Search of Changes in the Temperature of Urban Environment with Use of Satellite Data on the Example of the Krasnoyarsk

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Abstract. Changes in the urban environment can be detected using satellite images of different spatial resolutions in the visible and far infrared range. Landsat data is currently the most accessible, complete, and open for studying these changes. Thermal imaging is widely used for research and monitoring of man-made objects such as pipelines, urban facilities, industrial facilities and pollution. The paper presents the results of the assessment of the land surface temperature in the Krasnoyarsk city for the two-year period from September 2016 to September 2018 based on the analysis of Landsat-8 satellite images.

Keywords: thermal infrared imagery, TIR, Landsat, land surface temperature, LST, climate of the urban environment.

1 Introduction

A change in the urban environment entails a change in the microclimate of the city, which directly affects the change in the temperature of the earth's surface; these changes can be estimated using field measurements and remote methods. Far-infrared satellite imagery of the Earth is used as source data for remote methods for studying temperature [1]. Thermal imaging is widely used for research and monitoring of anthropogenic and natural objects [2].

Since 1984, the systematic collection of Landsat imagery has produced more 60-120 m high spatial resolution thermal infrared (TIR) imagery of the Earth's land surfaces than any other satellite system. Yet unlike other NASA Earth Observation System missions, the Landsat production system does not produce derived physical parameters, such as surface temperatures, from the calibrated at-satellite radiance data. Additional calculations, and sometimes – additional data, are needed to determine them [3].

Launched on February 11, 2013, Landsat 8 is the most recently launched Landsat satellite. It is collecting valuable data and imagery used in agriculture, education, business, science, and government.

The Landsat 8 satellite system consists of two major segments: the observatory and the ground system. The observatory consists of the spacecraft bus and its payload of two Earth-observing sensors, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) [4].

Land surface temperature (LST) is a key environmental climate variable derived from Thermal Infrared (TIR) data that is used in surface energy balance models in studies ecology and climate research. Research in this area is carried out for areas in different parts of the world, including the territory of Krasnoyarsk, a city in Siberia with a population of more than a million people [5].

This paper considers examples of land surface temperature changes over two-year period from September 2016 to September 2018 based on analysis of Landsat-8 satellite TIR images, which is very important as TIR images contain information that is virtually impossible to obtain in any other way such as using visible and near infrared images [6]. A technique is presented for detecting temperature changes within one territory for a certain time interval and its applicability for determining anthropogenic changes in the landscape is shown. The choice of this time period is associated with active development of the city for the XXIX World Winter Universiade 2019 in Krasnoyarsk [7].

2 Remote sensing data

Land Surface Temperature, in the most basic sense, is how hot the ground feels to the touch. From the point of view of a satellite, the land surface is the first solid surface encountered, whether it is the actual ground or something like the top of a tree canopy or building. This surface is considered to be a few millimeters in thickness, and can be any type of terrain such as grass, forest, desert, snow, water, among others [8].

Problems with observing the Earth's surface often occur with the presence of clouds, which prevents the satellite from gathering accurate measurements of the land surface. The land surface temperature especially on a global scale would be useful by itself as well as for use in obtaining other variables and properties of the Earth's surface and terrain. Remote sensing data provides the ability to monitor the land surface temperature over the Earth's surface.

2.1 MODIS

The Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) instrument produces a daily land surface temperature product using multiple thermal bands. MODIS can provide global coverage, high spectral resolution, and accurately calibrated data. MODIS utilizes multiple bands in atmospheric windows for its LST retrieval; it implements a generalized split-window algorithm and a physics-based day/night algorithm. With seven available thermal infrared bands, this algorithm can adjust for uncertainties in temperature and water vapor profiles without simultaneous retrieval of surface data or atmospheric variable profiles. Emissivity is also immediately required for an operational product, so MODIS estimates classification-based emissivities from land-cover types using thermal infrared bidirectional reflectance distribution function (BRDF) and emissivity modeling. Over certain land cover types in the range of 263 K to 300 K, the MODIS LST can be better than 1 K, but can underestimate temperatures in semi-arid regions due to inaccuracies in the estimated surface emissivity [9]. MODIS does have lower spatial resolution than Landsat, which makes this product difficult to apply in certain applications that require LST, such as field specific agriculture or irrigation studies.

