The Study of the Temperature Regime of the Novosibirsk Agglomeration According to the Satellite Sensing Data

Polina V. Voronina[1,2], Dmitri L. Chubarov[1]; Nikolai N. Dobretcov[3]

[1] Institute of Computational Technologies SB RAS, Novosibirsk, Russia, pol.voronina@gmail.com
[2] Novosibirsk State University, City2, Novosibirsk, Russia
[3] Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, nickdobretsov@gmail.com

Abstract. The paper presents the first results on the study of the temperature regime of the Novosibirsk agglomeration according to the data of satellite sensing.
Keywords: MODIS, satellite remote sensing data processing, Land Surface Temperature (LST), statistical deviations, method RST (Robust Satellite Technique).

1 Introduction

Currently, more than half of the world's population is concentrated in cities, which is growing every year. The construction in cities is increasing, due to economic reasons, the connection between large settlements and the small settlements surrounding them is being strengthened, thereby forming an urban agglomeration. By urban agglomeration we mean a compact cluster of settlements, mainly urban ones, in places that grow together, combined into a complex multicomponent dynamic system with intensive production, transport and cultural ties. The developing urban agglomeration has a powerful impact on the natural environment: there is pollution of water, air, soil; atmospheric processes are changing. Stable positive air temperature anomalies formed on the territory of cities are called "heat islands". This phenomenon was first described as early as the 19th century; it arises as a result of the entry into the atmospheric air of various impurities from industrial facilities, transport, and other sources of atmospheric pollution and a decrease in its transparency. As a result of development, the proportion of absorbed solar radiation increases compared to natural landscapes. Due to the reduction of areas with open soil cover and green spaces, the heat consumption for evaporation is reduced, which leads to an increase in the heat balance.

In addition to the formation of the urban "heat island", an increase in surface temperature occurs. The temperature regime of this complex natural-anthropogenic complex is one of the tools in the study of the ecological condition of the territory [1–4]. A comparison of surface temperatures in cities with suburban temperatures, ecological and geographical mapping of urbanized territories was proposed in [5, 6].

In the process of studying the surface temperature of the urban agglomeration and adjacent territories, one of the sources of information may be satellite imagery data taken in the thermal infrared range [7–9]. It is reasonable to use data of average spatial resolution (about 1 km) as such data (for example, data obtained from the MODIS spectroradiometer installed on the Terra satellite) [4, 5, 10, 11]. The advantage of using such materials is their high repeatability. And, despite the low spatial resolution, such data make it possible to conduct studies not only of the urban "heat island", but also of its effect on the surroundings, and make it possible to assess the total thickness and extent of such a "thermal island" [4, 10].

The present work is devoted to the study of the temperature regime of the Novosibirsk agglomeration and its environs according to the data of remote sensing of average spatial resolution (MODIS / Terra). To do this, it is supposed to analyze the average in a pixel surface temperature of the Earth obtained from remote sensing data for various time intervals. To obtain a more informative picture of the surface temperature distribution within the agglomeration, the spatiotemporal series of temperature data will be studied in order to identify outliers in the series according to the Robust Satellite Technique (RST) algorithm [12, 13].

The Novosibirsk city agglomeration is a leader in the development of large urban areas in the Asian part of Russia, formed around the center of the Novosibirsk region of Novosibirsk. The core of the agglomeration is formed by the cities of Novosibirsk, Berdsk, Iskitim, Ob, the working village of Krasnoobsk and the science city of Koltsovo. There are still small villages surrounded by urban areas, but not administrative urban units (Fig. 1). Novosibirsk agglomeration covers an area of more than 36 thousand square meters. km, which is home to more than 2 million people. A characteristic feature of the Novosibirsk city agglomeration is its pronounced monocentricity: Novosibirsk is much larger than all the other settlements included in its composition combined.

An information infrastructure is being developed at ICT SB RAS, which provides storage, archiving and user access to Earth remote sensing data [14]. In contrast to the traditional unloading of individual scenes from archives

and connection to a geographic information system, which allows visualizing data in the form of sets of thematic layers, but makes it difficult to use a large number of satellite images using complex processing functions, the hVault technology proposed in [14] provides virtual integration of in the data archive in a relational DBMS. This technology is based on the principle of presenting data in the form of a set of tables containing satellite image data or information products built on their basis, with the subsequent implementation of algorithms for analyzing spatio-temporal series by means of a DBMS.

