Albedo of some types of the underlying surface in Western Siberia

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The albedo measurements obtained with airborne pyranometers for Novosibirsk city and its outskirts are presented. It is shown that in winter the albedo of a forest area varies from 6 to 30%, while in summer it averages 8%. The interannual variations of the forest albedo are 5–11% in spring–summer and 10–30% in winter. In the seasonal behavior of albedo of the Ob Reservoir, the maximum was observed in January and the minimum took place in summer (6–8%).

Introduction

Albedo of the underlying surface is one of the factors determining the radiative regime of the "underlying surface – atmosphere" system and affecting development of the processes of formation of the general circulation and climate. Its long-term trends are observed at present time, which can affect the global change of climate. For example, according to the long-term data obtained at 27 Russian actinometric stations, positive trends of albedo in summer and negative in winter have been revealed.[1] Noticeable differences in albedo between the periods 1930–1960 and 1961–1990 were observed.[2]

The albedo magnitude is determined by direct measurements or calculated from the measurement data. Ground-based observations allow one to estimate this parameter only for small areas of the underlying surface, and the results do not always hold for extended territories. To determine the albedo of vast territories, data of aircraft or satellite observations must be used.[3–5]

The first airborne measurements of albedo in the former USSR were carried out by V.L. Gaevskii[6] and L.I. Zubenok[7] in 50th. In 60th, the quantity of airborne measurements significantly increased both in USSR and abroad. They are being continued in the present time, but mostly abroad. A quite detailed analysis of them is presented in Refs. 8–10. As a rule, these measurements were carried out in summer. Therefore, it is difficult to characterize seasonal variations of albedo based on the airborne data. We failed to find some literature data on the aircraft albedo measurements concerning Western Siberia. In this paper we attempt to fill this gap.

Technique of flights and primary data processing

Since 1997, regular flights of the AN-30 "Optik-E" aircraft-laboratory are performed at the Institute of Atmospheric Optics SB RAS. The aircraft flies every month in the vicinity of Novosibirsk city and at the south of the Novosibirsk Region. In the framework of complex sensing of atmospheric parameters, measurements of the downward ($Q_\downarrow$) and upward ($Q_\uparrow$) fluxes of total solar radiation in the wavelength range 0.4–2.3 μm are carried out by means of two pyranometers M-115M. One pyranometer is installed on the upper part of the aircraft fuselage, and another is mounted on its lower part. The pyranometers are periodically calibrated in the Western Siberia calibration department of the Russian Hydrometeorologic service. The value of albedo is determined as

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

The flights are carried out according to the following scheme. The aircraft takes off from the Severny airport of Novosibirsk. Then the flight route lies above the city territory, its vicinities, the Ob Reservoir, to the working region located at the right bank of the southern part of the Ob Reservoir (Fig. 1).

Reaching the region of measurements, the aircraft smoothly gains altitude of 7000 m. Then it descends to a minimal height of 500 m with intermediate measurements at horizontal "plates." Measurements at each plate are carried out during 12 minutes at two opposite courses. Horizontal plates correspond to heights of 7000, 5500, 4000, 3000, 2000, 1500 and 500 m. Then the aircraft ascends to 3000 m and returns to the airport of Novosibirsk.

For data processing, 58 flights carried out under favorable conditions were selected. There was no one failure of instrumentation during these flights. During the flights, the aircraft is subject to spatial vibrations both along longitudinal axis (pitch) and cross axis (bank), which affected the pyranometer readings. Such readings must be corrected.[10] In our case, the signals were recorded with the frequency of 1 Hz. Simultaneously with the pyranometer readings, the data on the aircraft spatial position have been read from the sensors of bank and pitch angles. The pyranometer readings corresponding to the bank > 5° and pitch > 2° were removed in the process of the primary data processing. Such values were set based on the magnitude of double error of the applied sensors. Then the filtered data were averaged over the homogeneous parts of the surface.

