Monitoring of Water Level Variations of Bosten Lake based on Ice Cloud and Land Elevation satellite-1/2 Altimetry Data

Ji Miaomiao1,2,a, Hu Shanshan1,d*, Zhang Tao2,e*, Wang Hongxing1,b, Zhou Demin1,c

1Beijing Laboratory of Water Resources Security, College of Resource Environment and Tourism, Capital Normal University, Beijing, China
2Land Satellite Remote Sensing Application Center (LASAC), Beijing, China;
aemail: 2190902110@cnu.edu.cn, bemail:wanghongxing1997@163.com, cemail: zhoudemin@cnu.edu.cn
*dCorrespondence: demail: hushanshan@cnu.edu.cn, eemail: zhangt@lreis.ac.cn

Abstract: Bosten Lake is located in the arid area of China, it has experienced drastic change on water level due to the climate environment changes and human activities. Based on ICESat-1/2 satellite altimetry data, this paper extracted the water level data of Bosten Lake from 2003 to 2020, and analysed the multistage dynamics of water level. The result shows that: the overall water level of Bosten Lake appeared an upward trend from 2003 to 2020, and the annual rate of change was 0.06 m/a. From an annual perspective, the lake’s water level gradually declined from 2003 to 2009, and then continued to rise until 2020. The lake water level fluctuates in a bimodal shape during the year, and March and October are the peak water level months. The research results can provide reference for the comprehensive management of water resources utilization in arid areas.

1. Introduction

Bosten Lake is located at the end of the Kaidu River and the front end of the Peacock River, and is the natural reservoir of the both[1], it is also the key to regional economic and social development and ecological protection. Bosten Lake is increasingly affected by global climate change, increasing human activity and rapid economic development, resulting in the closure of the lower reaches of the Peacock River, the drying up of Lop Nor, the withering of the forest and the rampant wind and sand[2]. This will pose a serious threat to the regional water balance, the ecological environment, and the production and life of surrounding towns[3]. Therefore, it is important to understand and grasp the changes of water dynamics of Bosten Lake and make reasonable regulation and control.

Generally, the water level of lakes is mainly obtained through water level stations, which requires a lot of manpower, material and financial resources, and is inconvenient for large-scale measurement, it’s also susceptible to the influence of temperature and environment leading to the work of water level stations to stop or even damage. With the development of satellite altimetry technology, it has become an efficient means to obtain the water level of lakes. In recent years, altimetric satellites have been widely used in the study of lake water level changes (e.g., ICESat-1, CryoSat-2, EnviSat, Jason). Wu et al.[4]combined with ICESat-1, EnviSat, ERS and Jason altimetry data to analyze the interannual change trend of the water level of Bosten Lake from 1900 to 2015. Zhang et al.[5] used ICESat-1 data to analyze the changes in water level and volume of China’s top ten lakes, and pointed out the water level of Bosten Lake declined at a rate of -0.41 m/a from 2003 to 2009. Although altimetry satellites are widely used to
analyze the interannual changes of lake water levels, the use of altimetry satellites to analyze intra-
annual water level variations in lakes is relatively rare, mainly due to the limitation of satellite operation
cycle and the lack of more continuous monitoring data within the year.

The ICESat-2 (Ice Cloud and Land Elevation satellite-2) laser altimeter satellite was launched by
NASA in September 2018. As the continuation of the ICESat-1 mission, the coverage, sampling density,
vertical resolution and operation period have been greatly improved. In this paper, in order to understand
the changes in the water level of Bosten Lake in recent years, and the difference between the changes
in the water level during the year, grasp the dynamic changes of the water level of Lake Bosten. Based on
the ICESat-1/2 satellite altimetry data, the lake water level information in Bosten Lake from 2003 to
2020 was extracted, and the inter-annual variation of lake water level in Bosten Lake was analyzed. The
continuous observation data of ICESat-2 satellite are also used to analyze the intra-annual water level
variation characteristics of the lake. It provides a reference for the rational regulation of water resources
in Bosten Lake.

