Outburst Flooding of the Moraine-Dammed Zhuonai Lake on Tibetan Plateau: Causes and Impacts

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***Abstract*—The Kekexili region of the Tibetan Plateau has become warmer and wetter since the 1960s, resulting in a significant expansion of Zhuonai Lake (+0.46 km^2/year, $p < 0.05$) before an outburst flood event occurred on September 15, 2011, and mapped by the Chinese Huanjing (HJ)-A/B satellites with a two-day revisit ability and a 360-km orbit swath. The direct cause of the outburst was due to relatively heavy precipitation from May to September 2011, specifically the continuous rainfall from later August to middle September. Two nearby earthquakes that occurred two months before the outburst might have impacted the natural structure of the lakebed and moraine dam to accelerate the outburst. The outburst event of Zhuonai Lake caused large environmental impacts on the region: 1) the desertification of the exposed lakebed of Zhuonai Lake; 2) the significant expansion of the three downstream lakes Kusai, Haidingnuoer, and Salt Lakes that not only caused the grassland reduction and deteriorations but also the potential threat to the operations of the Qing-Tibet Railway and Highway; and 3) the calving relocation of Tibetan antelopes to the shore area of Kusai Lake due to the deep cutting riverbanks caused by the overflow of Zhuonai Lake. This study provides some scientific clues or alerts for local or central governments to pay some attention on this very issue so that possible future devastative disasters and environmental damages would be avoided or mitigated.**

***Index Terms*—Huanjing satellite, impact, Kekexili, outburst flood, Zhuonai Lake.**

Manuscript received October 21, 2015; revised December 17, 2015; accepted January 12, 2016. This work was supported in part by the National Natural Science Foundation of China (31228021), by the Chinese Ministry of Agriculture (201203006), and by the Changjiang Scholars and Innovative Research Team in University (IRT13019).

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Digital Object Identifier 10.1109/LGRS.2016.2525778

I. Introduction

THE Tibetan Plateau (TP) is an ecologically fragile region and is sensitive to global climate change. The TP contains one of the densest networks of lakes in China and even in the world. These lakes are remote and high (in altitude) and are almost intact by human activities. The shrinking or expansion of such lakes can clearly reflect changes in local climate and environment and is a sensitive indicator of climate change [1]–[3]. During the past 50 years (since the 1960s), the climate of the TP has exhibited a significant warming and wetting trend, with an increasing temperature of +0.37 °C/decade and a precipitation of +9.1 mm/decade, although there were regional differences [4].

The Kekexili region is sparsely populated and has challenging natural conditions, with a mean elevation of over 4000 m. It is usually difficult to obtain data reflecting the dynamic changes of lakes in the region using conventional methods [5], [6]. Satellite remote sensing thus provides an effective tool for monitoring the changes of lakes and environments on the region as well as in the entire TP [7]–[9].

In recent years, the dynamic changes of lakes on the TP have been conducted using various satellite data. For example, Amatya obtained information regarding changes in the surface elevation of Namco Lake using Envisat RA-2 data and ICESat data [10]. Shao *et al.* analyzed changes in certain key lakes on the TP during the previous 25 years using data from the Landsat Multispectral Scanner (MSS) and Enhanced Thematic Mapper (ETM) [11]. Duan *et al.* studied the characteristics of the changes in 67 lakes larger than 1 km^2 in the Qiangtang Basin of the TP from 1976 to 2010 and analyzed the climate and hydrologic changes by using Landsat MSS, TM, and ETM+ satellite data [12]. Zhang *et al.* studied lake changes of the TP using Landsat images and found the overall increase in lake area and numbers for the past 40 years and even faster increase in the past 20 years [13]. Most of these studies, however, were based on remote sensing data/images of low temporal resolution (e.g., Landsat), and most of them were greatly affected by cloud. Therefore, none of these data can really monitor the occurrence and development of outburst flooding events within a short time period nor the effects of floods on the surrounding environment. Fortunately, the newly launched Chinese Huanjing (HJ)-A/B (environment and disaster monitoring constellation) satellites provide the same 30-m spatial resolution as Landsat but a much wider swath (360 km versus 185 km) and a faster revisit ability (2 days versus 16 days), with a great potential to get more clear-sky images due to the faster revisits.

