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REMOTE GEOTHERMAL SENSING OF WESTERN SIBERIA BOGS (THE CASE OF TARMANY MARSH MASSIF)

SUMMARY. This article describes the results of experimental application of remote geothermal sensing to study the process of repeated marsh formation in Tarmany geosystem. The natural conditions of Tarmany marsh massif are considered. The article covers the technological description of the remote geothermal mapping. The characteristics of the surface temperature marsh massif distribution in a thermal infrared image are discussed. As a result there have been drawn geothermal maps of Tarmany geosystem, received by processing satellite images formed using TM and ETM+ instruments (Landsat-4, Landsat-5, and Landsat-7 satellites). The author shows the spatial–temporal dynamics of the thermal field of the marsh massif surface from 1984 to 2011. The obtained results are recommended to use in estimating the process of repeated marsh formation and the marsh temperatures in Western Siberia.

KEY WORDS. Remote sensing, remote geothermal sensing, secondary bogging, thermal infrared survey.

The study took place in Tarmany marsh massif located on the second above-the-flood-plain lacustrine-alluvial terrace of the Tura River. The terraced occurrence of the massif explains its finger shape lying parallel to the main hydrographic elements. Tarmany marsh massif is of lowland type having ground-pressure influx (from 15% to 87%) [1]. The massif is 136 km long, 7 km to 40 km wide. The total area of the water shed is 2160 km^2, with 1240 km^2 (57%) of marsh. The average peat depth over the marsh is 2 m. The 25 cm deep peat is 1505±50 years old, the 65 cm deep peat is 3685±40 years old, the peat accumulation rate is about 0.16 mm per annum [2].

A part of the marsh massif under study was drained in the 1960s and 1980s. The reclaimed area is 272 ha with 60 ha drained via 0.9, 1.2, 1.5 deep tile drainage spaced 8 m, 24 m, 40 m respectively. The rest of the area is drained via open trenches spaced 100 m, 150 m, 200 m, and 250 m [3]. In the 1990s there was no operation department to maintain hydraulic engineering works, the drainage systems went dead, which added to the natural processes leading to repeated marsh formation. These data were provided by monitoring observations of geohydrological wells [4]. The main task is to choose the strategies and techniques to study the whole process as well as to estimate and forecast its evolution.

Hydromorphic soil reclamation is known to cause the significant temperature changes [5], [6], [7], and the thermal field defective distribution indicates the on-going processes and phenomena in the area.

The geothermal mapping technique using IR GPS survey was applied. As a rule the survey is performed within the SWIR and TIR (1.5–0.3 μm and over 0.3 μm respectively). These spectrum ranges display the heat radiation of the ground surface. The higher is the ground surface heat, the higher is the radiation rate and it depends on the solar radiation rate, the ground albedo, the radiation value, the heat lag, the earth interior heating rate, the soil moisture, the landscape and ground texture, the weather, the optically active gas (CO_2, SO_2) concentration, and the time. The IR survey helps to estimate the radiation [8], [9], [10].

Experimental part. The survey used the remote geothermal mapping data received from Landsat satellite instruments. Prior to the survey satellite images of the cloudless ground for different seasons and different years were selected. The ENVI software helped to draw the initial geothermal scenes.

Channel 6 (120 m spatial resolution) was used to convert TM radiometer data, channels 61 and 62 (60 m spatial resolution) were used to convert ETM+ radiometer data.

The Landsat 4, 5, and 7 data conversion into the surface temperatures was performed in two stages:

during the first stage of the Landsat scene processing the DN non-dimensional values of the initial shot brightness were converted into the incoming sensor values under the formula [11]:

$$L_\lambda = \frac{L_{max\lambda} - L_{min\lambda}}{Qcal_{max} - Qcal_{min}} (Qcal - Qcal_{min}) + L_{min\lambda} \quad , (1)$$

where: $L_?$—the amount of incoming radiation (W/m^2);

L_{min}—the amount of incoming radiation being Q_{min} after scaling;

L_{max}—the amount of incoming radiation being Q_{max} after scaling;

$Qcal_{min}$—DN minimum calibrated value (0 or 1);

$Qcal_{max}$—DN maximum calibrated value (255);

Qcal—the shot brightness pixel calibrated value (DN).

During the second stage the incoming radiation values were converted into the temperature values.

The Kelvin conversion was performed under the formula

$$T = \frac{K_2}{Ln\left(\frac{K_1}{L_\lambda}\right) + 1} \quad , (2)$$

The Celsius conversion was performed under the formula:

$$T = \frac{K_2}{2.302585093 * Log_{10}\left(\frac{K_1}{L_\lambda}\right) + 1} - 273.15 \quad , (3)$$

where: T—C/K degrees;

K1—calibrating constant 1;

K2—calibrating constant 2;

L_7—incoming radiation at the first stage.

Calibrating constants 1 and 2 are given in Table 1 [11], [12].

Table 1

Calibrating constants for Landsat thermal channels

Radiometer/ Constant (measurement unit)	Constant 1 (watts/(m^2 * ster * ,m)	Constant 2 (Temperatue K)
TM 4	671.62	1284.30
TM 5	607.76	1260.56
ETM +	666.09	1282.71

The ENVI Color Table was used to colour the received geothermal scenes. The selection of distinct colour for each scene allowed displaying the slight difference in the surface thermal properties.

