B-4.3.2 Observation of Soils and Vegetation in Siberia by Use of Multiple Satellite Sensors

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Abstract

Two categories of satellite sensors were used for observing conditions of soils and vegetation in the west Siberian lowland; one is a high-spatial-resolution sensor (SPOT/HRV) and the other is a wide-coverage coarse-spatial-resolution sensor (NOAA/AVHRR). A SPOT/HRV image was used for detailed classification of wetland ecosystems at Plotnikovo test site. Methane emission from the image area was estimated by combining the result of ecosystem classification with ground methane flux data. This methane emission estimate was about 34 % less than that obtained from airborne methane measurements. NOAA/AVHRR data were used for monitoring seasonal changes of vegetation and surface temperatures in west Siberian wetlands. From the time histories of NDVI values derived from AVHRR data, land cover types were classified in the whole west Siberian lowland area. Seasonal changes of ground surface temperature in west Siberia were estimated using AVHRR thermal infrared channels.

I. Introduction

Western Siberian wetlands are presumed to be large sources of atmospheric methane, which is one of the most important greenhouse gases. Recent Japan-Russia joint research project conducted by our research institute and Russian co-workers is yielding the results supporting this presumption (Panikov, 1994). To evaluate the role of the western Siberian wetlands as sources of atmospheric methane, it is necessary to classify wetland ecosystems and to measure mean methane flux for each ecosystem type. In this research we investigate the vegetation in western Siberian wetlands by using remote sensing techniques and estimate regional methane emissions by combining the results of satellite observations with ground methane measurements. We use two categories of satellite sensors: high-spatial-resolution sensors like SPOT/HRV and JERS-1/OPS & SAR and wide-coverage coarse-spatial-resolution sensors like NOAA/AVHRR and ADEOS/OCTS. The former is used for detailed classification of wetland ecosystems in selected test sites. The latter is used to estimate the synoptic wetland distributions and to monitor the seasonal change of vegetation in the whole western Siberian lowland.

The objectives of this study are to develop the method for estimating the conditions of soils and vegetation using satellite sensors and to examine the relation between ground surface conditions and the dynamics of greenhouse gases. In this report we present the results of analysis of a SPOT/HRV image at Plotnikovo test site and NOAA/AVHRR images in the west Siberian lowland.

II. Analysis of a SPOT/HRV image at Plotnikovo in the western Siberian lowland

1. SPOT/HRV image at Plotnikovo

A SPOT/HRV image was obtained at Plotnikovo test site on 8 July 1995. Plotnikovo settlement is located at the map coordinates (85°05'E, 56°51'N) in the basin of Ob' river and belong to the south east part of the western Siberian wetlands (see Figure 1). The SPOT/HRV is a high resolution imaging system with a ground resolution of 20 m and has three spectral bands of green, red and near infrared wavelengths (0.50-0.59, 0.61-0.68 and 0.79-0.89 μm). We selected this place as one of our test sites because ground observations of vegetation and atmospheric gasses have been made since 1993 by the Moscow Institute of Microbiology.

Based on the ground truth data and aerial photographs obtained in 1994 and 1995, we classified the land cover types in the image area into eight categories (birch forest, conifer forest, bog_1, bog_2, bog_3, water, grass and bare soil) using the supervised maximum likelihood classification technique. Figure 2 shows the result of land cover classification. Birch trees are dominant in forested areas and coniferous forests are found along rivers. Bog_1 is identified as peat land with low pine trees and shrubs, bog_2 as peat land with sparse dwarf trees and shrubs, and bog_3 as peat land mainly with grasses such as sedges and cotton-grasses. The circle symbol in Figure 2 shows the location of methane measurements.

2. Estimation of methane emission from the SPOT image area

To estimate the methane emission from the SPOT image area, we used the methane flux data measured on the ground by the Moscow Institute of Microbiology (Panikov, 1994). Table 1 shows the mean methane emission rates from July to August. The value for open bogs was obtained from the measurements at six microplots in 1994 and the value for forested bogs was obtained from measurements at one microplot in 1995.