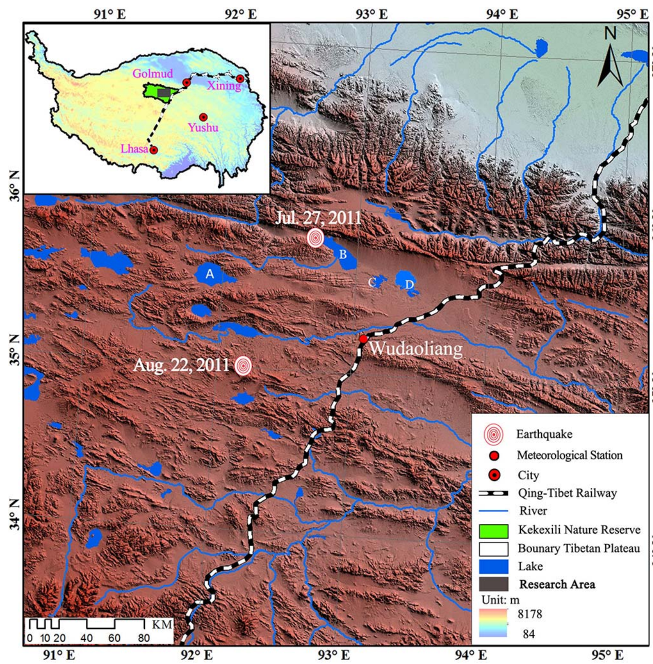

Fig. 1. Locations of the lakes in the Kekexili region of the TP, with Qing-Tibet Railway passing through the area (A. Zhuonai Lake, B. Kusai Lake, C. Haidingnuoer Lake, and D. Salt Lake).

This letter presents a case study of using the HJ-A/B satellites to examine an outburst flooding event of a moraine-dammed lake, nearby the Qing-Tibet Railway (QTR) and Highway (QTH), which otherwise impossible to do so due to the remoteness and lacking of *in situ* observations. The possible reasons of this outburst event and potential impacts to the surrounding environments, such as to the QTR and QTH, are also discussed.

II. Data Source And Method

A. Study Area

The study area inside the Kekexili is in the southern Kunlun Mountains of the TP, with the QTR, the highest (elevation) railway of the world, passing through (Fig. 1). The Kekexili region has a mean elevation of 4600 m [14], with the western portion 300 m higher than the eastern portion. The total area of the Kekexili is 49 120.10 km^2, with a population of only 259 Tibetan due to the harsh natural environment, and there is no or little industrial and infrastructure, except the QTR and QTH passing over. The QTR and QTH are extremely important in connecting the Plateau with the booming economic growth and development of inland China. The examined four lakes Zhuonai Lake, Kusai Lake, Haidingnuoer Lake, and Salt Lake are all located in a closed basin. On September 15, 2011, an outburst flooding event occurred in the moraine-dammed Zhuonai Lake, triggering a flood disaster. The mouth of the broken dam was later measured at 200 m in width and 16–20 m in depth. A large amount of water discharged from Zhuonai Lake, flowed eastward, through Kusai Lake and Haidingnuoer Lake, and eventually entered Salt Lake (Fig. 1). This resulted in significant expansions of the three lakes, especially the Salt Lake, only 8 km away to the QTR. Among these four lakes, Zhuonai Lake and Kusai Lake are salt lakes, whereas Haidingnuoer Lake and Salt Lake are saline lakes (Fig. 1).

TABLE I
Remote Sensing Data Used

Data	Time	Resolution	Source
Landsat TM/ETM+	11/30/1976,10/24/1994,5/15/2002,9/7/2006	30m	USGS/NASA
HJ-A/B CCD	8/30/2009,9/6/2010,7/15/2011,8/22/2011,9/14/2011,9/18/2011,10/12/2011,8/19/2012, 9/13/2012, 9/5/2013, 8/18/2014, 9/30/2015	30m	China Center for Resources Satellite Data and Application

B. Data and Method

The Chinese HJ-A/B satellites, launched in September 2008, are equipped with optical, thermal infrared, and radar sensors. The HJ satellite data used in the present study are obtained from the HJ Satellite Data Product and Sharing Service (http://www.secmep.cn). Table I lists the HJ images and historical Landsat images used for the study. The temperature and precipitation data of Wudaoliang Meteorological Station (Fig. 1) are obtained from the Qinghai Meteorological Bureau. The digital elevation model data at a scale of 1 : 250 000 are from the Shuttle Radar Topography Mission of NASA.