Results and discussion. Hydromorphic soil reclamation causes significant temperature changes that have spontaneous character and influence the underlying surface due to drainage. These changes are clearly seen in the received geothermal scenes (Figure 1).

The lighter spots show the least temperature values, the dark spots show the respectively biggest values.

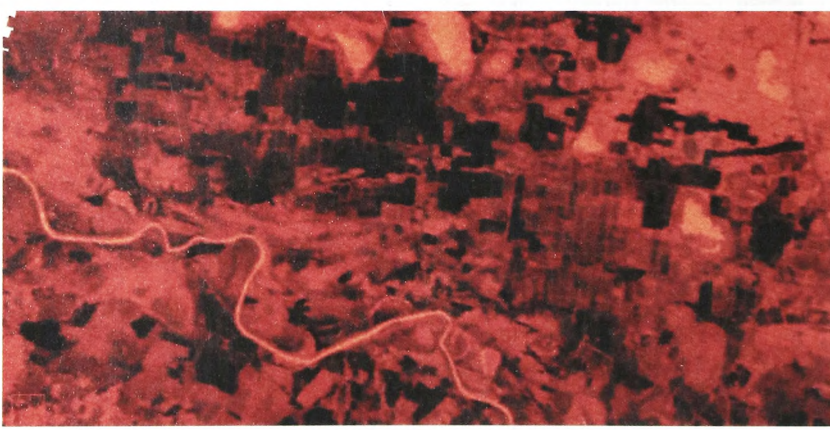

Figure 1: Thermal scene fragment of 2 July 1984 (Landsat-5).

The comparison between uncultivated and cultivated parts of the marsh shows that the cultivated parts have a shorter thermal period. In spring and early summer the uncultivated parts have the highest surface temperature. In the second half of summer the drained peat soils are much warmer. The main reason for this may be the decrease in water content of drained soil compared to the uncultivated marshes and as a result the change in heat capacity and heat conductivity.

The study proved that the thermal regime of peat soils differs from that of the mineral ones. They warm up more slowly than the surrounding mineral islands and during summer their surface stays cooler. The drained peat-bogs thaw up more slowly, delaying the agricultural use of land.

The multitemporal geothermal analysis shows that in the 1990s the area under study experienced the repeated marsh formation proved by equal thermal regimes of the uncultivated and cultivated parts of the marsh (Figure 2).

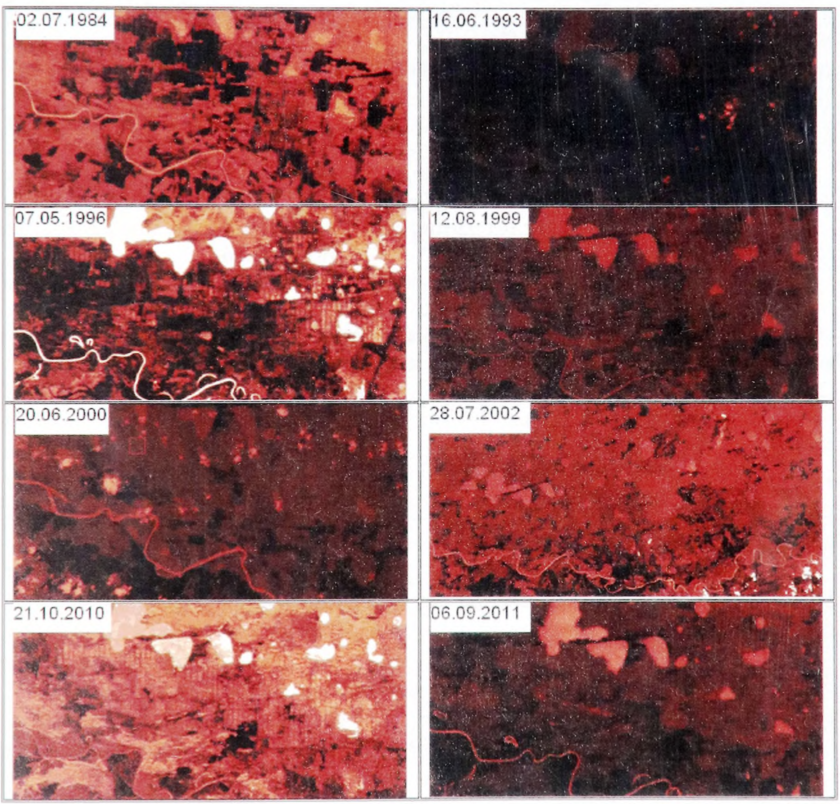

Figure 2: Multitemporal geothermal scenes.

Conclusion. The remote geothermal sensing can be successfully used for studying Western Siberia bogs and marshes, its application can improve the information provision for the territorial studies. The interpreted results of this survey can help to study distant hard-to-reach marshes.

The remote measurements of marsh surface temperatures calculated with satellite single-shot data help to study in detail the thermal field differentiation and give enough information to solve a wide range of problems.

The materials of the remote geothermal sensing can be used in analyzing the rate of repeated marsh formation in reclaimed lands as drained and undrained soils have different thermal regimes.

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