Impact of urban environment on land surface temperature in local climate zones

Anna Gosteva[1*], *Sofia* Ilina[1], and *Aleksandra* Matuzko[2]

[1]SFU, Krasnoyarsk, Russia
[2] Institute of Computational Modelling of the Siberian Branch of the Russian Academy of Sciences (ICM SB RAS), Krasnoyarsk, Russia

Abstract. The replacement of the natural landscape by artificial environment has led to changes in the ecosystem and physical properties of the surface, such as heat storage capacity, and thermal conductivity properties. These changes increase the difficulty of heat transfer between urban areas and the environment. Land surface temperature (LST) images from various satellites are widely used to represent urban thermal environments, which are more convenient and intuitive way. LST maps provide full spatial coverage, which distinguishes them from air temperature data obtained from meteorological stations.
The study of LST according to the Landsat 8 data of Krasnoyarsk city over the past 10 years allowed the authors to talk about the observation of constant seasonal urban heat islands (UHI). For a more detailed consideration of the urban environment, this study further considers urban landscapes, thus the idea of local climate zone (LCZ) is introduced to study these diverse impacts in addition to the traditional map of LST. And analysis of the interaction of UHI and LCZ.

1 Introduction

Humanity has noticed differences in air quality between the city and its surroundings since the 19th century. The city has a different climate, called the urban, which differs from the surrounding area in temperature, wind, wetness and other meteorological variables. Today, these differences are increasing because the climate is changing.

The study is aimed at examining the ecological situation in Krasnoyarsk, studying the perennial heat islands and their relationship with the urban industry [1]. The level of air pollution at constant emission parameters depends on the temperature distribution with height, wind speed and direction, the intensity of solar radiation, air humidity, the amount and duration of precipitation. For low-altitude and cold emissions (chimneys and ventilation exhaust) near the source the concentration of the impurity is low, it increases on the leeward side and reaches a maximum at some distance from the pipe, depending on the wind speed. For high-altitude and hot emissions (chimneys of enterprises of ferrous and non-ferrous metallurgy, some chemical industries, power plants, etc.), the distribution of impurities in the atmosphere depends both on the speed and direction of the wind, and on the vertical

* Corresponding author: agosteva@sfu-kras.ru

distribution of air temperature. With a weak wind, the concentration of impurities near the ground decreases, and with a strong wind, the rate of transport of impurities in the horizontal direction increases.

If the temperature drops with altitude, then in summer during daytime conditions are created for an intense turbulent exchange, which leads to the appearance of significant concentrations of impurities coming from high-altitude sources in the lower surface air layer and to noticeable fluctuations in concentrations with time. If the temperature rises with height in the surface air layer, then the dispersion of impurities reduces. In the case of powerful and long-term inversions at low fugitive emissions, the concentration of impurities can increase significantly [2].

The concentration of impurities in smog can greatly increase due to surface inversion and increased air humidity. Winter smog is often associated with fog, where high concentrations of harmful impurities are retained in the surface air for a long time [3].

With the development of urbanization, the urban heat island (UHI) has attracted a lot of attention due to its adverse effects on the health of residents. UHI was formed from the land surface temperature (LST) of the Landsat 8 data series (https://earthexplorer.usgs.gov/).

Local climate zone (LCZ) is the basis for land cover classification for UHI studies. In this study, we investigated the influence of different seasons UHI in various LCZ of the city. High-resolution series of remote sensing images from OpenStreetMap (https://www.openstreetmap.org/) data was used to map LCZ on a city scale. UHI was formed using Landsat 8 satellite data.

2 Materials and methods

Krasnoyarsk is located at the junction of three geomorphology countries: the West Siberian Plain, the Central Siberian Plateau and the Altai-Sayan mountainous country. Krasnoyarsk is located on both banks of the Yenisei River in its middle reaches. Its width on different banks is not the same: on the right, it varies from one kilometer at the Laletin stream to 8 km at the confluence of the Berezovka River. The left-bank valley expands significantly up to 6 or 8 km [4]. A diversity of landscape and geological structures with water areas and vegetation determines different types of natural landscapes, which determines the development of the city's architecture.

For Krasnoyarsk the wind regime is characteristically constant throughout the year, which is explained by the conditions of orography. Tthe direction of the Yenisei valley coincides with the prevailing wind direction. The width of the Yenisei valley within the city is sharply limited, which affects the speed of the wind flow and, as a consequence, the intensity of ventilation of the territory. Industry is located on the outskirts of Krasnoyarsk [5].