The corrected TM image on September 7, 2006, is used to geometrically correct the HJ satellite images, with a root-mean-square error of less than 0.5 pixel. The lake boundaries are extracted using thresholds method in which the $\mathrm{CH4}/\mathrm{CH2} < 1$ and $\mathrm{CH4} < 0.5$ (CH2 and CH4 of HJ are 0.52–0.60 and 0.76–0.90 μm, respectively, similar as the Landsat channels) [15], [16]. The vector boundary of each lake is further modified by visually inspecting the original imagery.

III. Results And Discussion

A. Change of Zhuonai Lake Based on HJ-A/B Imagery

As shown in Fig. 2(b), the surface area of Zhuonai Lake on August 22, 2011, was the largest (274.1 km^2), followed by September 14, 2011 (267.7 km^2), right before the occurrence of the outburst flooding event on September 15, 2011. The area only dropped by 6.4 km^2 in 23 days (or 0.28 km^2/day) before the outburst occurred. The lake area then quickly dropped 26.4 km^2 in 4 days (or 6.6 km^2/day) from September 14 to 18, another 81.1 km^2 in 24 days from September 18 to October 12 (or 3.4 km^2/day). The dropped areas occurred mostly in the western, southern, and eastern portions of the lake [Fig. 2(a)]. The lake area remains ~161 km^2 thereafter [Fig. 2(c)].

1) Climate Change: From 1961 to 2014, the temperature in the Kekexili region exhibits an increasing trend ($R^2 = 0.72$, $P < 0.01$), with +0.32 °C/decade [Fig. 3(a)], even faster increase since 1998. The mean annual temperature from 1998 to 2014 was −4.5 °C, which was 0.6 °C higher than the mean from 1981 to 2010. The mean annual temperature was −4.0 °C in

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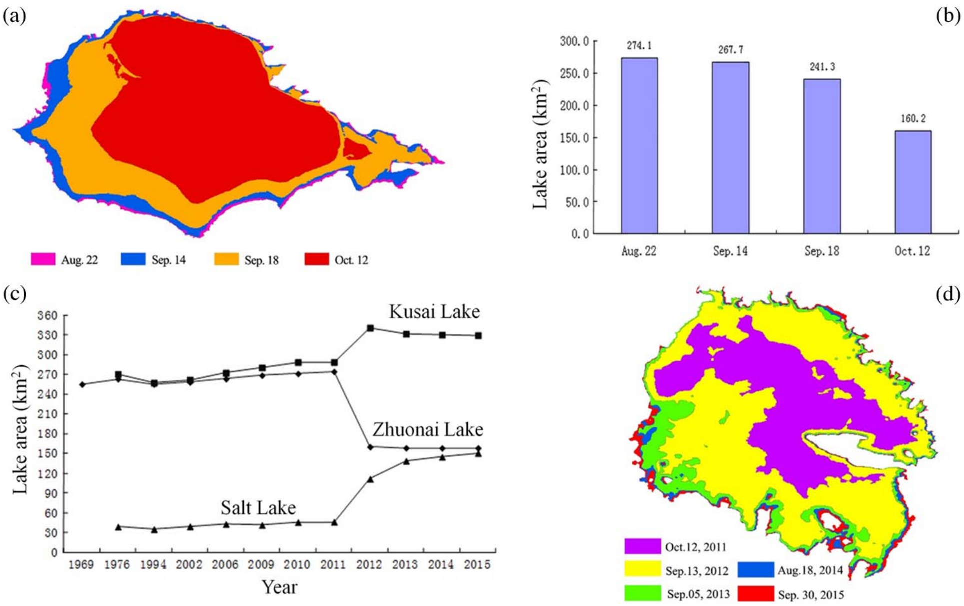

Fig. 2. (a) and (b) are, respectively, the lake boundary and area changes of Zhuonai Lake on August 22, September 14, September 18, and October 12, 2011. (c) Lake area changes in the past 40 years (combined from both Landsat and HJ satellites). (d) Lake boundary changes of Salt Lake from 2011 to 2015, possible causes of the outburst flood at Zhuonai Lake.