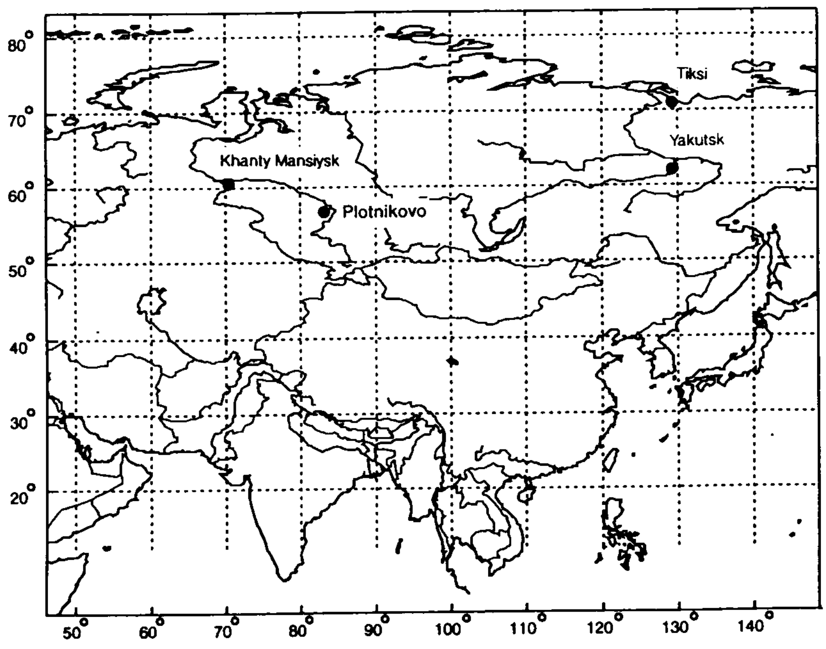

Figure 1. Location of Plotnikovo test site.