2.1.1 Modis Product

The MOD11A1 V6 product provides daily per-pixel Land Surface Temperature and Emissivity with 1 kilometer (km) spatial resolution in a 1,200 by 1,200 km grid. The pixel temperature value is derived from the MOD11L2 swath product. Above 30 degrees latitude, some pixels may have multiple observations where the criteria for clear-sky are met. When this occurs, the pixel value is a result of the average of all qualifying observations. Provided along with the daytime and nighttime surface temperature bands are associated quality control assessments, observation times, view zenith angles, and clear-sky coverages along with bands 31 and 32 emissivity from land cover types.

2.2 Landsat

Landsat, as the longest and only continuous record of the global land surface, can be applicable in work concerning agriculture, geology, forestry, mapping, and change detection among other applications. This dataset has been accessible to a wide community of users since all Landsat data became freely available in December 2009 [10]. Landsat sensors is designed for single thermal band imagery (Landsat 4, 5, and 7). The only modification from one sensor to another is inserting a different spectral response function.

The launch of the Landsat-8 satellite took place in February 2013. Landsat 8 satellite receives data using two different sensors - Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). The TIRS scanner was created in the NASA Goddard Space Flight Center and is intended for imaging in the far infrared. GaAs-based Quantum Well Infrared Photodetector (QWIP) photodetectors are installed in the focal plane of TIRS. Landsat-8 images consist of 11 spectral bands, where the 10th and 11th are far infrared bands with a spatial resolution of 100 m, which allows them to analyze the energy of the Earth's surface rather than the reflection of sunlight [11].

2.2.1 Landsat Product

Since 2016, all Landsat data, including Landsat-8, have been supplied with geometric and radiometric correction. Correction photographs are stored in the Landsat Level-1 Data Processing Levels or Landsat Level-1 data product sets. Additionally, the user can only perform atmospheric correction.

3 Methodology

Given that the surface temperature changes as a result of urban development. One can estimation by changes in temperature that changes occur in the urban environment. The paper describes a method for determining changes in the urban environment using remote sensing data. The supporting data is satellite Google Maps. The work was done in QGIS software.

3.1 Calculation of the atmospheric profile

Atmospheric correction using the "Radiative transfer equation" method is available due to access to all necessary parameters in open sources and when using the Calculator of atmospheric parameters.

Removing the effects of the atmosphere in the thermal region is the essential step necessary to use the thermal band imagery for absolute temperature studies. The emitted signal leaving a target on the ground is both attenuated and enhanced by the atmosphere. With appropriate knowledge of the atmosphere, a radiative transfer model can be used to estimate the transmission, and upwelling and downwelling radiance.

Traditionally, calculating the atmospheric transmission and upwelling radiance has been difficult and time consuming. The user has to know where to get the atmospheric data, convert it to the proper format for a radiative transfer model and integrate the results over the proper band pass. The Atmospheric Correction Parameter Calculator facilitates this calculation [12].

To obtain atmospheric profile, one has to enter date and time, latitude and longitude, select spectral response curve corresponding to used source of remote sensing data and optionally, surface conditions – elevation above sea level, normalized atmospheric pressure, temperature and relative humidity. If surface conditions are not provided, model predicted surface conditions will be used. In this work, pressure, temperature and humidity data were obtained from weather forecast and monitoring service [https://rp5.ru/].

3.2 Calculation LST

The LST calculation is performed in QGIS software, with the atmospheric correction “Radiative transfer equation”, using the parameters obtained in the Atmospheric Correction Parameter Calculator, using “the Land Surface Temperature Estimation Plugin”. We make two LST calculations for 2018 and 2016.