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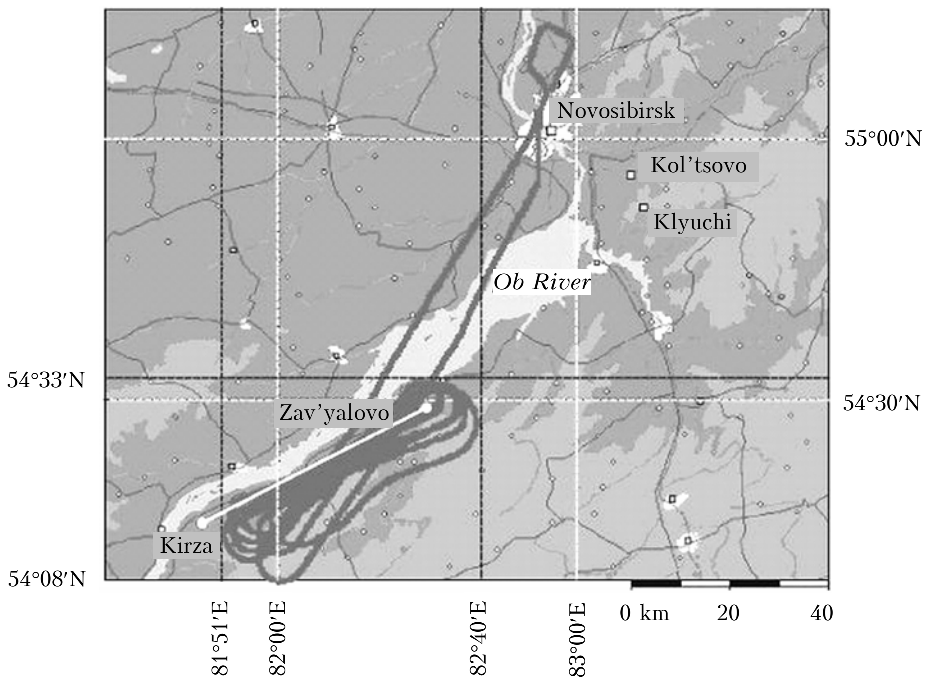

Fig. 1. Flight route.

The results obtained at a height of 500 m, minimal allowable for the flights, are presented below. It is clear that, together with the signal reflected by the surface, the lower pyranometer records some addition caused by the radiation scattering by the layer of the lower hemisphere. Our next paper will be devoted to estimation of the contribution of scattering by one or another layer. Here, we assume the measuring error to not exceed 5% (Refs. 2 and 10), because we applied similar sensing techniques and close characteristics of the pyranometers as used in Ref. 2. The taken value includes the contribution of scattering by lower air layers as well.[2,11–13]

Results of measurements

Measurements in the working region were carried out over the forest being 90% coniferous. Regularity and the invariable scheme of flights allowed us to construct seasonal behavior of albedo for a vast forest area. The results of airborne measurements from the height of about 500 m are shown in Table.

It is seen that the forest area albedo varies within a wide range (6–30%) in winter depending on the fraction of the area covered by snow and the snow cover state. The mean albedo of the coniferous forest area at a stable snow cover is 30%, at an unstable snow cover it varies from 10 to 20%. In fall and in the beginning of winter, when the snow covering the crowns of trees is more clean and dry, the mean albedo is somewhat greater than in spring. In summer, the range of its variation is not wide (6–11%).

We have compared the obtained results with data by V.L. Gaevskii. According to these data,[14] albedo of coniferous forest on the background of the fresh-fallen snow in March is 35–40% at the Sun elevation angle $h_\odot = 19$–$23°$, and the albedo of mixed forest (coniferous and deciduous trees) in June varies in the range 14–17% at $h_\odot = 39$–$55°$. In our experiments, the forest area albedo measured in March, 2002, on the background of the fresh-fallen snow was 30% at $h_\odot = 15°$, and in June it practically did not vary during the whole observational period (8–9% at $h_\odot = 44$–$49°$). The difference in the results, most likely, can be attributed to different composition and density of the forest.

Albedo of the coniferous forest area *A* (%) from the aircraft measurements

Year	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2004	5.8	6.1	11.9	3.1	–	7.7	4.5	5.2	7.2	3.3	–	7.1
2003	8.0	10.2	17.1	5.1	8.9	8.4	–	9.1	4.7	–	–	5.9
2002	–	15.8	29.5	8.8	9	–	8.7	6.7	9.0	7.8	11.4	–
2001	20.7	16.6	21.1	11.2	10.2	8.5	7.8	9.6	9.5	16.8	–	29.3
2000	4.3	9.1	10.4	7.7	–	7.8	9.3	11.5	–	24.1	18.4	30.8
1999	10.8	19.0	10.6	7.2	8.8	–	6.6	–	6.4	9.2	–	–
Mean	9.9	12.8	16.7	7.2	9.2	8.1	7.4	8.4	7.4	12.2	14.9	18.3

The obtained data array allowed us to analyze the inter-annual variability of the forest area albedo. Its variation in different seasons of 1999–2004 is shown in Fig. 2.

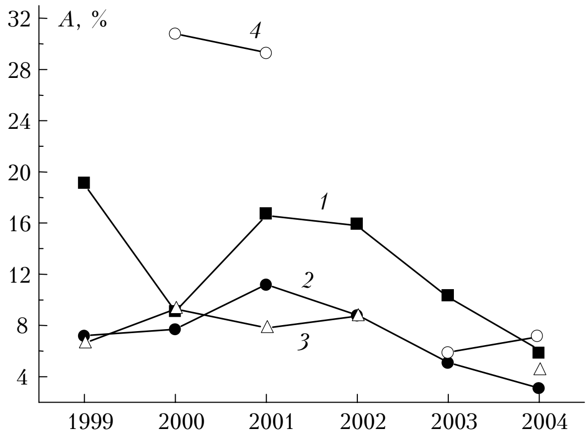

Fig. 2. Variations in albedo of forest area in 1999–2004: January (*1*), April (*2*), July (*3*), December (*4*).