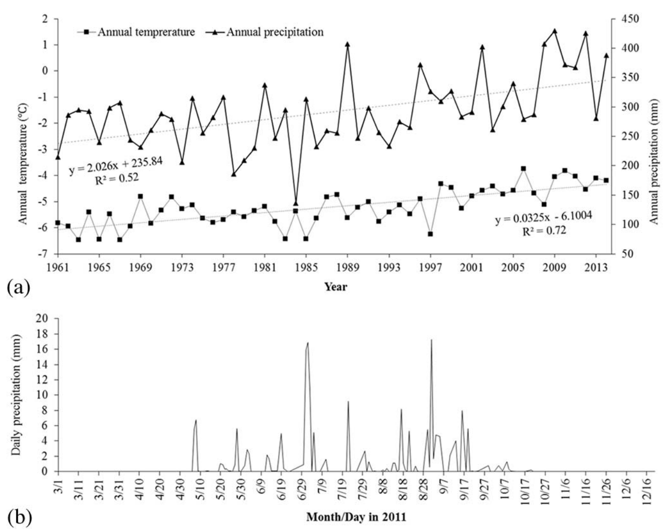

Fig. 3. (a) Mean annual temperature and precipitation in the Kekexili region from 1961 to 2014. (b) Daily precipitation at the Wudaoliang Meteorological Station from March to December 2011 (before and after the outburst at Zhuonai Lake on September 15).

2011 (the year of the outburst flooding event), which was 1.0 °C higher than the annual mean temperature from 1981 to 2010.

Precipitation shows a similar increase trend as temperature from 1961 to 2014 ($R^2 = 0.52$, $P < 0.01$), with a mean of 301.5 mm and a rate of +20.7 mm/decade for the mean annual precipitation accumulation, even faster increase after 1998 [Fig. 3(a)]. The mean annual precipitation was 367.4 mm in 2011, 20% higher than the mean annual precipitation from 1981 to 2010.

Therefore, during the 54 years from 1961 to 2014, the climate in the Kekexili region exhibited an overall trend of warming and wetting, a similar trend as that of the entire TP [17]–[21]. Increased precipitation was the dominant factor for the outburst flooding of Zhuonai Lake in 2011. This is consistent with other studies [16]. Increased temperature could also speed up glacier melting and permafrost degradation, both of which could contribute to the lake water/area increase. However, this contribution could be limited since the distribution of glaciers and permafrost in this area is limited and it is currently impossible to quantify their exact contributions [16], [22], [23] and is also beyond the scope of this study.

Fig. 2(c) shows an overall increasing trend in the surface area of Zhuonai Lake with $+19.17$ km^2 from 1969 to 2011 ($R^2 = 0.67, p < 0.05$) or at a rate of $+0.46$ km^2/year. After the outburst on September 15, 2011, the lake area decreased sharply over 100 km^2 and maintained a similar area of $\sim$161 km^2 after October 12, 2011. This suggests that Zhuonai Lake lost over 100 km^2 of the water storage function due to the outburst and excess water has always discharged to the downward lakes.

2) Continuous Precipitation Before the Outburst Event at Zhuonai Lake: Precipitation is the key factor, resulting in soil porosity and forming surface runoff [24]. According to the daily precipitation data recorded at the Wudaoliang Meteorological Station [Fig. 3(b)], the precipitation in 2011 fell almost no stop from May to early October (the total precipitation was 178.8 mm during the period). Continuous precipitation, particularly during two heavy rainfalls on August 17 and 21 (rainfall values were 16.9 and 17.3 mm, respectively), resulted in a rapid water rise at Zhuonai Lake until August 22, when the water started to spill over the moraine dam. The scouring effect of this overflow eventually led to undercutting the dam and caused the outburst flood on September 15, 2011.

