Analysis of Temporal and Spatial Variation Process of Dianchi Lake Surface Water Temperature Based on MODIS Remote Sensing Images

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Abstract. Lake surface water temperature (LSWT) is an important physical attribute that affects the ecological environment of lakes. It plays an important role in the ecological process of the water environment and directly affects human production and life, the ecological environment system of the water area, and the diversity of organisms. In order to adjust and improve the ecological conditions of the watershed, it is necessary to obtain a large amount of effective lake surface water temperature data, and use this as a basis to analyze the temporal and spatial change process of the LSWT. This study uses MODIS (MOD11A2) surface temperature product data to obtain the LSWT of Dianchi Lake, and then analyzes the temporal and spatial variation characteristics of the LSWT of Dianchi Lake on different time scales (year, season, month) during the day and night. The research results show that the annual, seasonal and monthly average values of the LSWT during the day and night are all increasing from 2001 to 2017. The average annual temperature rise rate of Dianchi LSWT during the day and night is 0.09°C yr⁻¹ and 0.05°C yr⁻¹, respectively. The spatial analysis results show that the LSWT increase area of Dianchi Lake is expanding.

1. Introduction

Lakes are the sentinels of climate change because they are sensitive to climate, respond quickly to changes, and integrate information about changes in watersheds[1]. Dianchi Lake is one of the important lakes in Yunnan Province. In the past 20 years, the rapid increase in population and rapid economic development have accelerated the process of urbanization. Dianchi Lake plays a vital role in urban water supply, industrial and agricultural water, aquaculture, etc. Therefore, the analysis of LSWT has a realistic demand for the governance of Dianchi Lake. The main reason for the lack of effective protection and governance of the Dianchi Lake Basin is that the current understanding of the formation mechanism of urban lake water pollution is insufficient, and the impact of changes in lake water surface temperature on the ecological system balance of Dianchi Lake is ignored. It is necessary to monitor the mechanism of LSWT change from a micro scale, analyze the time and space process of LSWT change from a macro scale, and then control and improve the lake water ecological environment from the source, monitor and...
warn water environment emergencies such as blue algae blooms[2]. And suitable water temperature is a necessary condition for the outbreak of cyanobacteria, so exploring the temporal and spatial dynamic change process of the LSWT of Dianchi Lake is the key to protecting and managing the water environment of Dianchi Lake[3][4].

There are also many research results on lake surface water temperature[5-8]. In 2017, Wei Wan & Huan Li et al. used MOD11A2 data to extract the surface water temperature of 291 lakes on the Qinghai-Tibet Plateau from 2001 to 2015, and processed them to obtain a complete lake surface temperature data set. Compared with the data set measured in situ, the surface water temperature of plateau lakes retrieved by MODIS data has higher accuracy[5]. Based on the boundary of Dianchi Lake extracted from Landsat data from 2001 to 2017, and the surface water temperature of Dianchi Lake retrieved from MOD11A2 data, this study analyzes the temporal and spatial characteristics of the surface water temperature of Dianchi Lake at different time scales (year, season, month) during the day and night.

2. Research area and Methods

2.1. Research area
Dianchi Lake is located in the Xishan District of Kunming City, Yunnan Province (102°10'-103°40'E, 24°23' to 26°22'N) (Figure 1). Dianchi Lake is a lake of earthquake fault subsidence type, distributed in a north-south direction. The lake body is slightly arched, with the back of the arch facing east. The altitude of the lake is 1886 meters, the north-south length is 39 kilometers, the east-west width is 13 kilometers, the average water depth is 5.12 meters, and the area is 306.3 square kilometers. With the acceleration of economic development and urbanization in the Dianchi Lake Basin, the population has increased rapidly, and the amount of pollutants produced in Dianchi Lake has increased rapidly. The water pollution of Dianchi Lake began in the middle and late 1970s. By the 1980s, especially in the 1990s, the eutrophication of the water body of Dianchi Lake became more and more serious. There are 29 main rivers entering the lake in Dianchi Lake, but the water quality is mostly inferior to Class V.