To solve this problem, we used products obtained as a result of processing data from Terra / MODIS devices. The temperature values reconstructed from the measurements of the intensity of infrared radiation recorded in channels 31 (wavelength - 11 μm) and 32 (wavelength - 12 μm) based on the algorithm [15] constitute MOD11A1 information products. The data contained in MOD11A1 are presented on a regular grid in a sinusoidal projection with a cell size of about 1 km. Under good atmospheric observation conditions, the algorithm [15] ensures the accuracy of temperature recovery within 1 K.

Figure 1. Novosibirsk agglomeration with suburbs.

The analysis of the spatiotemporal series of the surface temperature of the territory of the Novosibirsk agglomeration was carried out according to the calculated average temperature in pixel for each calendar year from 2001 to 2014 (data taken from the ICT SB RAS archive) for the whole year; for a snowless period from April 1 to October 31; for the winter period from November 1 to March 31. As an example of the results of the study, we consider the period from April 1, 2006 to March 31, 2007, which we will divide into two: "conditionally" snowless from April 1 to October 31, 2006 and "conditionally" snowy from November 1, 2006 until March 31, 2007 (the term "conditionally" appeared due to the fact that in different years the establishment of snow cover and its disappearance even within the city occur on different days).

The process of studying the temperature regime of the Novosibirsk agglomeration consistently consisted of solving the following problems:

1. assessment of the spatial structure of the surface temperature of the territory from the position of its heterogeneity by the average temperature in a pixel over a period;
2. obtaining comparative estimates of surface temperature in different seasons by the average temperature in a pixel for a period;
3. revealing the structure of the thermal field in the city of Novosibirsk by the average temperature in a pixel;
4. identification of thermal anomalies, which are statistical outliers in the spatiotemporal series of surface temperature data, according to the Robust Satellite Techniques (RST) method;
5. Testing the hypothesis of the presence of the "heat island" in the city of Novosibirsk and the settlements included in the Novosibirsk city agglomeration.

2 Discussion

Consider the results for each task.

1. In fig. Figure 2 shows the distribution of the average temperature in a pixel for a calendar year and from 2001 to 2014. The structure of the thermal field, as expected, is heterogeneous. The first thing that attracts attention is the

“warm” water surfaces (Ob reservoir, Berdsky Bay and the Ob River). The minimum average temperature in the study area was –6.3 ° C, the maximum: + 1.7 ° C. Further, we note a higher average surface temperature in comparison with the surrounding area inside the city of Novosibirsk (we will talk about the temperature distribution inside the city in more detail later). The average temperature inside the city limits exceeds the average temperature of remote areas by 4–6 degrees. It can also be seen that the average surface temperature inside small cities and settlements that are part of the Novosibirsk agglomeration (Berdsk, Gorny, Kolyvan, Kochenevo, Chik) is 2–4 degrees higher than the average temperature of nearby territories, but lower than in Novosibirsk (approximately the same as on the outskirts of Novosibirsk). But in Iskitim, the average temperature is close to the average temperature in Novosibirsk, the difference is 1-2 degrees.

