The specific features of the thermal radiation of lake Kenon during freeze-up in the infrared band

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Abstract. This work is the study of the infrared images of Lake Kenon located in the city of Chita. The images were obtained from a satellite Lansat-8. The images revealed the thermal anomalies of the said internal water body. The anomalies consisted in the fact that areas of open water having negative temperature are formed in the lake in the winter period. The phenomenon may be caused both by surface supercooling of the lake water and by formation of water aerosol at the temperature below 0°C. The emergence of areas with supercooled water may be, paradoxical as it may sound, due to the impact of the thermal power plant located near the lake. Its functioning prevents formation of the ice cover, especially at the locations of warm water discharge. Analysis of the satellite images in the IR-band obtained over the recent five years has shown the area of the higher water temperature on the lake surface not to exceed 10% of the total area of the lake. The time before the freeze-up in the absence of wind, October – November, is the best time for revealing the maximum temperature difference.

1. Introduction

Over the recent years, climate warming has accelerated all over the world, which is especially visible in the Arctic zone of the Russian Federation, which the temperature has risen by 1.2 °C…1.5 °C in the last decade [1]. This naturally leads to the rise of water temperature in internal water bodies, for example, in lakes. Climate warming may result in increased concentration of blue-green algae in the aqueous environment, which will lead to appearance of toxins in the water [2], and, consequently, to degradation of the ichthyofauna in the water lake.

In addition to the natural rise of water temperature related to the global trend, the rise of temperature in the water bodies may be also caused by the anthropogenic impact, for example, from a nearby anthropogenic source of heat. Investigating such sources of thermal contamination and their impact on the environment is a relevant task for scientists.

Sampling water from the water bodies and studying the water samples using direct methods do not always ensure the required effect. This is associated with the small spatial coverage of the area of the water body. Remote sensing with space satellites using different wavelengths: from radio waves to visible band radiation – comes to help in the monitoring of internal water bodies. In particular, in the microwave band, it is possible to reveal the contamination spots in the water bodies in the winter period by the thermal radiation of the ice cover of lakes, rivers and water reservoirs. This radiation will have the increased value of the radio brightness temperature, which characterizes the intensity of
the water body’s thermal radiation. Such a method of investigating the contamination spots has been described in [3, 4].

In the thermal IR-band (with wavelengths 8…14 µm), thermal anomalies on the surface of a water body may be registered using artificial satellites. The examples of revealing thermal contaminants based on survey in the IR-band have been provided in many studies, for example, in [5]. Active use of this band in remote sensing of the Earth with rather high spatial resolution allows scientists to measure the thermodynamic temperature of the thin surface layer of the medium under study. In addition, regular acquisition of data from different space apparatuses allows continuous monitoring of a water body to be conducted during a long period of time. Equally important are the relevance of the data obtained from the satellites and the high speed of their processing. Comparison of the satellite images in the visible and infrared bands allows us to obtain additional information about the water body under study.

In the winter season, many internal water bodies of different countries (Canada, northern China, Russia, etc.) are covered with ice. Resulting from anthropogenic impact or inflow of underground warm water sources into a lake, water reservoir or river, areas of water free from ice may exist in the water body. For this reason, the thin surface layer of water may have the temperature below the water-ice phase transition temperature, indicating that supercooled water having a number of surprising physical and chemical characteristics may be formed. The appearance of such water will be related to the impact of cold air on the water surface.

Thus, the specific features of the infrared radiation in the cold season are assumed, which requires development of the methods of revealing thermal anomalies in internal water bodies using remote sensing methods.

2. Methods and Results

In this study, satellite images of the freshwater Lake Kenon situated in Zabaikalsky krai, Russia, in the IR-band, obtained from the Landsat-8 space satellite (channel 10) were analyzed. The lake is situated in the territory of the city of Chita. It is stretched from east to west, its length is 5.7 km×2.8 km, and the biggest depth is 8 m. The freeze-up period on the lake lasts from early November to early May. Thickness of the ice cover reaches 150 cm; however, in the area of the Chita thermal power plant-1, located on the shore of the lake, part of the lake is not covered with ice. An example of such a thermal image of the lake is shown in figure 1. To make perception more convenient for the viewer, we averaged the temperature values on the lake surface.