It is seen that variations of the albedo absolute value in spring and summer are 5–11%, and in winter the amplitude of variations significantly increases (10–30%).

As was mentioned above, the flight route crossed the vicinities of Novosibirsk and the Ob Reservoir, agricultural fields and forests. Seasonal behavior of albedo for different underlying surfaces is shown in Fig. 3. As is seen, for the Ob Reservoir, the maximal albedo is observed in January (57%), and minimal in summer (6–8%). In March, when the reservoir is covered by gray porous snow, the albedo is equal to 45%, that is in agreement with the data from Ref. 9.

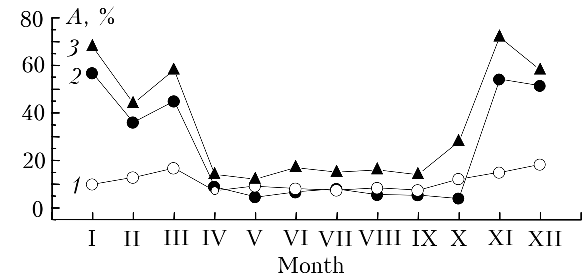

Fig. 3. Seasonal behavior of the underlying surface albedo: forest area (*1*), Ob Reservoir (*2*), agricultural fields (*3*).

The range of albedo variations for agricultural fields free of snow is insignificant (14–20%). It increases from 20 to 70% in the period of the unstable snow cover. This coincides with summer results for albedo of the fields sowed with different agricultural crops.[15]

Conclusions

1. The value of albedo of the forest area consisting 90% of coniferous trees varies in winter from 6 to 30% depending on the fraction of the area covered by snow and the state of the snow cover. In summer, the albedo of the forest area is, in average, 8%.

2. Inter-annual variations of the forest area albedo are 5–11% in the spring–summer period and from 10 to 30% in winter.

3. Seasonal behavior of albedo for the Ob Reservoir is characterized by its maximum in January and minimum in summer (6–8%).

4. The range of albedo variations for agricultural fields free of snow is insignificant (14–20%), and reaches 70% at a stable snow cover.

Acknowledgments

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References

1. O.M. Pokrovskii, E.L. Makhotkina, I.O. Pokrovskii, and L.M. Ryabova, Meteorol. Gidrol., No. 5, 37–48 (2004).
2. T. Ben-Gai, A. Bitan, A. Manes, P. Alpert, and A. Israeli, Theor. Appl. Climatol. **61**, Nos. 3–4, 207–215 (1998).
3. Xiwei Yin, Theor. Appl. Climatol. **60**, 121–140 (1998).
4. Wenbo Sun, Norman G. Loeb, and Seiji Kato, J. Geophys. Res. D **109**, D02210 (2004).
5. Kaicun Wang, Jingmiao Liu, Xiuji Zhou, Michael Sparrow, and Min Ma, J. Geophys. Res. D **109**, D05107 (2004).
6. V.L. Gaevskii, Tr. Gl. Geofiz. Obs., Issue 39, 150–163 (1953).
7. L.I. Zubenok, N.A. Efimova, and V.V. Mukhenberg, Tr. Gl. Geofiz. Obs., Issue 76, 98–112 (1958).
8. K.Ya. Kondratyev, *Radiative Characteristics of the Atmosphere and the Earth's Surface* (Gidrometeoizdat, Leningrad, 1969), 682 pp.
9. K.Ya. Kondratyev, D.V. Pozdnyakov, and V.Yu. Isakov, *Radiative-Hydrooptical Experiments on Lakes* (Nauka, Leningrad, 1990), 114 pp.
10. A.V. Vasil'ev and I.N. Mel'nikova, *Short-Wave Radiation in the Earth's Atmosphere. Calculations. Measurements. Interpretation* (NIIH, State University Publishing House, St. Petersburg, 2002), 388 pp.
11. P.M. Kuhn and V.E. Snomi, J. Meteorol. **15**, No. 2, 172–174 (1958).
12. I.A. Arch. Met. Geophys. und Bioklim. **13**, No. 1, 376–384 (1963).
13. S. Liang, J. Stroeve, and J.E. Box, J. Geophys. Res. D **110**, D10109, doi:10.1029/2004JD005493 (2005).
14. V.L. Gaevskii, Tr. Gl. Geofiz. Obs., Issue 109 (1961).
15. J. Song, Int. J. Biometeorol. **42**, No. 3, 153–157 (1999).