3) Earthquakes: Another possible reason for the outburst could be the two nearby earthquakes (July 27 and August 22, 2011) that occurred in that time period (epicenters marked in Fig. 1). According to reports presented in the China Earthquake Networks Center's website (http://www.ceic.ac.cn), a magnitude 4.0 earthquake with a focal depth of 6 km occurred at 07:42 on July 27, 2011, with the epicenter just $\sim$62 km from Zhuonai

Lake. The second one of magnitude 3.1 and focal depth of 10 km occurred at 05:05 on August 22, 2011, with the epicenter just ∼57 km from Zhuonai Lake. These two earthquakes did not directly result in the outburst but could have affected the natural structure of the lake basin and moraine dam, which failed later to cause the outburst flooding.

B. Potential Impacts by the Outburst Flood and the Failed Moraine Dam at Zhuonai Lake

1) Impacts on Downstream Lakes: Three lakes, namely, Kusai, Haidingnuoer, and Salt Lakes, located in the downstream of Zhuonai Lake, were directly impacted by the outburst flood of Zhuonai Lake. The area of Kusai Lake increased rapidly from 288.43 km^2 on August 22, 2011 (before the outburst) to 340.49 km^2 on August 19, 2012 (after the outburst), kept similar or slightly decreased from 2012 to 2015 [Fig. 2(c)]. The area of Salt Lake increased sharply from 111.20 km^2 on August 22, 2011, to 144.50 km^2 on August 19, 2012, and continued to increase from 2012 to 2015 [Fig. 2(c); the water areas of Haidingnuoer Lake are not extracted due to its excessively fractured lake bank, but a clear expansion can be noticed from the images (not shown)]. This suggests that water loss from Zhuonai Lake has continued to feed the downward lakes, especially the Salt Lake. This might be a potential hazard to the QTR and QTH, only 8 km away, once the Salt Lake would suffer from such an outburst event in the future.

The area of Salt Lake exhibits a continuously increasing trend from 2009 to 2015 [Fig. 2(c)]. It was 40.9 km^2 on August 30, 2009, to 46.8 km^2 on October 12, 2011, i.e., an increase of approximately 6 km^2 in three years. The significant increase, however, is seen on August 19, 2012 (111.19 km^2), continued to 140.05 km^2 on September 5, 2013, and to 150.41 km^2 on September 30, 2015. The detailed analysis based on the areas mapped by HJ-A/B [Fig. 2(d)] finds that the significant areal increase in Salt Lake did not occur until after October 12, 2011. This implies that the overflow from Zhuonai Lake on September 15, 2011, did not directly feed Salt Lake but was stored by Kusai Lake and Haidingnuoer Lake. After these two lakes went over their storage limits, the water was then flowing into Salt Lake. One result of the Salt Lake expansion was the integration of the old Salt Lake and the other small lakes around Salt Lake. This integrated Salt Lake system expanded rapidly in all directions, particularly southward [Fig. 2(d)].

2) Impacts on the Surrounding Ecological Environment and Major Engineering Facilities: As shown in Fig. 2(a), after the outburst event, the large areas in the western, southern, and eastern portions of the Zhuonai Lake's shoreline shrank greatly, resulting in desertification of such areas, i.e., the former lakebed, now dry and desert. In addition, tens of small lakes or ponds developed in the northern and eastern portions of the former lakebed. Another scouring effect of the outburst-caused overflow was the formation of newly and deeply cut riverbanks (up to 600 m in width and 10 m in depth) that now become a migration barrier for Tibetan antelopes who usually migrate from the Three Rivers Source area (east of the region) to the southern shore area of Zhuonai Lake to calve. The shrinkage of the water body of Zhuonai Lake also increases the distance that the Tibetan antelopes needed to travel for drinking water. The result was that numerous Tibetan antelopes started calving in the area around Kusai Lake.

The expansions of Haidingnuoer Lake and Salt Lake, both containing high concentrations of salts (up to 221.35 g/L, with even a 2.5-m-thick halite layer located in the east band of Salt Lake) [25], could have already impacted or damaged the grassland vegetation in the surrounding areas. In particular, the Salt Lake expansion and continuous expansion would potentially impact nearby facilities, such as oil pipelines, thus threatening the safety of the operation of the QTR and QTH. From September 2011 to September 2015, the shoreline of Salt Lake advanced 5 km southeastward and reached a point approximately 8 km from the QTR and QTH (Fig. 1). If the moraine-dammed Kusai Lake and/or Haidingnuoer Lake breaks or the Zhuonai Lake further breaks in the future, the Salt Lake would then rapidly expand southward and would encroach the QTR and QTH, as well as other major engineering facilities, a possible devastative disaster, if local or central governments do not pay much attention on this very issue.