2. Materials and Methods

2.1. study area
Bosten Lake is located in the Bazhou region of Xinjiang, China, and is the largest inland freshwater lake
in China. (86°19′~87°28′E, 41°46′~42°08′N), with a total area of about 1646 km². Bosten Lake has
sufficient light, dry climate and little rainfall throughout the year. It is a common warm temperate arid
desert climate in arid areas[6]. The annual average temperature is 10.4℃, the average annual precipitation
is 188.1 mm, and rainfall occurs frequently from May to September[7]. Bosten Lake is a reservoir of
water resources in Bazhou, which plays a role in regulating river runoff in the basin.

Figure 1 Schematic diagram of Bosten Lake and its basin

2.2. Data source and methods

2.2.1. Data source. ICESat-1/2 altimetry data is used as lake water level data, provided by the NSIDC
(National Snow and Ice Data Center, https://nsidc.org/). The main mission is to monitor changes in the
polar and Greenland ice sheets of the satellite, but it is also widely used in atmospheric monitoring and
terrain and vegetation monitoring. The ICESat-1/2 satellite can provide lake water level data for the two
time periods 2003-2009 and 2018-2020. ICESat-1 satellite is equipped with advanced GLAS
(Geoscience Laser Altimeter System), it has a wide range of spatial coverage, dense sampling points
and high vertical resolution, can obtain high-precision water level monitoring data[8, 9]. As a continuation
of ICESat-1 mission, was launched in 2018 with ATLAS (Advanced Topographic Laser Altimeter
System) of ICESat-2. ICESat-2 is close to three-dimensional space observation, which improves the
accuracy of ground elevation measurement in time and space. The spatial coverage of ICESat-2 is more
than three times higher than ICESat-1, and the surface elevation accuracy can reach 10 cm. The multi
beam system and micro pulse radar technology of photon counting can ensure the accuracy of elevation
measurement. The comparison of ICESat-1 and ICESat-2 parameters is shown in Table 1.
This paper uses ICESat-1/GLAH 14 global land elevation data and ICESat-2/ATL13 global inland lake altimetry data. The dataset contains multiple parameters such as surface height, location, acquisition time, and related quality control information. Through data screening and quality control, 16 periods of water level data from October 2003-June 2009 (ICESat-1) and 47 periods of water level data from October 2018-November 2020 (ICESat-2) were finally obtained for Bosten Lake.

2.3. Study methods

2.3.1. Data extraction and filtering. The original ICESat-1/2 data is in HDF5 format. From the original ICESat-1/2 altimetry data, we extract the relevant information of the data such as longitude, latitude, water surface elevation, and distance from the reference ellipsoid to the geoid, and convert the extracted data into vector altimetry data, and the ICESat-1/2 valid data within the lake area are extracted by using the lake vector boundary. According to the elevation quality control index provided by ICESat-1/2 data, the elevation points with errors are removed and corrected. Considering the uncertainty of the lake boundary, we use the frequency method and refer to the maximum/minimum water level, standard deviation and average value of the elevation data of each track on the filtered ICESat-1/2 elevation data to remove disturbed anomalies and points that may be out of range of lake waters.

2.3.2. Data Elevation Conversion. Different elevation reference frames were selected for the lake levels acquired by the ICESat-1/2 satellite. ICESat-1 uses the Topex/Poseidon ellipsoid as reference datum and ICESat-2 uses the WGS 84 ellipsoid as reference datum. Therefore, the elevation reference ellipsoid of the ICESat-1/2 needs to be converted to the same reference system. Based on the geodetic heights and the geoid gap relative to EGM2008 provided by the GLAH14 and ATL13 files, Convert the altitude of the ICESat-1/2 satellite to the orthometric height relative to EGM2008. The conversion formula is as follows:

$$H_{elev} = H_{ICESat} + H_{geoid}$$

In the formula: $H_{elev}$ is the final lake level; $H_{ICESat}$ is the water level elevation value extracted from ICESat1/2; $H_{geoid}$ is the geoid gap, which is extracted from the original ICESat data.

