Analysis of the temperature regime of basin geosystems of the Krasnoyarsk Territory using MODIS satellite images and ground-based data

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Abstract. With the availability of a highly sparse and even shrinking network of ground-based weather stations in recent years, satellite remote sensing is a worthy alternative to traditional methods of measuring temperature, which provides long-term homogeneous data series for the studied territories. This article addresses the problem of the applicability of MODIS satellite data for analyzing the temperature characteristics of the regions of the Krasnoyarsk Territory. The thermal regimes and effective heat sum of the territories using ground-based data from weather stations and satellite images have been compared. Statistical data on the temperature regime in the basin geosystems of the Krasnoyarsk Territory has been obtained.

1. Introduction
The temperature of the surface air layer is one of the main characteristics of the climate, which must be taken into account in a number of sectors of the economy (construction and operation of buildings and structures, agriculture, recreation and tourism).

Information on the thermal resources of the vegetative period of plants (specific crops) is necessary to solve various problems of agricultural production: determining the timing of sowing and ripening, optimizing the varietal and species composition of cultivated crops, assessing the likelihood of damage to plants by high and low temperature, etc. [1, 2].

One of the main conditions determining the geography of crop distribution is effective heat sum (active temperatures) of a given territory, temperature fluctuations, compliance of the duration of the warm, frost-free period and the length of the growing season with the requirements of cultivated crops. Effective heat sum is the sum of positive temperatures for a period with a stable temperature above 10°C [3]. Therefore, to characterize the production capacity of crops, identifying the thermal regime and assessing the effective heat sum of a particular territory is important [4].

There are various data sources for determining the temperature regime in a particular area. On the one hand, there is data from weather stations, the archive of which is freely available on the Internet. However, today in Russia only 156 stations have been preserved with continuous observations throughout the entire twentieth century. In a number of regions of the country (the Arctic, central regions of Siberia and the Far East), the density of weather stations has decreased many times and tens of times
(for example, in Taimyr out of more than 15 weather stations there are currently 5). The average Russian density of the current meteorological network (10.5 thousand km\(^2\)) is comparable to the density of 1950. The density of the meteorological network is extremely uneven, in some regions, in particular in the Republic of Sakha (Yakutia) and on the Arctic coast, it is 8–10 times lower than in the central and southern regions of the European part of Russia [5].

On the other hand, information about the temperature regimes of territories from satellite data of the thermal infrared range is now available. This information has a fairly good spatial resolution, but the time intervals are much larger than for data from weather stations [6].

Currently, MODIS sensor data is one of the most popular sources of satellite information [7, 8]. The information accumulated since 2000 is available through specialized data portals, for example, EOSDIS.

MOD11 family is temperature data source of the Terra / Aqua MODIS information products In particular, MOD11A2 data contains an average 8-day per-pixel Land Surface Temperature and Emissivity (LST&E) values with a 1 kilometer (km) spatial resolution in a 1,200 by 1,200 km grid. Each pixel value in the MOD11A2 includes average LST daytime and nighttime surface temperature data collected within that 8-day period with taking into account associated quality control assessments, clear-sky conditions, etc. [9, 10]

This paper presents the results of an analysis of the temperature regime and an assessment of the effective heat sum of the basin geosystems of the Krasnoyarsk Territory based on the analysis of satellite data and ground data from weather stations.

Our research objectives are as follows: 1) receiving and processing MODIS data; 2) receiving and processing data from ground-based weather stations; 3) a statistical analysis of temperature indicators, such as monthly average, annual average, annual temperature amplitude, sum of active temperatures, etc.; 4) comparison of the thermal indicators of terrestrial and satellite data; 5) assessment of effective heat sum in basin geosystems of the Krasnoyarsk Territory [11, 12].