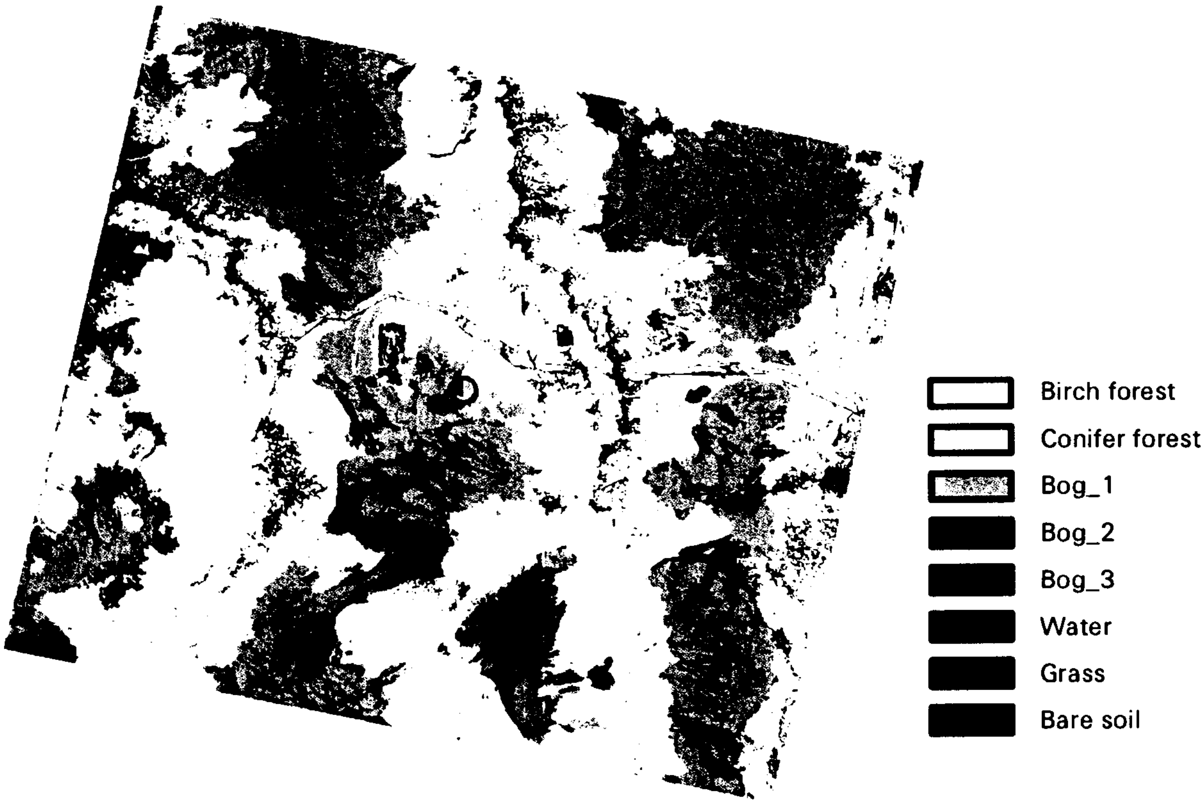

Figure 2. Land cover classification at Plotnikovo site.

Table 1. Mean methane emission rates measured on the ground from July to August.

site	No. of microplots	Mean (mg CH_4 m^{-2} day^{-1})
Forested bogs	1	118
Open bogs	6	166

Table 2 shows the area size, areal ratio, assigned methane emission rate for each land cover type and estimated methane emission. We calculated the methane emission by multiplying the emission rate with area size for each land cover type. The emission rate for birch and conifer forests were set zero, because it is reported that forests does not release much methane and in many cases consume atmospheric methane at very low rates (Bartlett et al., 1993). The emission rate for bog_1 wetland was set 118 mg CH_4 m^{-2} day^{-1} (mean flux forested bogs). We assumed that the emission rate for bog_2 and bog_3 wetlands is the same, i.e. 166 mg CH_4 m^{-2} day^{-1} (mean flux in open bogs). The emission rate for water was taken from a literature value that had been obtained at bog pools in Canadian wetlands located at nearly the same latitude (Bartlett et al., 1993). We neglected the contributions from grass and bare soil areas, because methane flux data were not available for these land cover types and their areal ratio was small (6.3 % in total). This may lead to somewhat underestimating methane emission. The total methane emission from the SPOT image area was estimated as 234.9×10^6 g CH_4 day^{-1} and the mean methane flux over the SPOT image area was calculated as 55 mg CH_4 m^{-2} day^{-1}.

Table 2. Estimated methane emission from the SPOT image area.
(Mean methane flux in the image area: 55 mg CH_4 m^{-2} day^{-1}).

Land cover types	Area (km^2)	Areal Ratio (%)	Emission rate ($mgCH_4/m^2/day$)	Methane flux (10^6 g CH^4/day)
Birch forest	1515	35.7	0	0
Conifer forest	789	18.6	0	0
Bog_1	819	19.3	118	96.6
Bog_2	417	9.8	166	69.2
Bog_3	406	9.6	166	67.4
Water	29	0.7	60	1.7
Grass	251	5.9	-	-
Bare soil	15	0.4	-	-
Total	4241	100.0	-	234.9

3. Comparison with airborne methane measurements

The atmospheric team of the Japan Russia join research project measured vertical profiles of methane concentration above Plotnikovo test site on 3, 5 and 6 August 1994 using an observation aircraft (Tohjima et al., 1995). Figure 3 shows the flight path of the aircraft on 5th August. The rectangle is the SPOT image area. From the vertical profiles of methane concentration, we can calculate the amount of methane accumulated in a vertical column of air. We can also determine the accumulation period of methane, because the accumulation of methane starts in night time at around 9 o'clock when a temperature inversion layer begins to develop. Hence we can estimate regional methane fluxes by dividing the amount of accumulated methane by the accumulation period. Table 3 shows accumulated methane, accumulation period and estimated regional methane fluxes for three measurement days. The