As seen from the satellite image provided, the maximum gap in the temperature of the lake water surface is reached in the autumn period before the freeze-up. This phenomenon may be explained by the fact that the ice has not yet covered the water surface of the lake but, due to the beginning of the heating season in the apartment buildings of Chita, the production capacity of the Chita thermal power plant-1 are somewhat higher than normal, leading to increased discharge of warm water into the lake. The temperature difference between the maximum and minimum values of the temperature of the water surface reaches 5 °C...6 °C. It is noteworthy that over the recent five years, this figure has remained constant, suggesting stability of the discharge of warm water into the lake. In the summer season, this temperature difference reaches only 1 °C...2 °C. In winter and in spring, it is difficult to measure its value, as the greater part of the lake is covered with ice. However, the temperature gradient near the open part of the lake does not exceed 5 °C...6 °C, either.
If we analyze the data from the satellite images obtained before the beginning of the freeze-up, its existence and degradation, a number of interesting details may be seen. Shown in figure 2 are the results of thermal survey (B) and the images taken at the same time in the visible band (A) from the same satellite (Landsat-8).

In the visible band, formation of the ice cover, its evolution and degradation are observed. As seen from the satellite images, during the freeze-up period, the area of the open water surface of the lake decreases to reach its minimum value in February, before the beginning of the destruction of the ice cover. In the middle of March, the ice cover the water body has the minimum value of the albedo, which is related to formation of capillaries in the ice, along which water rises to the ice surface. In addition, the surface water is formed as a result of snow melting. As a result, ice turns out to be filled with water, leading to the decrease of albedo. After increase of the diameter of the capillaries in the ice cover, water leaves the upper surface of the ice, resulting in its dry-up. This leads to the increase of albedo due to radiation dissipation, which can be seen, for example, from the satellite image taken on April 16, 2020. In the images taken in November (another freeze-up period of 2018-19), the value of the albedo of the ice cover is lowest, which, however, is related to the absence of snow on the ice cover.

Thus, it is not possible to discover the presence of the ice cover on a water body if the ice on its surface is not covered with snow and if the wide network of cracks caused by thermal impact on it or by external loads on ice, like transport traffic, seismic and wind impacts, etc., is missing.

The images taken in the IR-band well demonstrate the distribution of the water surface temperature in the freeze-up period. The temperature of the upper layer of the clouds observed during the photography of the lake can be observed on the image taken on October 23.

**Figure 1.** Distribution of the average temperature (T) of the surface water of Lake Kenon in October 23, 2019.
Figure 2. Satellite images obtained from the Landsat-8 satellite showing the water surface of Lake Kenon in the freeze-up period of 2019-2020. A – the image taken in the visible band; B – the image taken in the IR-band (wavelengths 8…14 µm). On top of each image, its date is indicated.
The satellite image taken on January 11, 2020 should be considered. On that day, according to the meteorological data provided, the minimum air temperature in the city of Chita in the area of Lake Kenon was registered. The night air temperature on that day dropped to $-30^\circ C$, while the day air temperature was $-20^\circ C$. In this period, a segment of the surface of Lake Kenon free from ice seemed to be supercooled to $-9^\circ C$. This phenomenon may be related to supercooling of the surface layer of water, cooled down due to interaction with the adjacent cold air. On the other hand, this effect may take place due to existence of water aerosol over the water surface, emerging as a result of evaporation of water from the water surface and condensation of water vapor in the atmosphere. In the framework of this study, this issue is not examined in detail.

As a result of the study, we discovered supercooled water of the water surface or a layer of supercooled drops in the aerosol over the water surface. In any case, for such an effect to exist, low air temperatures are required.

Analysis of the data of the recent five years produced the following results, The area of the warm spot on the water surface does not exceed 10% of the total area of the lake in the autumn period, before the beginning of the freeze-up. The area of the spot varies insignificantly, but, exposed to external factors, like winds and water currents, the spot changes its location, At the same time, the source of the thermal radiation is in a stable position, near the power plant.

It is to be noted that Lake Kenon, compared to the other nearest water bodies located near Chita, has a somewhat higher temperature value (as a rule, not exceeding 2 °C) in the summer time. This proves once again that the city water bodies are subject to the urban impact, including the thermal impact.

A large amount of filamentous algae are found near the thermal power plant. This sector was found to be most contaminated in the water body [6]. Indirectly, it is possible to reveal, by satellite images obtained in the IR-band, the areas of the most contaminated water in the city water body.

### 3. Conclusion

Thus, by the example of Lake Kenon located in the territory of Chita, the place of discharging warm water was revealed, related to the presence of the thermal power plant located on the shore of the lake. It has been found that the optimal time for discovering thermal anomalies is the period between the freeze-up in the absence of wind. Analysis of the meteorological data of the recent five years has shown that the area of the warmed water does not change and that the difference between the cold and warm segments of the lake surface does not exceed 6 °C. The area of the warm spot does not exceed 10 % of the total area of the lake surface. Under conditions of the city water body, the space satellite images of the water body surface were instrumental in the discovery of supercooled water having the temperature reaching $-9^\circ C$ (according to the radiation data).

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