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Estimation and trend detection of water storage at Nam Co Lake, central Tibetan Plateau

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SUMMARY

Nam Co Lake is the highest lake in the central Tibetan Plateau, and existing research on water storage and water level variations are lacking. This paper provides a method for estimating the lake water storage based on historical meteorological records from 1976 to 2009, remote sensing images scattered in this period, in situ bathymetric survey, and GIS techniques, and presents a comprehensive 34-year analysis of intra-annual and inter-annual variations of Nam Co Lake water storage. The multi-year mean water storage of Nam Co Lake is 842.36×10^8 m^3, with the maximum water depth of about 98 m. During 1976–2009, the lake water storage increased from 786.06×10^8 m^3 to 870.30×10^8 m^3, with a tendency value of 2.67×10^8 m^3/a; the lake area enlarged from 1927.48 km^2 to 2015.12 km^2, with a tendency value of 2.71 km^2/a. The lake area fluctuations annually, increasing from April of each year until late September and early October, then decreasing until March of the next year. Climate change has a significant impact on the water storage variation of the lake. A general pattern of warming temperature is evident with the regional annual mean air temperature increasing significantly by 0.404 °C/10 a. Preliminary analysis indicates that the enlarging status of Nam Co Lake water storage is closely related to increasing of precipitation and stream runoff especially coming from the input of glacial meltwater. By combining this data with other research, it can be presented that under the trend of global warming, on Tibetan Plateau, the inland lakes which depend on the rainfall and river supply in the basin are shrinking, while the lakes which depend on glacial meltwater supply are enlarging. Climate change is an important factor promoting the lake variation.

1. Introduction

Climate changes are expected to seriously affect the water resources of the Tibetan Plateau (Immerzeel et al., 2010). Inland lakes that are widely distributed on the Tibetan Plateau have minimum impact of human activities and are an important component of the water supply in China. The enlargement and shrinkage of inland lakes reflect the changes in water and heat balance, which is a sensitive indicator of the climate change (Shi, 1990). Lake water storage variation provides information about temperature, rainfall, humidity and solar radiation, while regional water storage variations reflect the climate change in a larger scale (Redway, 1924; Hartmann, 1990; Jones et al., 2001; Novaky, 2008). Lake water level variation directly records the process of water storage balance in the basin, which is a quite sensitive response to the climate change (Li et al., 1998). Therefore, fluctuation of inland lakes in the Tibetan Plateau (variation of area, water level, water storage, etc.) is an important indicator of climate change. Understanding these variations and the role of climate is important for water resource management as well as for predicting future changes in lake hydrology as a result of climate change.

Existing research on lake variations mainly focus on the monitoring of area changes in lake. Due to the wide monitoring scope, fast speed and low cost, remote sensing technology has unique advantages in the dynamic monitoring of lakes in inaccessible areas of the Tibetan Plateau (Quincey et al., 2007; Chu et al., 2008; Yang et al., 2008). Previous work utilized middle and high resolution optical image data to analyze the fluctuation in the area of main lakes on Tibetan Plateau and the results indicated that lakes which depend on the supply of glacial meltwater in the middle and northern Tibetan Plateau are stable and tending to enlarge, including Nam Co Lake, Serlincuo Lake, Palgon Lake and Hala Lake (Yang et al., 2003; Zhao et al., 2006; Wu and Zhu, 2008). Lakes located in the northeastern and western Tibetan Plateau, which depend on the supply of inland rivers and rainfall are shrinking, including Qinghai Lake, Yamdrok Lake, Zhari Namco Lake, Dangreyong Lake, Ayakkum Lake and Ulan Ul Lake (Morrill, 2004; Lu et al.,

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2005; Shao et al., 2007;Ye et al., 2007). Still, research related to water storage only exists in three areas with hydrological observation stations, namely, Qinghai Lake, Yamdrok Lake and Zabuye Salt Lake (Ding and Liu, 1995; Li et al., 2005; Qi and Zheng, 2006; Bian et al., 2009), and the water storage research of lakes in other areas of the vast Tibetan Plateau is limited.

This study focuses on the Nam Co lake, the largest lake on Tibet plateau as well as the highest large lake in the world. Altogether 42 images of three kinds of remote sensing image data were used in combination with hydrological data actually measured in the field, and meteorological station data, to quantitatively acquire the information of surface fluctuation, water storage variation, and to study the lake response to climate change from 1976 to 2009 for the first time. The results provide theoretical support and data for further understanding the processes and extent of water resource response to global climate change, and provide a scientific basis for rational development and utilization of water resource in Tibetan plateau.

2. Study area and data

Nam Co Lake is the largest lake in the Tibet Plateau as well as the highest large lake in the world. It is located at 90°16′–91°03′E, 30°30′–30°55′N (Fig. 1). It belongs to Damxung County of Lhasa City and Baingoin County of Nagqu Prefecture of Tibetan Autonomous Region. Its elevation is 4718 m and the water area is 1920 km^2 measured in 1979 (Guan et al., 1984), and the maximum depth is over 90 m (according to the data measured from 2005 to 2007).