2.2. Data sources
This study uses Landsat-8 satellite remote sensing data to extract the water boundary of Dianchi Lake. Landsat-8 is obtained from the Geospatial Data Cloud (http://www.gscloud.cn), with a spatial resolution of 30m. The surface water temperature of Dianchi Lake is extracted from MOD11A2 (Terra LST level3) remote sensing images, and the data is obtained from the Geospatial Data Cloud (http://www.gscloud.cn). MOD11A2 is a composite surface temperature product of MOD11A1 (1 scene per day) every 8 days, with a time resolution of 8 days and a spatial resolution of 1km.
2.3. Methods

2.3.1. Boundary extraction method of Dianchi Lake
Mcfeeters proposed the Normalized Difference Water Index (Normalized Difference Water Index, NDWI) in 1996[9], use the remote sensing image to perform normalized difference processing with a specific band to highlight the water information in the image. Xu Hanqiu proposed an improved Normalized Difference Water Index (MNDWI) in 2005, experiments on the index were carried out on remote sensing images containing different types of water bodies, and most of them obtained better results than NDWI, especially in the extraction of water bodies within the city[10]. NDWI index images are often mixed with urban construction land information, which expands the scope and area of the extracted water bodies. MNDWI is better than NDWI to reveal the subtle characteristics of water bodies, such as the distribution of suspended sediments and changes in water quality. In addition, MNDWI can easily distinguish between shadows and water bodies, which solves the difficult problem of removing shadows in water body extraction. Therefore, this study uses MNDWI to extract the boundary of Dianchi Lake.

\[
\text{MNDWI} = \frac{(P(\text{Green}) - P(\text{MIR}))}{(P(\text{Green}) + P(\text{MIR}))}
\]

2.3.2. Extraction process of LSWT of Dianchi Lake
Use MODIS Reprojection Tool (MRT) to resample the acquired MOD11A2 remote sensing image data into 1km resolution image, reproject, mosaic and convert to GeoTIFF format, and replace the pixel value affected by the cloud with Null; Extract the pixel value of the LSWT in the MOD11A2 remote sensing image data using the processed lake boundary file. Use the raster calculator in the ArcMap toolbox to perform raster calculations to convert the DN value to degrees Celsius. The formula is: \[ T = P \times 0.02 - 273.15 \], where P is the remote sensing image pixel value, and T is degrees Celsius; Dealing with missing values and outliers.

2.3.3. Trend Analysis
The trend of the LSWT of Dianchi Lake under different time scales is analyzed. Based on the LSWT data of Dianchi Lake from 2001 to 2017, a univariate linear regression equation was established for the results to analyze the change trend of the LSWT. R2 is the square value of the trend line, between 0 and 1.

3. Results and analysis

3.1. The temporal and spatial changes of the LSWT of Dianchi Lake

3.1.1. Monthly average change of LSWT of Dianchi Lake
During the day, the monthly average LSWT of Dianchi Lake showed a downward trend in April and August, and all other months showed different upward trends. The upward trend was obvious in May, June, September, October, November, and December. During the day, the monthly average LSWT of Dianchi Lake is the lowest in January (Tmin=20.4℃) and the highest in May (Tmax=29.6℃). At night, the monthly average LSWT of Dianchi Lake showed a downward trend in February, April, July, and August, and all other months showed different degrees of upward trend. At night, the monthly average surface water temperature of Dianchi Lake is the lowest in January (Tmin=12.5℃) and the highest in July (Tmax=23.7℃).

3.1.2. Seasonal average change of LSWT of Dianchi Lake
The seasonal changes in the LSWT of Dianchi Lake during the day from 2001 to 2017 showed an overall upward trend (Figure 2a). The rising trend of LSWT in Dianchi Lake during the day is weak in spring. The LSWT of Dianchi Lake during the day fluctuates greatly in summer, and there are three obvious inflection points. The LSWT of Dianchi Lake during the day reached the lowest temperature of 23.9℃.
in 2009 and the highest temperature of 29.7 °C in 2012. During the day, the average LSWT of Dianchi Lake in autumn showed a continuous upward trend, with the lowest and highest values appearing in 2001 and 2015 respectively. During the day, the LSWT of Dianchi Lake showed an upward trend in winter, and there was a slight downward trend in 2004, 2007, 2011, and 2015.