3.3 Comparison of MODIS and Landsat-8 data

To talk about the accuracy of LST obtained because of calculations using the data of the Landsat-8 heat band, we consider the obtained values with the data of the finished MODIS product, and with the data obtained from Automatic Weather Station (AWS). Let's compare at several points (test sites) in the city (Fig. 1), two of them have AWS installed. And others have a uniform distribution of the landscape on the territory of more than 1200 * 1200 meters.

Figure 1. Test sites, located in the city of Krasnoyarsk (the border of the city is marked in green).

Table 1 presents the average temperature in degrees Celsius between the time of flight of Landsat-8 (about 12 hours of the day) and MODIS (about 13 hours of the day).

Location (a) is situated near the weather station in the area of low-rise buildings in the North-Western suburbs of Krasnoyarsk. Location (b) is located in a dense mixed forest near the Akademgorodok district. Location (c) is located on a hill in a relatively open space near the cemetery and the racetrack. The location (d) corresponds to a typical urban development with 5-and 9-storey buildings on the right bank of the river in the city.

Despite the ease of use of MODIS data, its spatial resolution is not sufficient for studies of changes in the urban environment. Therefore, this paper uses Landsat-8 data. The temperature channel Landsat-8 has a resolution of 100 meters, but the temperature map is built using visible channels, which allows you to build combined images with higher accuracy, in this case, it is possible to increase the spatial resolution up to 30 meters.

The obtained results of the comparative analysis of ready-made values of the surface temperature in the archive of MODIS data and the calculated values of Landsat allowed us to conclude about the correctness of the implementation methodology of the calculations. The values for several test sites are almost the same. The discrepancy with the AWS data seems to be due to the fact that the AWS values given are the air temperature values at a height of 2 meters, not the surface temperature.

Table 1. Comparison of temperature data for test sites.

Date	**09/05/2016**			**09/20/2018**		
Location \ Data	**MODIS**	**Landsat-8**	**AWS**	**MODIS**	**Landsat-8**	**AWS**
a	17,2	17,5	16,1	14,4	14,7	12,6
b	16,4	16,1		12,8	12,1	
c	19,4	19,8	16,3	15,6	15	12,3
d	20,7	20,5		16,6	16,44	

The result of changes in urban development, artificial changes in relief, deforestation, leads to a change in the microclimate of the urban environment. Accordingly, there is a change in the surface temperature of the city. Thus, a change in the surface temperature of the city is a sign of changes in the urban environment.

3.4 Methods for detection of urban changes based on Land Surface Temperature

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The methodology for detecting changes in the urban environment is based on the use of temperature maps obtained from Landsat-8 satellite data in the thermal and visible ranges [13]. During implementation, the following stages are distinguished:

The first step is the preliminary processing of satellite data, which includes atmospheric correction of the source layers by the Radiative transfer equation method.

The next step is calculating LST on selected dates to study, in our case this 09/20/2018 and 09/05/2016.

The study area is limited to the boundaries of the Krasnoyarsk city, therefore, further it is necessary to conduct an overlay operation along the city border for each LST.

An important step is the normalization of data to allow comparison of the obtained temperature maps with each other. Using the statistical characteristics of each image, namely, the average temperature value of the map, an increment value is calculated for the normalization operation. After this, the mathematical operation of maps algebra is carried out, allowing one map to be subtracted from another. The result is a new image containing the difference between the temperature values in each pixel.

For the correct detection of changes in two satellite images, it is necessary to use cloudless one-season satellite images with the most similar meteorological conditions. To test the methodology for detecting changes in the urban environment, the authors selected satellite images to the territory of the Krasnoyarsk city with identical weather conditions for September 2016 and September 2018.

