to the mean values. These data characterize the conditions of a separate experiment.

In conclusion we present data on the absolute difference in the solar radiation coming per unit surface in the city of Novosibirsk and its suburb.

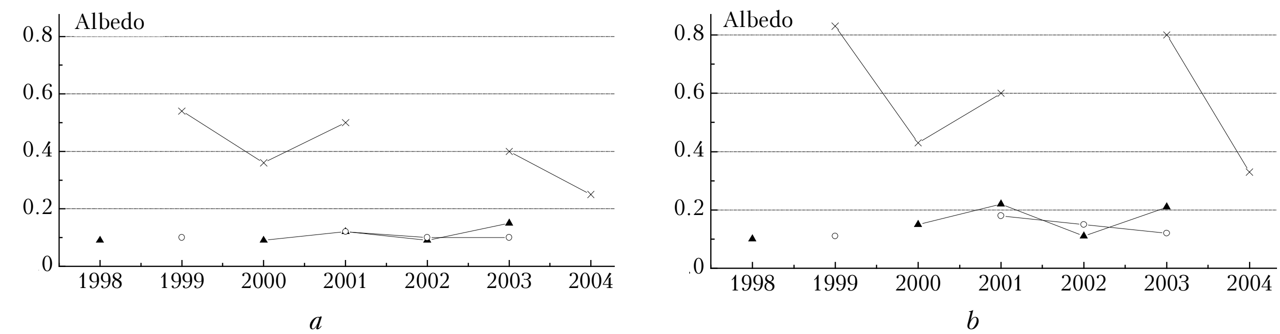

Fig. 4. Albedo variations over a period from 1998 to 2004: the city of Novosibirsk (*a*); Novosibirsk environs (*b*) (–×– January, –▲– April, –○– September).

Table 2. The maximum possible influx of solar radiation in the city and its suburb, with the account of albedo, their differences, W/m²

Month	January	February	March	April	May	June
Q_{city}	168.5	324.2	444.7	849.5	995.9	995.9
Q_{suburb}	103.1	274.3	306.9	811.8	965.8	949.9
ΔQ	65.4	49.9	137.8	37.7	30.1	46.0
Month	July	August	September	October	November	December
Q_{city}	1028	888.8	712.1	437.5	174.3	105.8
Q_{suburb}	950.7	850.3	686.3	413.7	99.6	67.4
ΔQ	77.6	38.5	25.8	23.8	74.7	38.4

From Table 2 it is seen that this difference value ranges from 23.8 to 137.8 W/m^2 and its well-defined annual behavior is not available. Three maxima can be recognized in March, July, and November and two minima: in May and September–October. The origin of this phenomenon is still unclear.

Acknowledgments

This work has been performed based on the interdisciplinary project of SB RAS No. 130 “Ecology of industrial cities of Siberia”.

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