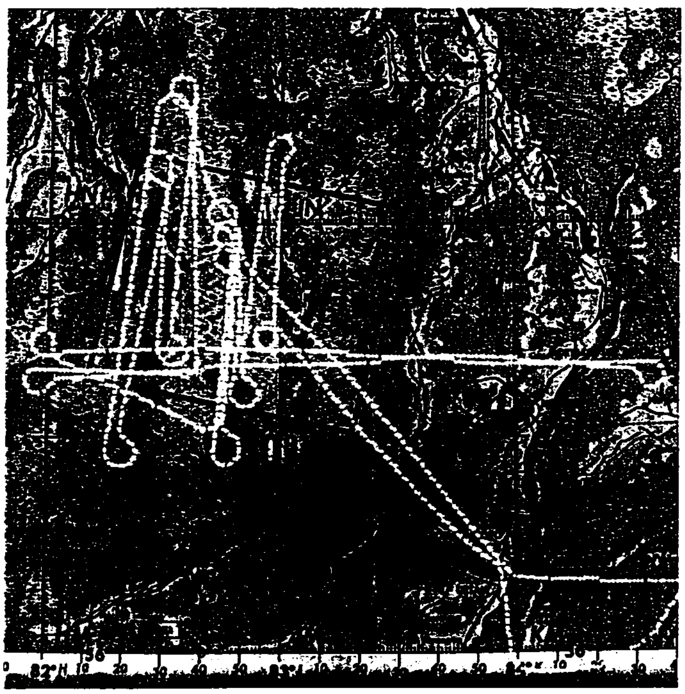

Figure 3. Flight path of the observation aircraft on 5 August 1994. The rectangle shows the SPOT image area.

Table 3. Regional methane fluxes estimated from the methane vertical profiles (Tohjima et al., 1994).

Date	Accumulated methane (mg m^{-2})	Accumulation period (hour)	Methane flux (mg CH_4 m^{-2} day^{-1})
3 Aug. 1994	55	15	88
5 Aug. 1994	20	14	34
6 Aug. 1994	79	15	126
Average	-	-	83

values of the regional methane flux varies from 34 to 126 mg CH_4 m^{-2} day^{-1}. This large variation would be ascribed to spatial and temporal variability of methane concentration. The average methane flux for three days observations was 83 mg CH_4 m^{-2} day^{-1}, which is about 1.5 times larger than the estimate of 55 mg CH_4 m^{-2} day^{-1} obtained from the combination of satellite and ground measurements. This discrepancy might be partly due to neglecting the contributions from grass and bare soil in the latter estimate. However, if we note that both estimates are based on measurement data of fairly large variations, we could say that they are within a range of probabilistic variability.

III. Observation of vegetation and surface temperatures in west Siberian wetlands by NOAA/AVHRR data

1. Seasonal changes of vegetation in west Siberian wetlands

For monitoring seasonal changes of vegetation, we used the Normalized Difference Vegetation Index (NDVI) derived from AVHRR data:

$$NDVI = (Cr2 - Cr1) / (Cr2 + Cr1)$$

where Cr1 is the reflectance value in the visible channel (0.58-0.68μm) and Cr2 is the reflectance value in the near-infrared channel (0.725-1.10μm). It is well known that the NDVI is highly correlated with vegetation parameters such as green-leaf biomass and green-leaf area (Justice et al., 1985). Vegetated surfaces generally has higher NDVI values than non-vegetated surfaces such as barren soil, water, snow, ice or clouds.

We retrieved 10-day maximum NDVI composites for the period of April to September 1993 from the 1-km AVHRR global data set produced by the EROS (Earth Resources Observation Systems) Data Center of the US Geological Survey. From these data we then derived monthly maximum NDVI composites, by selecting the highest NDVI value from three sequential 10-day composites. (Calculation of monthly maximum NDVI was necessary to make cloud contamination unnoticeable.) Figure 4 shows the seasonal changes of the monthly maximum NDVI from April 1993 (top left) to September 1993 (bottom right) in west Siberia (50°-75°N, 65°-87°E). The color codes of purple, blue, green, yellow and red are assigned in order of increasing NDVI values. We can clearly see the increase and decrease of vegetation activities. From these time histories of NDVI values we can classify land cover types. Figure 5 represents the result of land cover classification by using the ISODATA (Iterative Self-Organizing Data Analysis Technique) unsupervised classification algorithm. Land covers are classified into mountain tundra, tundra, wetland, boreal forest, mixed forest, prairie, and steppe.