A set of satellite images is presented on dates 09/20/2018 and 09/05/2016 from the Landsat-8 satellite. Table 2 presents the air temperature at the study date and the surface temperature of the earth obtained from satellite images. The temperature in the image corresponds to the time of shooting Landsat-8 at 12 noon.

Table 2. Weather data for satellite images.

Date	**Air temperature, °C**		**Average land surface temperature on image, °C**
09/20/2018	day +15	night +4	15.9
09/05/2016	day +19	night +14	19.7

For temperature comparison in 2016 and 2018, we will conduct normalization by the average value of the land surface temperature in Table 1 within the boundaries of the Krasnoyarsk city. After normalization, the average values become equal and in the next step the mathematical operation of the map algebra is performed, subtracting the LST2016 map from normalized LST2018.

As a result of the subtraction, a new image is obtained containing the difference between the temperature values in each pixel for the studied dates. The obtained values are divided into 3 classes: no change, minor changes with a temperature difference of 1-3 degrees and significant changes with a temperature difference of more than 4 degrees.

4 Results

As a result of approbation of a technique of detection of changes of an urban environment on land surface temperature the corresponding thematic map has been created (Fig. 2). This map shows areas with significant temperature changes, where temperatures have changed by 4 degrees or more over two years. Several characteristic points on the map of the city, in which there is a change in the urban environment, are marked with numbers 1 - 4.

Let us consider the results in more detail. Figure 3 shows these parts of the city on a larger scale.

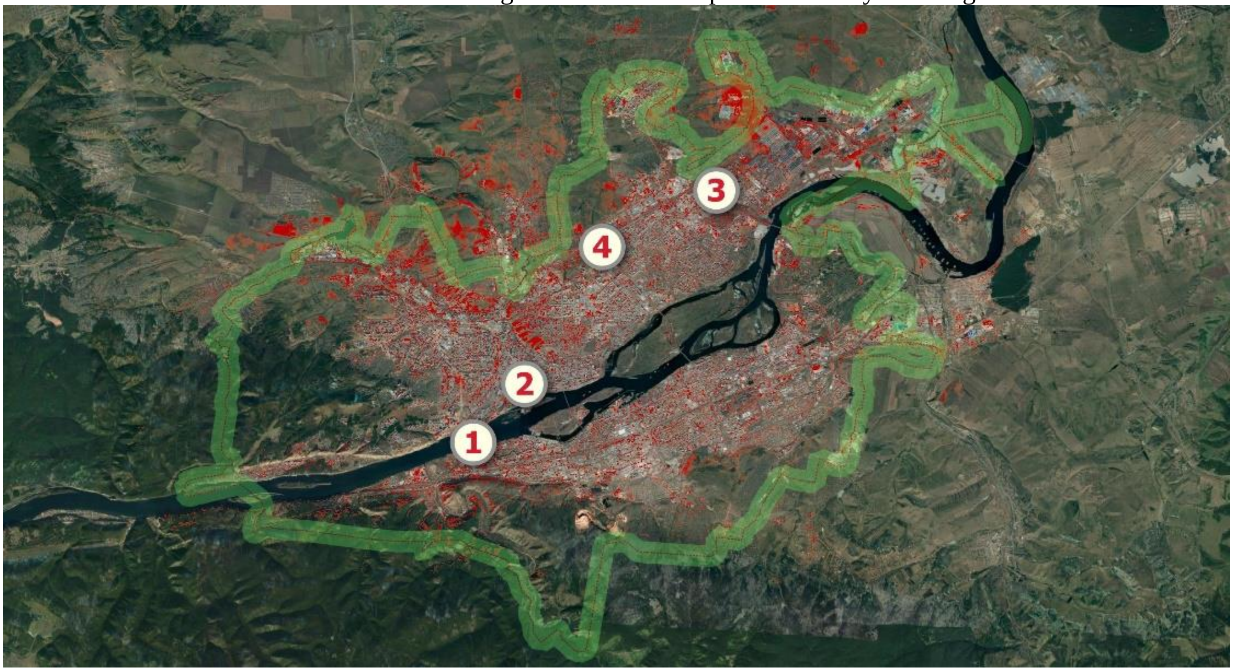
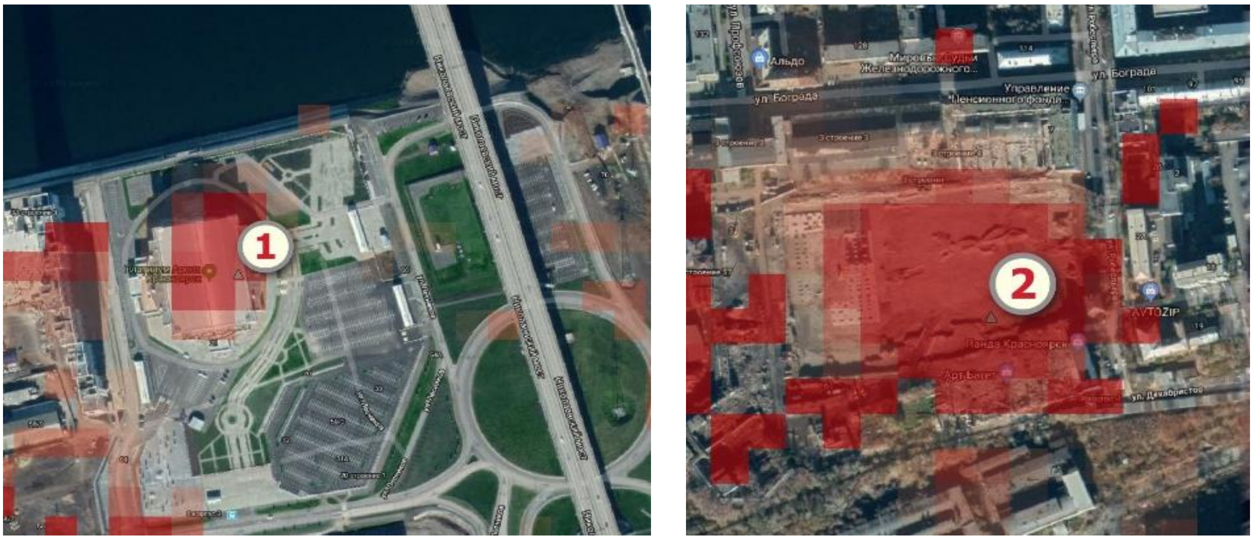