2. Materials and methods

The following data were used as input sources:

- Digital model of basin geosystems of the Krasnoyarsk Territory obtained using a digital elevation model MERIT Hydrologically Adjusted Elevations [13].
- A set of satellite images MODIS / Terra Level-3 MOD11A2 version 06, which are obtained using daily data MOD11A1 on the temperature of the earth’s surface as the average temperature over eight days, excluding days when the surface is covered by clouds. Variations in surface temperature over the course of a year by 46 eight-day MOD11A2 datasets that include information about day and night surface temperatures with a spatial resolution of about 1 km are described [14].
- Data archive from weather stations of the Krasnoyarsk Territory, that have been obtained from the site rp5.ru.

Data processing MOD11A2 using QGIS has been carried out. The obtained scenes of day and night surface temperatures of MOD11A2 according to the coordinates of the study area have been cropped, and the average daily temperature has been calculated. Average daily temperature value through the module “Zonal statistics” for each watershed has been calculated. The following temperature indices for each watershed: monthly average, annual average, maximum and minimum for a month, maximum and minimum for a year, annual amplitude, effective heat sum for the territory have been calculated.

Processing of weather station data and comparing them with MODIS data, using Excel, has been carried out.

3. Results and discussion

Two catchments areas of the Kan and Mana rivers have been selected for this study, which are the watercourses of the Yenisei River watershed.
Digital model of the Kan River geosystem is represented by 7 basins of the 2nd level of catchment area; 40 basins of the 3rd level and 437 basins of the 4th level. The digital model of the Mana River geosystem consists of 1 basin of the 2nd level, 13 basins of the 3rd level and 94 basins of the 4th level [15]. Figure 1 shows the boundaries of the basins. Figure 1 also shows the distribution of temperature amplitudes in 2019. For example, in the Mana River basin, more than 89% of the territory has a temperature amplitude of 35-40°C. The annual temperature amplitude is the difference between the average temperature of the coldest month and the average temperature of the warmest month of the year. MODIS data allows constructing distributions for each basin of the 2nd, 3rd or 4th order.

Figure 1. Annual temperature amplitude according to MODIS.

The analysis of the main temperature indicators based on satellite and ground-based data has been carried out. There are 6 weather stations on this territory, the data archives of which have been taken for research. These are Aginskoye, Irbeyskoye, Uyar, Solyanka, Anastasino, Kansk (see figure 1). Comparison of the annual temperature variation according to weather stations and MODIS shows a good agreement between them. For example, figure 2 shows annual temperature course in 2019 corresponding to the catchment basin where the Aginskoye weather station is located. The course of positive
temperatures is almost the same. The observed differences at negative temperatures are apparently due
to an incorrect determination of the temperature of the earth’s surface covered with snow. Similar figures
for the other five weather stations have been obtained. Nevertheless, the correlation of the data on the
annual course of temperatures for all weather stations in comparison with the MODIS data exceeds 0.9.

Figure 2. The annual temperature course in 2019 according to MODIS and the Aginskoye weather
station.

To study the effective heat of the growing season in the catchment areas, the sums of temperatures
above 10°C were calculated. Comparison chart (figure 3) and a map (figure 4) of the effective heat sum
assessment of basin geosystems in the Krasnoyarsk Territory are presented below. Figure 3 shows the
effective heat sum of some catchment basins in the territory where the corresponding weather stations
are located. The correlation of MODIS data and weather stations correlation has been found equal to
0.9.

Figure 3. Comparison of accumulated temperatures according to MODIS and weather stations for 2019.

Figure 4 shows a fairly large variety of effective heat sum for different watersheds of the territory
under consideration.
4. Conclusions

Thus, a comparison of ground-based and space-based observations shows their good agreement with a correlation greater than 0.9.

Statistical data on the temperature regime in the basin geosystems of the Krasnoyarsk Territory have been also obtained during this study. A geobase of data on their basis has been formed. It can be used for agroclimatic zoning of the Krasnoyarsk Territory, to identify favorable factors of agricultural production, geoecological assessment of the territory, and a number of other tasks.
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