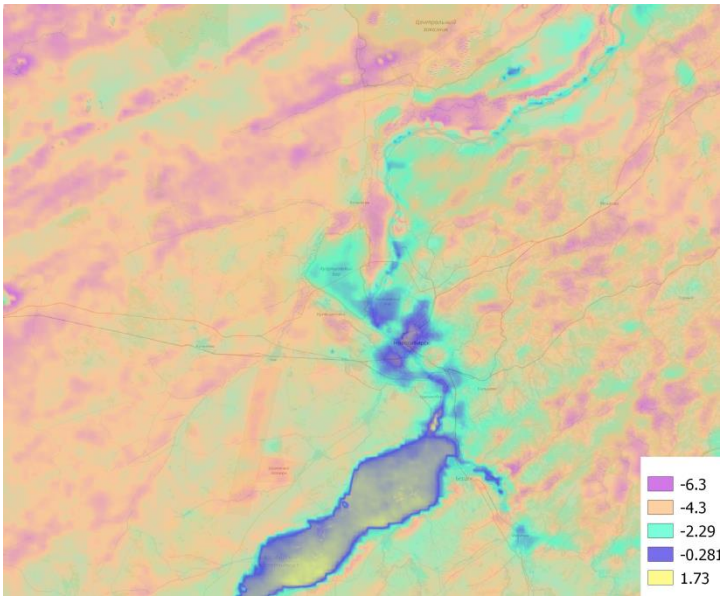
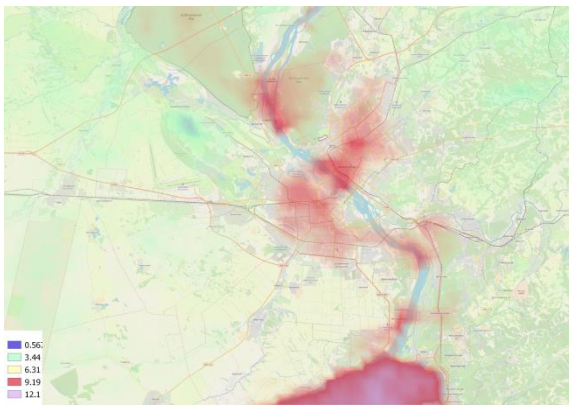


Figure 2. Distribution of average temperature in a pixel from January 1, 2001 to December 31, 2014 (temperature is indicated in degrees Celsius).

2. From April 1 to October 31, 2006, within the analyzed range covering Novosibirsk and its environs (Fig. 1), the average surface temperature varied from + 0.5 ° C to + 12 ° C. In most of the territory, the average temperature in a pixel is below + 6.3 ° C. In the territory of Novosibirsk, the average temperature is unevenly distributed. Most of the city’s territory has a surface temperature of + 8 ° C to + 11 ° C (Fig. 3, a). In the cities of Berdsk and Iskitim, the average surface temperature is + 8-9 ° C, which is comparable to the average temperature in Novosibirsk. Whereas the average temperature in a pixel for the indicated snowless period in the city of Ob and in small villages (Gorny, Kolyvan, Koltsovo, Kochenevo, Krasnoobsk, Moshkovo, Chik) does not differ from the temperature of neighborhoods with no urban development.

Consider the period from November 1, 2006 to March 31, 2007, when snow cover is established almost annually in the study area and winter begins. Average surface temperature in 2006–2007 varied from –21.5 ° C to –10.7 ° C. In most of the territory, the average temperature in a pixel is below –18 ° C. In cities of regional subordination (Berdsk, Iskitim, Ob) and small villages (Gorny, Kolyvan, Koltsovo, Kochenevo, Krasnoobsk, Moshkovo, Chik) the average temperature in a pixel is higher: about –16 ° C. In the territory of Novosibirsk, the average temperature is unevenly distributed. Most of the city’s territory has a surface temperature of –12.5 to –13.5 ° C (Fig. 3, b).

а)



б)

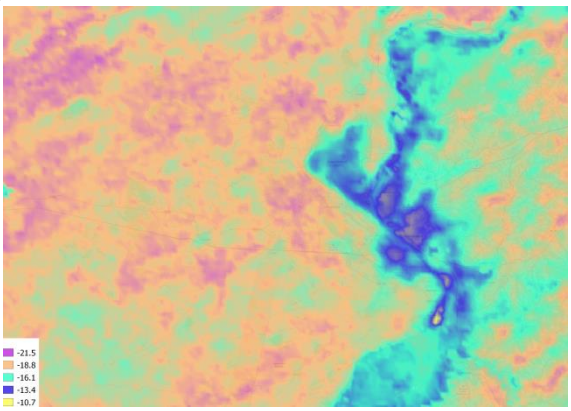


Figure 3. The distribution of the average temperature in a pixel: a) from April 1 to October 31, 2006, b) from November 1, 2006 to March 31, 2007 (temperature is indicated in degrees Celsius).

3. In fig. Figure 4 presents a fragment of the map of Novosibirsk with the presentation of only two intervals with the highest temperature for the winter period (above –13 ° C), which allows us to identify the structure of the heat field in the city. On the territory of the main subject of agglomeration - the city of Novosibirsk - there are several areas with a higher average temperature in relation to the rest of the territory: this is Zaeltsovsky Park, a part of the city bounded by Dusi Kovalchuk, Vladimirovskaya, Factory, Nikitina, Volochaevskaya, Uchitelskaya, George Kolonda. In the left-bank part of the city, an area stands out, bounded by the streets of Nemirovich-Danchenko, Stantsionnaya, with a higher average temperature relative to the whole part of the city.