Figure 2. Thematic map is analysis of results.



a *b*

c *d*

Figure 3. Location with temperature changes

Figure 3a shows the change in surface temperature as a result of the construction of a sports facility. In 2016, construction of the facility was just beginning. The red color shows areas with an increase the land surface temperature, which coincide with the contour of the object constructed in 2018.

Figure 3b shows the territory of the former Combine Plant, where in 2017 the demolition of industrial buildings for the construction of residential buildings began.

Figure 3c shows an example of urban development in the Soviet district, where instead of a wasteland in 2016, warehouses appeared in 2018.

Figure 3d shows the new Preobrazhensky microdistrict, the places of changes the land surface temperature, which correspond to new houses under construction in 2018, shown in red in the figure.

5 Conclusions

Test of the LST from remote sensing data MODIS and Landsat-8 show that they values are the same. This is very important for further research and application of LST from Landsat-8. We can use the values LST from Landsat-8 for search of changes in the environment of the Krasnoyarsk city. As result we created the map of the temperature difference for two research dates (05/09/2016 and 20/09/2018).

When analyzing areas with a maximum temperature change, it is clear that this is due to a change in urban development, for example, the construction of new microdistricts, shopping mall, and a change in the natural landscape, for example, destruction of forests. Comparison of LST for two different dates of the same season with similar weather conditions allows you to find changes in urban development. It is also possible to evaluate the influence of these changes on the urban thermal outline.

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