At night, the seasonal change of the surface water temperature of Dianchi Lake has a relatively stable overall upward trend, and the temperature fluctuation range is also relatively small (Figure 2b). The summer LSWT of Dianchi Lake at night reached its lowest value in 2006 and reached its highest value in 2012. The average LSWT in summer is the highest among several seasons, and in winter is the lowest, in line with general seasonal changes. The LSWT of Dianchi Lake at night has the most significant increase in autumn, where the fluctuation range of LSWT in winter is the smallest, and the fluctuation range of LSWT in summer is the largest.

![Figure 2](image)

**Figure 2** (a) Seasonal average LSWT change during the day, (b) Seasonal average LSWT change at night.

### 3.1.3. Annual average change of LSWT of Dianchi Lake

From 2001 to 2017, the average annual surface water temperature of Dianchi Lake during the day and night showed an upward trend (day:+0.09 °C yr⁻¹, night:+0.05 °C yr⁻¹) (Figure 3). During the day, the highest annual average LSWT of Dianchi Lake was in 2014 (Tmax=26.8 °C), and the lowest was in 2009 (Tmin=24.6 °C). The highest temperature of the annual average LSWT of Dianchi Lake at night was in 2014 (Tmax=19.9 °C), and the lowest temperature was in 2008 (Tmin=18.5 °C).

![Figure 3](image)

**Figure 3** Annual average LSWT changes during the day and night.
3.2. The spatial distribution characteristics of LSWT of Dianchi Lake
From 2001 to 2017, the annual average LSWT distribution in Dianchi Lake fluctuated to a certain extent, and LSWT showed an upward trend in general, and the areas of warming gradually increased (Figure 4). In 2008, 2015, and 2016, the high temperature area of Dianchi Lake LSWT spread more obviously during the day, and the high temperature area of Dianchi Lake LSWT at night in 2012 was more obvious. During the day from 2001 to 2017, the annual average LSWT high temperature area of Dianchi Lake was mainly in the north, northeast and southwest coasts of Dianchi Lake. The low temperature area was mainly in the deep water area of the central Dianchi Lake, showing a decreasing trend from the lake coast to the lake center. The average annual spatial distribution of LSWT in Dianchi Lake at night is opposite to that in daytime.

![Figure 4](image)

Figure 4 (a) Spatial distribution of LSWT of Dianchi Lake during the day, (b) Spatial distribution of LSWT of Dianchi Lake at night

4. Conclusion
This study uses Landsat data to extract the water body boundary of Dianchi Lake, and processes the MOD11A2 data from 2001 to 2017, and obtains the average value of the surface water temperature of Dianchi Lake during the day and night, as well as the monthly average, quarterly average, and annual average, and analyzes different times the temporal and spatial variation characteristics of the surface water temperature of Dianchi Lake during day and night at different scales. The analysis results of the trend of surface water temperature in Dianchi Lake show that the surface water temperature during the day and night showed an upward trend at different time scales from 2001 to 2017. During the day, the monthly average surface water temperature of Dianchi Lake increased the fastest in June (+0.25°C yr⁻¹), and the monthly average surface water temperature of Dianchi Lake at night increased the fastest in November (+0.11°C yr⁻¹). During the day, the seasonal average surface water temperature of Dianchi Lake increases most significantly in autumn (+0.18°C yr⁻¹), and the seasonal average surface water
temperature of Dianchi Lake at night increases significantly in spring and winter (spring: $+0.05^\circ\text{C yr}^{-1}$, winter: $+0.05^\circ\text{C yr}^{-1}$). From 2001 to 2017, the average annual surface water temperature increase rate of Dianchi Lake during the day was $+0.09^\circ\text{C yr}^{-1}$, and the average annual surface water temperature increase rate of Dianchi Lake at night was $+0.05^\circ\text{C yr}^{-1}$. The spatial analysis results show that the surface water temperature increase area of Dianchi Lake is expanding, showing an expansion from the coast of Dianchi Lake to the center of Dianchi Lake and from the north to the south.

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