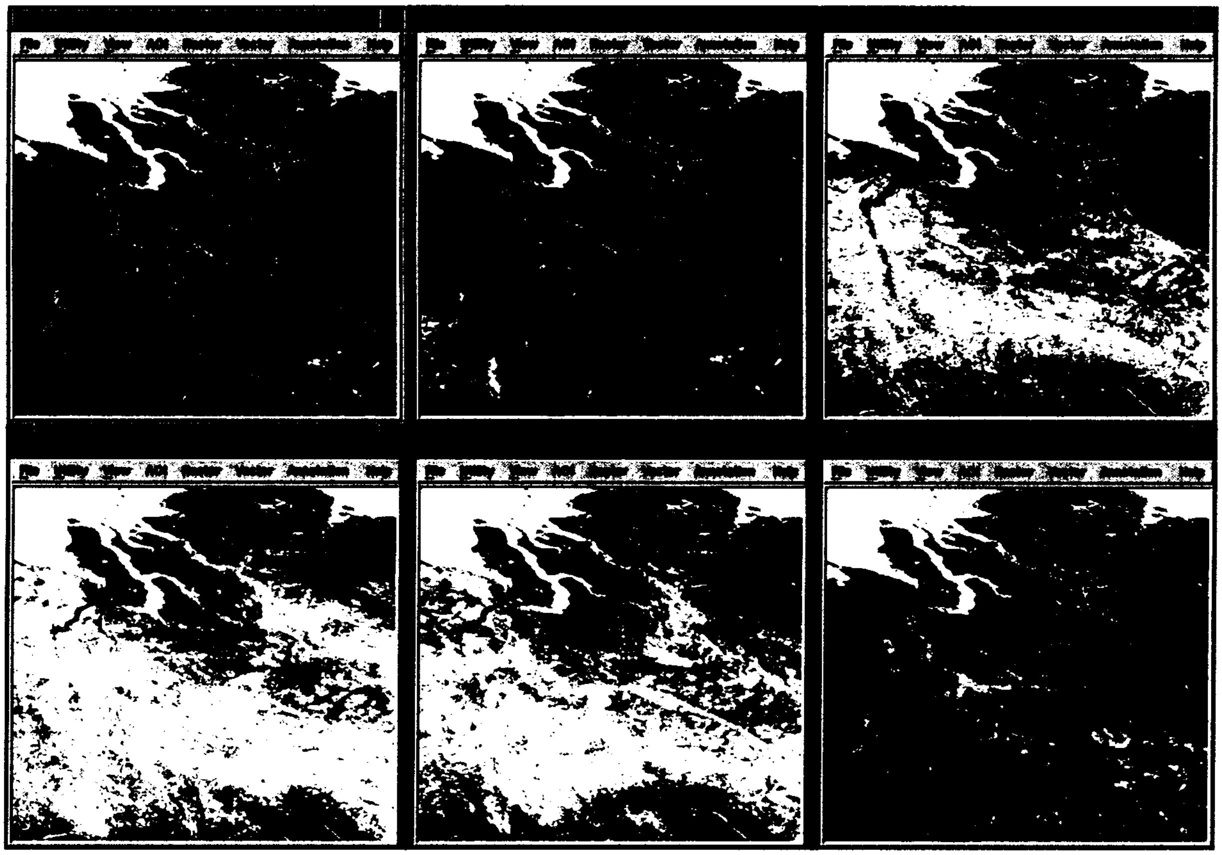

Figure 4. Seasonal changes of the monthly maximum NDVI in west Siberia from April (top left) to September 1993 (bottom right). The NDVI values increase in order of purple, blue, green, yellow and red colors. (Data source: USGS EROS Data Center).