IV. Conclusion

Due to warming climate, the Kekexili region of the TP has become warmer (+0.32 °C/decade) and wetter (+20.7 mm/decade) during the past 50 years. As a result, the surface area of Zhuonai Lake has shown a significant expansion (+0.46 km^2/year, $p < 0.05$) before September 2011. An outburst flood event that occurred on September 15, 2011, caused the lake's area to decrease from 267.7 km^2 on September 14 to 241.3 km^2 on September 18 and then to 160.2 km^2 on October 12, a ∼107.5 km^2 decrease in 28 days. This detailed mapping is made possible due to the Chinese HJ-A/B satellites with a two-day revisit ability and a 360-km orbit swath. Besides the long-term trend of climate warming and wetting, the relatively heavy precipitation from May to September 2011, specifically the continuous precipitation from later August to middle September, was the direct trigger of the outburst flood of Zhuonai Lake. The two nearby earthquakes that occurred just two months before the outburst might have affected the natural structure of the lakebed and moraine dam, thereby accelerating the outburst.

The outburst event of Zhuonai Lake caused large environmental impacts on the region mainly in the following aspects. The first one was the desertification of the lakebed that occurred mostly in the western, southern, and eastern portions of the lake due to exposure of these lakebeds. Second was the overflow-caused deep cutting riverbanks and significant expansions of the three downstream lakes, namely, Kusai, Haidingnuoer, and Salt Lakes. The deep cutting riverbanks became a migration barrier for Tibetan antelopes; most of them later had to choose the shore area of Kusai Lake for calving. The significant expansions of the three lakes have not only caused grassland reduction and deteriorations in the areas but also posed a potential threat to the safe operations of major engineering facilities such as the QTR and the QTH. This letter hopes to provide some scientific clues or alerts for local or central governments to pay more attention on this very issue so that possible future devastative disaster would be avoided or mitigated.

REFERENCES

[1] L. Zhu, M. Xie, and Y. Wu, "Change in the area of Lake Nam in Tibet from 1971 to 2004 and quantitative analysis of the cause of such change," *Chin. Sci. Bull.*, vol. 55, no. 18, pp. 1789–1798, Jun. 2010.

[2] Z. Wei, R. Huang, and W. Dong, "Interannual and inter annual variations of air temperature and precipitation over the Tibetan Plateau," *Chin. J. Atmos. Sci.*, vol. 27, no. 2, pp. 157–170, Feb. 2003.

[3] S. Li *et al.*, "A preliminary report on the changes in and investigation of the modern lakes on the Qinghai-Tibetan Plateau," *J. Lake Sci.*, vol. 10, no. 4, pp. 95–96, Apr. 1998.

[4] L. Li *et al.*, "Climate change and its regional difference over the Tibetan Plateau," *Adv. Clim. Change Res.*, vol. 6, no. 3, pp. 181–186, May 2010.

[5] V. Lakshmi, "Role of remote sensing in ungaged basins," *Hydrol. Process.*, vol. 18, no. 5, pp. 1029–1034, Apr. 2004.

[6] V. Lakshmi and K. Schaaf, "Analysis of 1993 midwestern flood using satellite and ground data," *IEEE Trans. Geosci. Remote Sens.*, vol. 39, no. 8, pp. 1736–1743, Aug. 2001.

[7] T. H. Syed *et al.*, "Analysis of process controls in land surface hydrological cycle over the continental United States," *J. Geophys. Res.*, vol. 109, no. D22105, pp. 1–11, Nov. 2004.

[8] D. Bian *et al.*, "The response of lake area change to climate variations in the North Tibetan Plateau during last 30 years," *Acta Geogr. Sin.*, vol. 61, no. 5, pp. 510–518, May 2006.