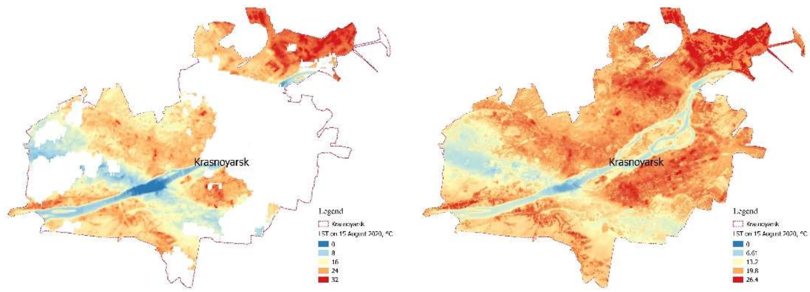
The relief of Krasnoyarsk is distinguished by a variety of forms. Due to the difficult relief of the city, it must be studied with a complex approach.

2.1 The Retrieval of LST

The article describes the application of Landsat 8 OLI/TIRS Collection 2, the dataset Level- 2 includes scene-based global Level-2 surface reflectance and surface temperature science products. Collection 2 includes Landsat Level-1 data for all sensors since 1972, as well as global Level-2 surface reflectance and surface temperature scene-based products from 1982 to present within defined constraints. Landsat Collection 2 Level-2 data became available on the official website only at the beginning of 2021. Access to data of this level removes the question of atmospheric correction of data and determination of atmospheric parameters [6].

Provisional Surface Temperature is generated from the Landsat 8 Collection 1 Level-1 thermal infrared bands, Top of Atmosphere (TOA) Reflectance, Advanced Spaceborne

Thermal Emission and Reflection Radiometer (ASTER) Global Emissivity Database (GED) data, ASTER Normalized Difference Vegetation Index (NDVI) data, and atmospheric profiles of geopotential height, specific humidity, and air temperature extracted from reanalysis data. The quality of the data on the territory of our study is not high enough, the problem became noticeable immediately after the first verification. The Landsat Collection 2 Level-2 data has data loss in the Emissivity layer, and as result in LST layers. Due to partial loss of data, Landsat 8 Collection 2 Level-1 data was used. Figure 1a show results with loss data and figure 1b illustrate the full LST data.



a *b*

Fig.1. The study area represented by LST image retrieved by Landsat 8 on 15 August 2020. (a) The Landsat Collection 2 Level-2; (b) The Landsat Collection 2 Level-1.

The LST for Landsat 8 data have been calculated, the process is described in detail in other works of the authors [7]. QGIS software was used for all calculation. The ground-based observation network of the Federal Research Center of the KSC SB RAS currently has 21 CityAir air monitoring stations. Meteorological stations measure the air temperature 2 meters above the ground, but it is necessary to consider the relationship between air temperature and LST. In addition to the air temperature the monitoring stations give the average value of the concentration in the atmospheric air of PM 2.5 suspended particulate matter.

2.2 Identify the constant UHI

Materials for studying the UHI was collected from the Landsat 8 satellite imagery archive from 2013 to 2020. More than 30 scenes were collected during the snowless period. For each scene, distinguished heat islands were formed using a technique consisting of the following steps:

- Calculate LST from Landsat 8 [7]. Temperature in degrees Celsius.
- For each calculation, determine min, max, average.
- Determine the range of maximum values.
- Convert raster data to vector format.
- Remove the polygons with area less than 2500 m^2.

The perennial UHI was formed in three seasons: spring, summer, and autumn. Since it has been observed that seasonality affects the distribution of the urban heat island.

The accumulated archive of thermal images makes it possible to analyze the dynamics of changes in the UHI from 2013 to 2020. The results obtained were divided into two groups of constant and variable UHI. The group of constants included those heat islands that kept their contours as much as possible from 2013 to 2020. Further, the analysis of the interaction of heat islands and LCZ was carried out.

2.3 Division of urban areas into LCZ

Krasnoyarsk city is being built up. To analyze the dispersion of pollution, in addition to taking into account the features of the relief, it is necessary to pay attention to the development of the city. For this, LCZ were outlined on the territory of the city, which made it possible to reduce various combinations of buildings and land cover to a limited number of classes. LCZ are areas with a uniform surface coverage, structure, materials and a special nature of human activity, and have a specific type of interaction with the surface layer of the atmosphere [8].