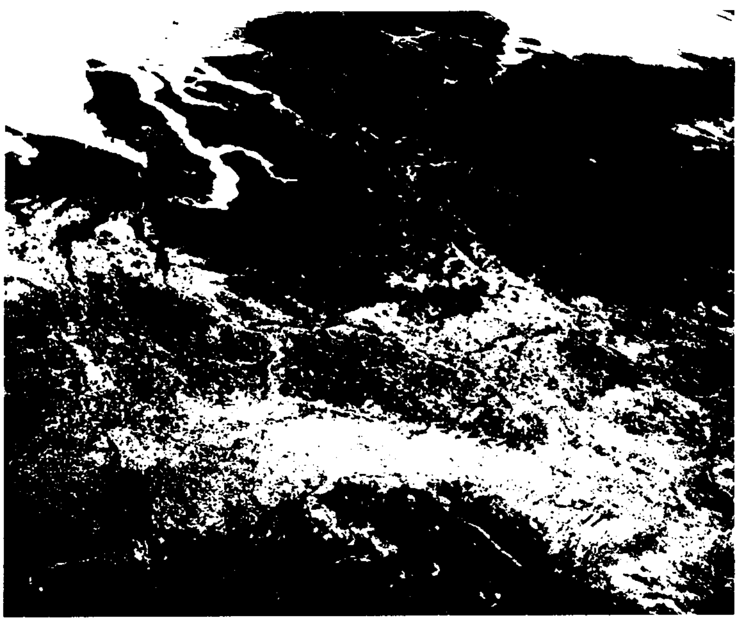

Figure 5. Classification of land cover types in west Siberia using time histories of the monthly maximum NDVI from April to September 1993.

2. Seasonal changes of surface temperatures

The NOAA/AVHRR sensor has two thermal infrared channels (10.30-11.3μm and 11.50-12.50μm), which can be used to estimate surface temperatures. We retrieved thermal infrared data from the 1-km AVHRR global data set of the EROS Data Center. Figure 6 shows channel 4 (10.30-11.3μm) images in the basins of Yenisey, Ob' and Irtysh Rivers (54°-63°N, 76°-84°E) in April and July 1993 respectively. Brighter tones represent higher brightness temperatures. Figure 7 shows seasonal changes of surface brightness temperatures obtained from AVHRR channel 4 data at Khalesavoy (63°23'N, 78°20'E) and Plotnikovo (56°51'N, 83°05'E).

IV. Summary

As basic data for evaluating the role of the west Siberian wetlands as sources of atmospheric methane, it is necessary to classify wetland ecosystems and to observe seasonal changes of vegetation and surface conditions such as surface temperatures and water level. In this study we used two categories of satellite sensors: a high-spatial-resolution sensor (SPOT/HRV) and a wide-coverage coarse-spatial-resolution sensor (NOAA/AVHRR).

A SPOT/HRV image was used for detailed classification of wetland ecosystems at Plotnikovo test site. Methane emission from the image area was estimated by combining the result of ecosystem classification with ground methane flux data. This methane emission estimate was about 34 % less than that obtained from airborne methane measurements. This underestimation would be partly ascribed to the lack of methane emission data from grass and bare soil. Taking account of the uncertainties in the measurement processes, we could say that both estimate are within a range of probabilistic variability. To reduce the uncertainties, it is necessary to increase the number of ground methane measurements.

NOAA/AVHRR data were used for monitoring seasonal changes of vegetation and surface temperatures in west Siberian wetlands. From the time histories of NDVI values derived from AVHRR data, land cover types were classified in the whole west Siberian lowland area. Seasonal changes of ground surface temperature in west Siberia were estimated using AVHRR thermal infrared channels.

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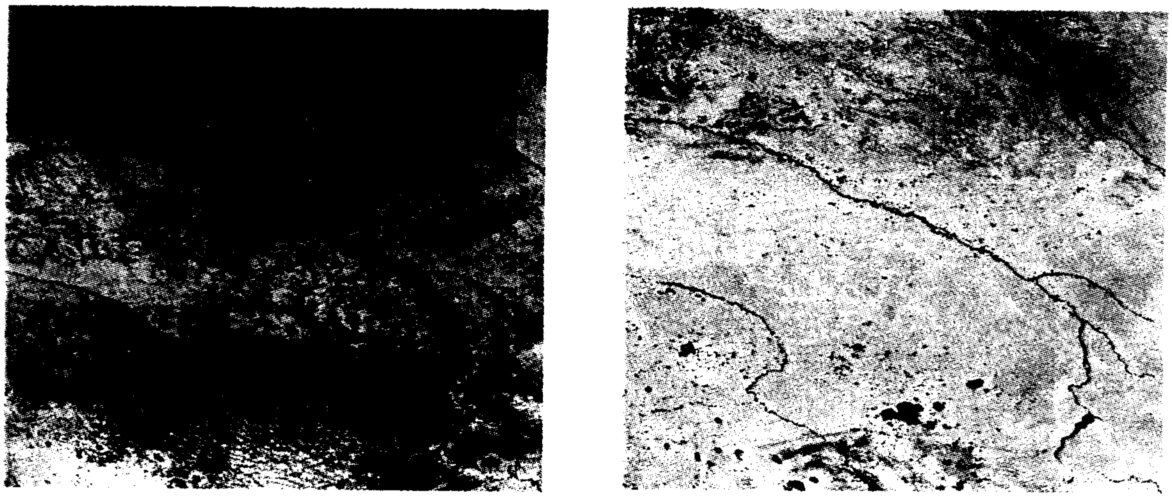