3. Results & Discussion

Figure 2 shows the change of water level of Bosten Lake from 2003 to 2020. The average lake level was 1048.06 m from 2003 to 2020, of which the lowest lake level in 2009 was 1045.76 m, and the highest lake level in 2003 was 1048.39 m. The water level of the lake showed different trends in different periods from 2003 to 2020. The lake level showed an obvious decrease trend from 2003 to 2009. In 2009, the lake level decrease by 2.63 m compared with 2003, and the rate of change was -0.37 m/a. This result is similar to the result obtained by Zhang et al.[5] based on ICESat-1 data; The average water level in 2018-2020 has risen significantly compared to 2009, the average water level in 2020 has risen by 2.55 m compared to 2009, the rate of change is 0.22 m/a. Although the water level of Bosten Lake has obvious rise and fall in different periods, in general, the water level shows an increasing trend from 2003 to 2020 with a change rate of 0.06 m/a. Yao et al.[10] point out that runoff is a major factor affecting the change of water level in Bosten Lake. The runoff into the lake decreased obviously from 2002 to 2012, but after 2012, the runoff into the lake increased rapidly, making the lake level rise.
ICESat-2 monitoring has good temporal continuity, can be used to analyze the intra-year variation of lake water levels. Figure 3(a) shows the two-year monthly average water level changes in Lake Constance for 2019 and 2020. The results show that the intra-annual water level variation showed a bimodal pattern of Bosten Lake. The water level of the lake showed a rising state from January to March; it began to fall in April and rose again after June; July to October was the period when the water level was high of Bosten Lake, and the water level reached its peak around October, and then the water level declined again. Li et al. [11] pointed out that, the main reason is that the water level of Bosten Lake dropped significantly after April due to the influence of the surrounding agricultural irrigation and lake water scheduling; Since June, the lake's water level has begun to rise due to increased precipitation and the melting of glacier snow caused by rising temperatures.

Figure 3(b) shows the water level changes of Bosten Lake in different years. The result in the figure shows, there are differences in the intra-year changes of the lake in different years. In 2019, the lake level remained basically stable from January to April, the average water level is lower than 2020; From April to October, the water level has been rising; From April to October, the water level has been rising. During this period, the water level rose more obviously from April to July. In June, the water level rose higher than the 2020 water level; After October, the water level began to fall. In 2020, the lake level showed an upward trend from January to March; The water level decreased from April to July, and after June, the water level fallen below 2019; Lake levels rebounded, after July, but not significantly; After October levels dropped again, and overall water levels were below 2019 levels, after June. The reason for this difference may be caused by different human activities. Bosten Lake, as a water source for the survival and development of the population in the Yanqi Basin and surrounding areas, is more affected by human activities in a short period of time [12, 13, 14, 15]. In addition, Feng [16] pointed out, different precipitation, temperature changes, and difference in contributions from glaciers and snow melting, can also cause differences in intra-annual water level variation in different years.

4. Conclusions
In this paper, through the analysis of ICESat1/2 satellite laser altimetry data, the trend of the water level of Bosten Lake from 2003 to 2020 is obtained. The main conclusions are as follows:

(1) The water level showed an overall increased trend of Bosten Lake from 2003 to 2020, with an annual change rate of 0.06 m/a. Among them, the lake level declined at a rate of -0.37 m/a, and dropped by 2.63 m from 2009 to 2003. Compared with 2009 the average water level increased by 2.55 m in 2020, and the average annual rate of change was 0.22 m/a.
The water level of Bosten Lake has seasonal peak characteristics, but the peak season is different between different years. The water level peaks in 2019 from September to October, and the water level peaks in March 2020. Mainly driven by ice and snow melt water for the September-October peak, the March peak is mainly caused by rainfall.