Nam Co Lake Basin is located at 89°21′–91°23′E, 29°56′–31°7′N, with an area of 10,610 km^2. It is a closed basin in the north of Gangdise-Nyainqentanglha Mountain in the plateau lake basin region of southern Qiangtang in Northern Tibet. The average altitude of Nyainqentanglha Mountain in the southeast of the basin is about 5500 m. There are many modern glaciers on the mountain, mostly short and small ones, and the glacial meltwater directly flows into the lake in a comb-like form passing a short distance of piedmont area. Northern and northwestern parts of the basin belong to a gently undulating, low mountainous area whose average altitude is about 5000 m. The whole basin receives strong solar radiation and gets a long duration of sunshine, which can reach 2900–3200 h a year. The basin belongs to the plateau subfrigid monsoon semiarid climate zone, which is cold and has no distinct seasons. The annual temperature range is larger than daily variability.

Because of its special geographical position, Nam Co Lake is barely influenced by human activities, and its water fluctuation only reflects long-term climate change information.

There was no meteorological observation station or hydrological station in the basin before 2005. After 2005, the Institute of Tibetan Plateau Research established the Nam Co Lake Multi-Layer Comprehensive Observation and Research Station (Nam Co Lake Station) of China Academy of Sciences and gradually began the monitoring of some regular parameters. Researchers conducted

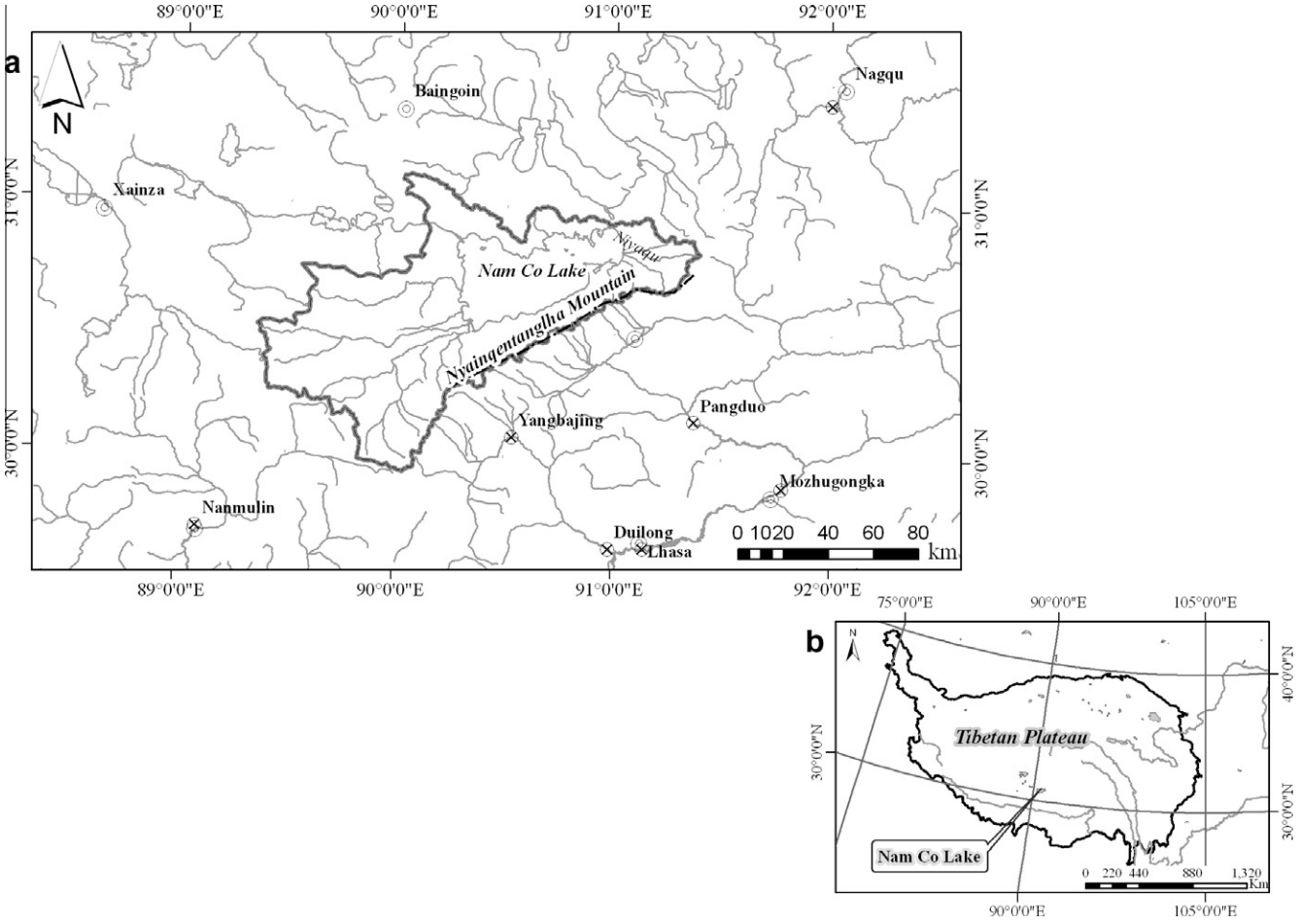

Fig. 1. Map-a showing the location of observation stations around Nam Co lake, the region enclosed by the dashed gray line represents the Nam Co lake basin, the light gray lines around the lake represent rivers, the double circle symbol represent the meteorological stations, and the fork circle symbol represent the hydrological stations; Map-b showing the position of Nam Co on the Tibetan Plateau.