4. For completeness of the study of the distribution of the thermal field of urban agglomeration, an analysis was made of the spatiotemporal series of surface temperature of the territory of the Novosibirsk agglomeration according to the RST method (Robust Satellite Techniques) [12] in order to identify statistical emissions. The method is based on a statistical analysis of satellite data sets of the Earth's surface temperature for a selected area. To eliminate the influence of the seasonal variation in temperature and heterogeneity of the relief, data is converted. First, the time interval of interest to the researcher is recorded, the temperatures are extracted on these days of the year for several years. Next, the RST index is calculated for the selected area. The main advantage of the index is that when choosing a region and a time interval of suitable sizes, it eliminates the influence of temperature variations caused by climatic processes, heterogeneity of the relief, and weather conditions [13,16]. In [16], the authors proposed a modification of the RST method by calculating the cumulative sum of index values recognized as anomalous, i.e. the index values that exceed the so-called threshold value are summed, in our case it is 2. At the same time, the number of days with an anomalous index value is also considered. The modified technique makes it possible to isolate abnormal manifestations that occur several times during the studied time interval, but manifest on different days.

Figure 4. The distribution of the average temperature in a pixel from November 1, 2006 to March 31, 2007. in Novosibirsk (temperature is indicated in degrees Celsius).

The RST method was applied for each year, from 2001 to 2014, and for each period: from April 1 to October 31 and from November 1 to March 31.

The result of 2006 from April 1 to October 31 is interesting. This year, during the considered time interval, thermal anomalies were revealed that manifested themselves in different areas of Novosibirsk: on the territory of Kudryashovsky Bor, Krivodanovka, almost the entire territory of the city turned out to be anomalous with varying degrees of intensity. Ob city was also abnormal. Chik, Kochenevo, Kolyvan, Gorny, Iskitim, a little bit of Berdsk.

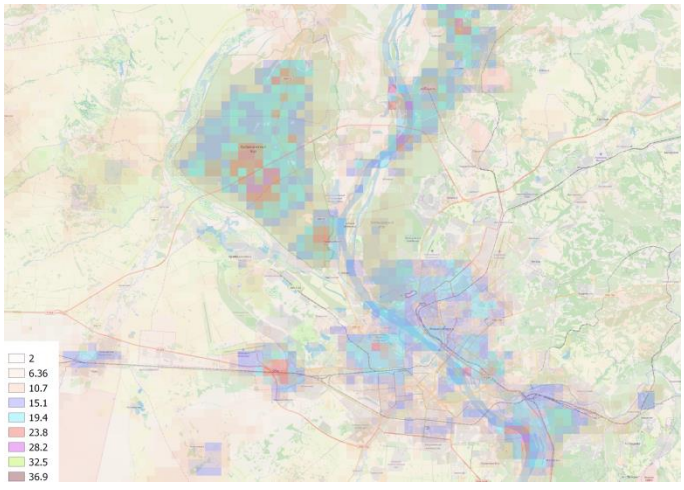


Figure 5. Fragment of a map of Novosibirsk with a cumulative sum of anomalous index values for the period from April 1 to October 31, 2006.

5. Based on the results of the research, the hypothesis of the existence of the urban “heat island” for the city of Novosibirsk and for the city of Iskitim was confirmed. However, for smaller urban formations, “heat islands” were not found.

3 Conclusion

The problem of the "thermal islands" of cities is becoming especially relevant at the present stage of the development of science in connection with the contribution of cities to processes affecting the ecology of the territory. Thermal images reveal the spatial structure of the “thermal islands” of cities. Such data may be images obtained from the MODIS spectroradiometer installed on the Terra satellite. Despite the low spatial resolution of such images, there is an advantage of the applicability of these materials in the study of the temperature regime of urban agglomeration. This is a high repeatability and two shooting channels of thermal infrared shooting. A wide coverage and low spatial resolution make it possible to conduct studies not only of the "thermal island" of the city, but also to evaluate its impact on the surroundings, the total thickness and extent of such a "thermal island".