This will provide reference significance for the reasonable use and timely regulation of Bosten Lake water. Due to the lack of ICESat data from 2010 to 2017, the analysis of Bosten Lake's interannual changes is not comprehensive enough. In the future, multiple altimetry satellites can be fused to perform a complete interannual water level change analysis.

Acknowledgments
This research was jointly funded by the National Natural Science Foundation of China Youth Fund Project (41501027) and Ministry of Natural Resources of China (NO.121133000000190020). The authors would thank NASA National Snow and Ice Data Center Distributed Active Archive Center for providing ICESat data download.

References
[1] Meng, Z., Wang, K., Kang, G.S.(2020).Research on the Impact of Climate Warming on the Ecological Environment of Bosten Lake[J].South China Agriculture,14:177-178.
[2] Wang, J.Z., Guo, P.P.(2021).Consideration on Bosten Lake watershed treatment based on the water control policy in new era[J].Water Resources Planning and Design,10-12+23.
[3] Li, X.Y., Chen, Y.N., Liu, L., et al.(2020).Design and implementation of water resources management decision support system in the Bosten Lake Basin[J].Water Resources Protection,36:53-59.
[4] Wu, H.B.(2019).Studies on changes in water level and storage of Bosten Lake based on satellite-borne radar altimetry data[J].Journal of Water Resources and Water Engineering,30:9-16+23.
[5] Zhang, G.Q., Xie, H.J., Yao, T.D., et al.(2013).Water balance estimation of Ten Lakes in China based on ICESat and Landsat[J].Chinese Science Bulletin,58:2664-2678.
[6] Gao, P.W., Li, X.G., Kasmu, A.(2019).Temporal and spatial variation characteristics of the Bosten Lake shoreline[J].Journal of Water Resources and Water Engineering,30:98-104.
[7] Tuersun, A., Rusuli, Y., Maimaiti, A., et al.(2020).Spatiotemporal Characteristics of Evapotranspiration and Driving Factors in the Bosten Lake Watershed, China[J].CLEAN – Soil, Air, Water,48:1900246.
[8] Zhang, G.Q., Xie, H.J., Kang, S.C., et al.(2011).Monitoring lake level changes on the Tibetan Plateau using ICESat altimetry data (2003–2009)[J].Remote Sensing of Environment,115:1733-1742.
[9] Wang, X.W., Gong, P., Zhao, Y.Y., et al.(2013).Water-level changes in China's large lakes determined from ICESat/GLAS data[J].Remote Sensing of Environment,132:131-144.
[10] Yao, J.Q., Chen, J., Tuoliewubieke, D., et al.(2021).Trend of Climate and Hydrology Change in Bosten Lake Basin and Its Influence on the Lake Level[J].Pearl River,42:19-27.
[11] Li, Y.J., Chen, Y.N., Zhang, Q.F., et al.(2021).Analysis of the change in water level and its influencing factors on Bosten Lake from 1960 to 2018[J].Arid Zone Research,38:48-58.
[12] Mamat, A., Halik, U., Keram, A.(2017).Remote sensing based analysis on environment changes of typical lakes in Tianshan mountains-A case study of Bosten Lake and Issyk -Kul Lake[J].Journal of Arid Land Resources and Environment,31:143-147.
[13] Li, J.L., Fang, H., Bao, A.M., et al.(2011).Spatio-temporal Analysis of Recent Changes of Lake Area and LakeWater Level at High Mountains in Central Asia[J].Resources Science,33:1839-1846.
[14] Eziz, M., Anwar, G., Abla, M.(2015).Water Variation Level Drivers of Bosten Lake Based on Principal Components Analysis[J].Journal of Salt Lake Research,23:1-7.
[15] Ghali, I., Yimit, H., Eziz, M., et al.(2015).The Driving Forces of the Bosten Lake Water Level Variations in 1858-2012[J].Journal of Desert Research,35:240-247.
[16] Feng, J.(2019).Study on the characteristics of water resources in Bosten Lake[J].Ground Water,41:129-131.