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Figure 6. Ground surface temperatures in the basins of Yenisey, Ob', and Irtysh Rivers in April and July 1993. Brighter tones represent higher brightness temperatures.

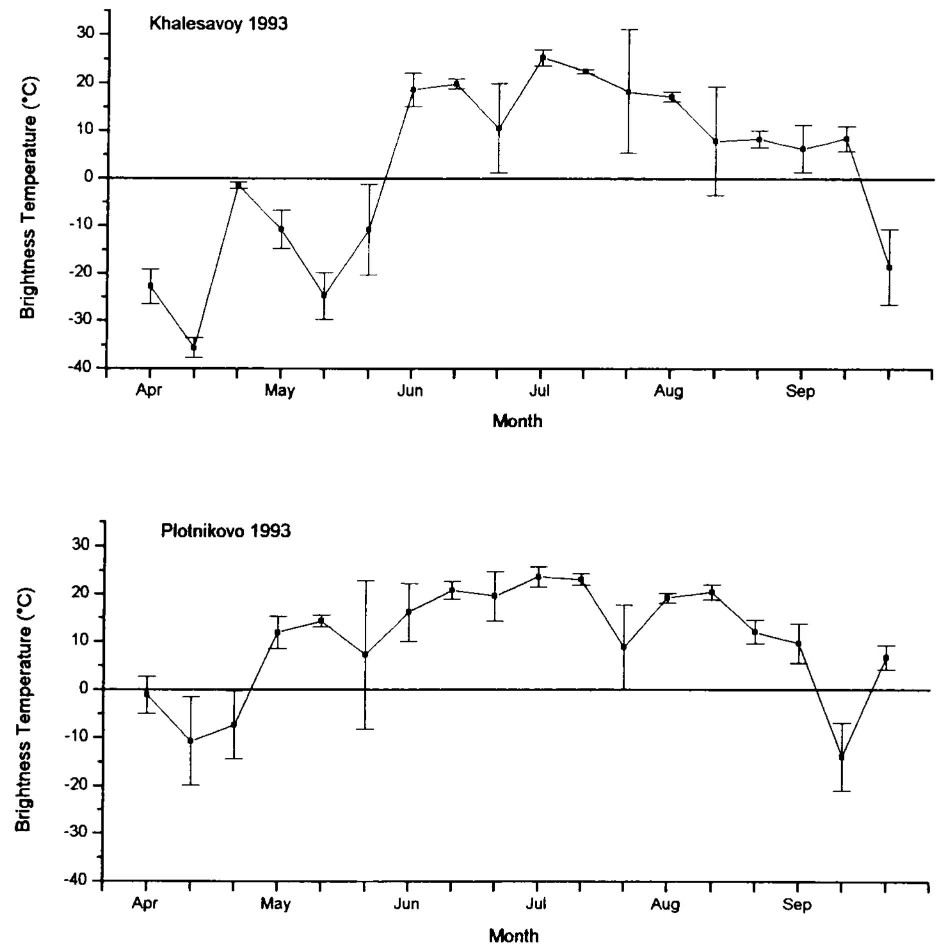

Figure 7. Seasonal changes of surface temperatures from April to September 1993 at Khalesavoy and Plotnikovo.