This article describes how to use the method of identifying LCZ proposed by Stuart I.D. and Oke T.R. [9] The method is a classification scheme for LCZ, which consists of 17 types of zones, based mainly on the properties of the underlying surface structure of the surface coating, number of storeys of buildings and building density. For Krasnoyarsk the predominant types of development are: the private sector, large-scale buildings and heavy industry, residential areas. It was decided to reclassify the LCZ proposed by Stuart I.D. and Oke T.R. for the relevance of their application for studying the Krasnoyarsk territory.

Also, the methods of microclimatic zoning of Krasnoyarsk's territory are described in the proceedings of K.S. Mokrinets [5], but in his works zoning was carried out according to the geomorphological features of the relief of Krasnoyarsk krai, and in this article microclimatic regions are distinguished by the prevailing type of development.

3 Results

Constant UHI have been identified for three seasons (spring, summer, autumn). Spring heat islands amount to 81 polygons, autumn heat islands amount to 21 polygons, and summer heat islands amount to 82 polygons.

The intersection of autumn UHI and LCZ is located in industrial areas. The autumn UHI are located in industrial areas and residential quarters and in quarters without any buildings. Summer UHI have been distributed across all types of LCZ.

The table shows the correspondence of the air temperature and LST data by 12 meteorological stations of the KSC SB RAS in 2020.

Table. Correspondence of the air temperature and LST.

Observation point	20 May 2020		12 June 2020		15 August 2020	
	Air temperature, °C	LST, °C	Air temperature, °C	LST, °C	Air temperature, °C	LST, °C
Akadem	21,72	31,97	20,15	24,03	20,33	20,93
Shachterov	20,84	36,66	19,45	25,93	20,48	20,16
Partizana	21,18	34,77	20,13	22,7	20,78	20,22
Sverdlovsk	20,42	35,8	21,04	27,45	20,41	18,26
Vetlujanka	19,82	33,35	19,59	26,4	19,58	18,34
Udachni	19,23	34,58	19,56	25,6	20,57	20,43
Pokrovka	20,23	40,15	19,2	20,93	19,97	20,3
Peschanka	21,27	38,06	20,48	27,95	20,82	22,54
Lenina	21,33	37,77	19,92	26,42	20,86	21,97
Sputnik	20,19	36,46	19,71	28,79	19,61	21,38
Kirovsky	20,45	37,58	20,83	27,64	20,17	20,6
KrAZ	23,03	30,92	21,13	24,87	22,08	22,42

The most similar results were obtained from observation on 15 August 2020 (as is shown in Figure 2).

a

b

c

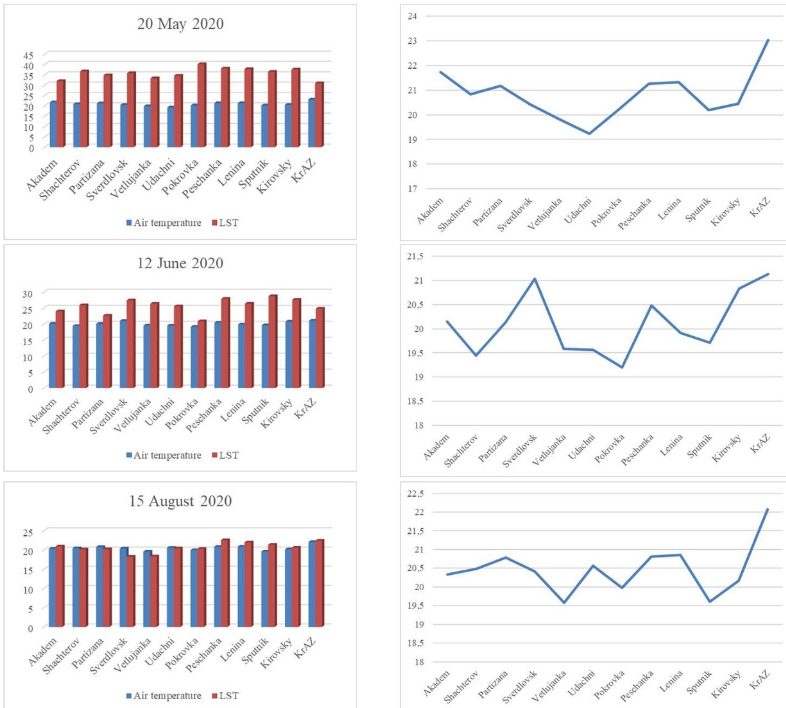
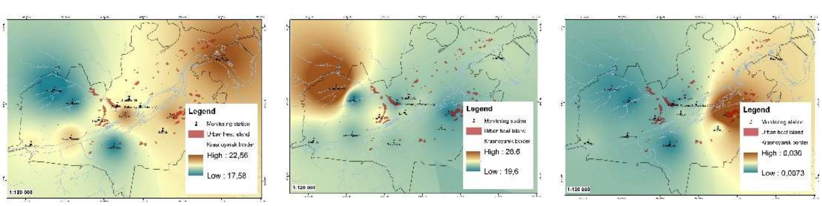