[9] Y. Wu, L. Zhu, Q. Ye, and L. Wang, "The response of lake-glacier area change to climate variations in Namco Basin, Central Tibetan Plateau, during the last three decades," *Acta Geogr. Sin.*, vol. 62, no. 3, pp. 300–311, Mar. 2007.

[10] P. M. Amatya, "Water level fluctuations of Namco Lake in Tibetan Plateau observed from radar and laser altimetry," M.S. thesis, Faculty Geo-Inf. Sci. Earth Observ., Univ. Twente, Enschede, The Netherlands, Jun. 2014.

[11] Z. Shao *et al.*, "Characteristics of the changes in the main lakes on the Tibetan Plateau in the recent 25 years," *Geol. Bull. Chin.*, vol. 26, no. 12, pp. 1633–1645, Dec. 2007.

[12] S. Duan, G. T. Liu, Q. Wu, and Y. Li, "The recent expansion features and the cause of formation of the lakes in Qinghai Qiangtang Basin," *J. Glaciol. Geocryol.*, vol. 35, no. 5, pp. 1237–1247, May 2013.

[13] G. Zhang, T. Yao, H. Xie, K. Zhang, and F. Zhu, "The state and abundance of lakes across the Tibetan Plateau," *Chin. Sci. Bull.*, vol. 59, no. 24, pp. 3010–3021, Apr. 2014.

[14] Y. Li and D. Chen, "Influence of environment with high altitude on soil forming and development in ice edge of Qinghai-Tibet Plateau," *J. Quanzhou Normal Univ. (Natural Science)*, vol. 23, no. 2, pp. 95–96, Feb. 2005.

[15] B. Liu *et al.*, "A dynamic study on the area of the Qinghai Lake based on the Huanjing satellites," *Pratacultural Sci.*, vol. 30, no. 2, pp. 95–96, Feb. 2013.

[16] X. Yao, S. Liu, M. Sun, W. Guo, and X. Zhang, "Dynamic change in the area of Kusai Lake in the Kekexili region and analysis of the cause of the spillover of lake water," *Acta Geogr. Sin.*, vol. 67, no. 5, pp. 689–698, May 2012.

[17] G. Zhang, H. Xie, S. Kang, D. Yi, and S. F. Ackley, "Monitoring lake level changes on the Tibetan Plateau using ICESat altimetry data (2003–2009)," *Remote Sens. Environ.*, vol. 115, no. 7, pp. 1733–1742, Jul. 2011.

[18] G. Zhang, H. Xie, S. Duan, M. Tian, and D. Yi, "Water level variation of Lake Qinghai from satellite and *in situ* measurements under climate change," *J. Appl. Remote Sens.*, vol. 5, no. 1, Jun. 2011, Art. ID 053532.

[19] Y. Xu, Y. Ding, and D. Li, "Climate change over Qinghai and Xizang in 21st century plateau meteorology," *Plateau Meteorol.*, vol. 22, no. 5, pp. 451–457, May 2003.

[20] Z. Xu, T. Gong, and F. Zhao, "Analysis of climate change in Tibetan Plateau over the past 40 years," *J. Subtropical Resour. Environ.*, vol. 1, no. 1, pp. 24–32, Mar. 2006.

[21] D. Qin, *Climate and Environment Change in China: 2012 Comprehensive Volume*. Beijing, China: China Meteorological Press, 2012, pp. 251–263.

[22] Y. Nie, Y. Zhang, M. Ding, L. Liu, and Z. Wang, "Lake change and its implication in the vicinity of Mt. Qomolangma (Everest), central high Himalayas, 1970–2009," *J. Lake Sci.*, vol. 5, no. 3, pp. 278–286, Jan. 2012.

[23] T. Yao, *Dynamic Characteristics of Cryosphere in the Central Tibetan Plateau*. Beijing, China: Geological Publishing House, 2002, pp. 199–206.

[24] V. Lakshmi, T. Piechota, U. Narayan, and C. Tang, "Soil moisture as an indicator of weather extremes," *Geophys. Res. Lett.*, vol. 31, no. 11, pp. 293–317, Nov., 2004.

[25] X. Zheng, M. Zhang, X. Xu, and B. Li, *Records of Chinese Salt Lakes*. Beijing, China: Science Press, 2002, pp. 178–186.