For the first time, according to space monitoring, an analysis of surface temperature for the Novosibirsk city agglomeration has been performed. The structural features of the heat field in summer and winter, as well as the limits of the territorial variability of the temperature of the urban surface are established. The thermal field within the city is very heterogeneous.

Revealing the structure of the thermal field of the Novosibirsk agglomeration will allow, in the authors' opinion, sound planning of the territory development taking into account the requirements for creating a comfortable living environment.

References

[1] Матузко А.К., Якубайлик О.Э. Мониторинг температуры земной поверхности территории Красноярска и окрестностей на основе спутниковых данных Landsat-8 // Успехи современного естествознания. – 2018. – № 7 – С. 177-182.

[2] Кораблёва Е.Г., Ленская О.Ю. Исследования острова тепла города Челябинска в зимний период // Вестник Челябинского государственного университета. Экология. Природопользование. 2010. № 8 (189). Вып. 4. С. 15–23.

[3] Погорелов А.В., Липилин Д.А. Тепловой «портрет» города Краснодара по данным спутниковых снимков // Вестник ПНИПУ. Прикладная экология. Урбанистика. 2016. № 4. С. 32–45.

[4] Cheval S., Dumitrescu A. The July urban heat island of Bucharest as derived from MODIS images // Theoretical and Applied Climatology. 2009. № 96. P. 145–153.

[5] Pu R., Gong P., Michishita R., Sasagawa T. Assessment of multi-resolution and multi-sensor data for urban surface temperature retrieval // Remote Sensing of Environment. 2006. № 104. P. 211–225.

[6] Коновалова Т.И., Трофимова И.Е. Картографирование экологического состояния урбанизированных территорий на основе материалов дистанционных исследований Земли // Исследования Земли из космоса. 2008. № 4. С. 36–44.

[7] Voogt J.A., Oke T.R. Thermal remote sensing of urban climates // Remote Sensing of Environment. 2003. № 86. P. 370–384.

[8] Weng Q. Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends // ISPRS Journal of Photogrammetry and Remote Sensing. 2009. № 64. P. 335–344.

[9] Weng Q., Quattrochi D.A. Thermal remote sensing of urban areas: An introduction to the special issue // Remote Sensing of Environment. 2006. № 104. P. 119–122.

[10] Hung T., Uchihama D., Ochi S., Yasuoka Y. Assessment with satellite data of the urban heat island effects in Asian mega cities // International Journal of Applied Earth Observation and Geoinformation. 2006. № 8. P. 34–48.

[11] Stathopoulou M., Cartalis C. Downscaling AVHRR land surface temperatures for improved surface urban heat island intensity estimation // Remote Sensing of Environment. 2009. № 113. P. 2592–2605.

[12] Tramutoli V., Di Bello G., Pergola N. and Piscitelli S. Robust satellite techniques for remote sensing of seismically active areas / // Annals of Geophysics. 2001. 44(2). P. 295–312.

[13] Corrado R., Caputo R., Filizzola C., Pergola N., Pietrapertosa C., Tramutoli V. Seismically active area monitoring by robust TIR satellite techniques: a sensitivity analysis on low magnitude Earthquakes in Greece and Turkey // Natural Hazards and Earth System Sciences. 2005. № 5. P. 101–108.

[14] Шокин Ю.И., Добрецов Н.Н., Мамаш Е.А., Кихтенко В.А., Воронина П.В., Смирнов В.В., Чубаров Д.Л. Информационная система приема, обработки и доступа к спутниковым данным и ее применение для решения задач мониторинга окружающей среды // Вычислительные технологии. 2015. Т. 20. № 5. С. 157–174.

[15] Wan Z., Dozier J. A generalized split-window algorithm for retrieving land-surface temperature from space // IEEE Trans. Geoscience and Remote Sensing. 1996. Vol. 34. № 4. P. 892–905.

[16] Воронина П.В., Чубаров Д.Л., Добрецов Н.Н. Развитие метода RST (Robust Satellite Technique) для выявления аномалий температуры поверхности на территории Горного Алтая // Интерэкспо Гео-Сибирь. 2018. Т. 4. № 1. С. 64–73.