Fig.2. Comparison of the air temperature and LST in observation points. (a) on 20 May 2020; (b) on 12 June 2020; (c) on 15 August 2020.

Having considered the graphs of the obtained temperature values from the monitoring stations, it was found that the values at the observation point "KrAZ" are maximum on all the studied data. It was decided to study the interpolation maps excluding the observation point "KrAZ". Figure 3 a, shows the interpolation by LST on 15 August 2020, this date is chosen as with the greatest coincidence of the data on LST and air temperature. Figure 3b shows interpolated map of air temperature from monitoring stations, and 3c is information about PM 2.5 in the atmospheric air in Krasnoyarsk.



a *b* *c*

Fig.3. Interpolated map on 15 August 2020. (a) by LST image retrieved by Landsat 8; (b) the air temperature from monitoring stations; (c) PM 2.5 from monitoring station.

4 Conclusions

An integrated approach to the study of the urban environment allows us to expand our understanding of the interaction of various factors, for example, industrial facilities, deforestation, difficult landscape, and the state of the environment.

The exclusion of observation points with abnormal temperature rises allows you to see other important parts of the city on interpolation. Taking into account the irregularity of obtaining remote sensing data, usually 3-4 cloudless images per season, it is important to determine constant UHI (preserved for 10 years) and find their relative position with the LCZ. General trends persist, both in the study of LST and the interpolation of air temperature. Studying the readings of pollution, it can be seen that the influence of industrial facilities spreads pollution much further than their territory.

Geospatial and remote sensing tools for urban studies provide an opportunity to plan urban development phases to mitigate the UHI effect. In the following works, socio-economic indicators, such as population density, can be used.

References

1. O. V.Antonenko, V. A. Bezrukikh, E. V.Avdeeva, E. I. Nazarova, A. M. Kislenko Landscape features of the city of Krasnoyarsk as a geological and geomorphological basis for urban planning // Conifers of the boreal area. Vol. XXXV, No. 1-2, P. 15-20 (2017)
2. Grimm, N.B.; Faeth, S.H.; Golubiewski, N.E.; Redman, C.L.; Wu, J.; Bai, X.; Briggs, J.M. Global Change and the Ecology of Cities. S., 319 (2008)
3. Adjustment of the free volume of maximum permissible emissions for the city of Krasnoyarsk [Electronic resource]– http://krasecology.ru/About/PDV (accessed on 24.06.2021).
4. Avdeeva E.V., Wagner E.A., Izvekov A.A. Landscape resources - the basis for the formation of urban greening systems (for example, the city of Krasnoyarsk and its green zone) [Text] // Bulletin of BSU. **2**. 85-90 (2012)
5. Mokrinets K.S. Microclimatic potential of the relief of the territory of the city of Krasnoyarsk as a condition for the formation of the quality of the surface layer of the atmosphere [Text] / K.S. Mokrinets // Bulletin of the Krasnoyarsk State Pedagogical University. V.P. Astafieva. No. 4. P. 295-300 (2011)
6. Landsat 8-9 Calibration Validation Algorithm Description Document [Electronic resource] – https://www.usgs.gov/media/files/landsat-8-9-calibration-validation-algorithm-description-document (accessed on 08.11.2021).
7. Matuzko A.K., Yakubailik O.E., Urban heat island effects over Krasnoyarsk obtained on the basis of Landsat 8 remote sensing data, E. and E. S., **211**, (2018)
8. Samsonov T.E., Trigub K.S., Mapping of local climatic zones of Moscow from space images. G. and C. **6**, 14-25 (2018).
9. Oke, T.R.; Mills, G.; Voogt, J.A. Urban Climates; C. U. P: Cambridge, UK (2017)