A dataset for lake level changes in the Tibetan Plateau from 2002 or 2010 to 2021 using multi-altimeter data

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Abstract.

The Tibetan Plateau (TP), known as the Roof of the World and the Water Tower of Asia, has the largest number of lakes in the world, and because of its high altitude and near absence of disturbances by human activity, the plateau has long been an important site for studying global climate change. Hydrological stations cannot be readily set up in this region, and *in situ* gauge data are not always publicly accessible. Satellite radar altimetry has become a very important alternative to *in situ* observations as a source of data. Estimation of the water levels of lakes via radar altimetry is often limited by temporal and spatial coverage, and, therefore, multi-altimeter data are often used to monitor lake levels. Restricted by the accuracy of waveform processing and the interval period between different altimetry missions, the accuracy and the sampling frequency of the water level series are typically low. By processing and merging data from eight different altimetry missions (Envisat, ICESat-1, CryoSat-2, Jason-1, Jason-2, Jason-3, SARAL, and Sentinel-3A), the developed datasets provided the water level changes for 361 lakes (larger than 10 km^2) in the TP from 2002 to 2021 (181 lakes for the time series from 2002 to 2021 and 180 lakes for the time series from 2010 to 2021). The period for the lake level change series, which affords high accuracy, can be much longer for many lake systems. The present datasets and associated approaches are valuable for calculating the changes in lake storage, trend analyses of the lake levels, short-term monitoring of the overflow of lakes, flooding disasters on the plateau, and the relationships between changes in the lake ecosystems and changes in the water resources.

1 Introduction

As primary water reservoirs, lakes not only play an important role in the supply and adjustment of surface water but also reflect the impact of climate change and human activities on regional and global environmental change (Adrian et al., 2009; Schindler, 2009; Song et al., 2015; Chen and Liao, 2020). The water level of lakes is a key indicator for regional climate change and human disturbance. Generally, it is assumed that the changes in lake bottoms are very slight over decades, so understanding the changes in lake levels can help to evaluate the impact of climate change and human activities on regional water resources. Observation by use of a water gauge is the traditional method to measure the changes in water levels in lakes; *in situ* gauge measurement of lakes can afford high precision but such equipment is expensive to maintain and challenging to operate in remote areas. Furthermore, the total number of monitoring stations has decreased in recent years (Frappart et al., 2006; Kleinherenbrink et al., 2014), and lake level data in many countries and regions are not freely available to the public. Alternatively, satellite altimetry technology is an effective tool that can be used to measure the dynamics of the surface elevation of the Earth and has been successful in measuring lake levels. The Tibetan Plateau (TP), known as the Roof of the World and the Water Tower of Asia, has numerous and some of the largest natural lakes in the world, and because of its high altitude and the near absence of human disturbances, the plateau is an important location for studying global change. Changes in the water level in lakes are one of the important indicators for the water balance of the TP and these are directly affected by temperature, precipitation, evaporation, glaciers, perennial snow cover, and permafrost (Zhang et al., 2012; 2013a; 2013b). The TP is the source of many major rivers, and more than 1.4 billion people depend on water resources from the plateau (Pritchard, 2017). However, due to the vastness and remoteness, it is a challenge to set up *in situ* monitoring stations. There are only a few lakes (such as Qinghai Lake, Namtso, and Yamdrok Yumtso) with *in situ* gauge stations for lake level measurements (Zhang, 2018). Most lakes in the TP lack such a measurement capability making it difficult to understand the long-term spatial and temporal characteristics regarding the evolution and dynamics of the water levels of the lakes.

Satellite altimetry has become the most important means to measure lake levels and their changes in the plateau. Numerous studies have focused on the use of satellite altimeters for measuring changes in lake levels in the TP. For example, Gao et al. (2013) employed multi-altimeter data from Envisat, CryoSat-2, Jason-1, and Jason-2 to examine water level changes at 51 lakes between 2002 and 2012 in the OTP. Zhang et al. (2011) used Ice, Cloud, and the land Elevation Satellite (ICESat) data to determine changes in lake levels in Tibet from 2003 to 2009. Hwang et al.(2016) obtained two decades of lake level measurements at 23 lakes in the TP from the T/P-family altimeters. Song et al. (2015) combined ICESat-1 and Cryosat-2 altimetry data to access the water level dynamics of Tibetan lakes from 2003 to 2014. Kleinherenbrink et al. (2015) and Jiang et al. (2017) used the CryoSat-2 data to measure changes in the water levels at 125 lakes and 70 lakes in the TP, respectively. Hwang et al. (2019) constructed a lake level time series for 61 lakes on the TP between 2003 and 2016 and discussed the trends of the time series. Li et al. (2019) constructed high-temporal-resolution water level datasets for 52 large lakes on the TP. These studies in the TP reveal that estimation of the lake levels with a given radar altimeter is often limited by temporal and spatial coverage, and, therefore, multiple altimeters are needed to obtain multiple decades of changes in the water levels of lakes. Although some websites also provide open access lake level data in the TP, the number of lakes is limited, e.g., Hydroweb has only 36 lakes and DAHITI has only 62 lakes in the TP (Cretaux et al. 2011; Schwatke et al. 2015). However, due to the large size of the radar altimeter footprint and contaminations from the steep lakeshore or surrounding land, the observations of lake levels via satellites are noisy, and it is difficult to obtain the distance from the altimeter to the nadir points. Therefore, waveform retracking processing may be used to remove the contamination by land signals when lake levels are retrieved from multi-altimeter data. In this study, by combining eight sets of altimeter data from Envisat, ICESat-1, CryoSat-2, Jason-1, Jason-2, Jason-3, SARAL, and Sentinel-3A, the trends of the changes in the water levels for 361 lakes (>10 km^2) in the TP during 2002-2021 were estimated using retracking and outlier detection algorithms.

The primary objective of this study was to determine the changes in the water levels of 361 lakes in the TP from multi-altimeters and evaluate the accuracy of the time series and the performance of the multi-altimeter data with respect to monitoring the long-term variations in the water levels of the lakes. Readers can access the dataset described in this paper at https://doi.org/10.1594/PANGAEA.973443 (Chen et al., 2021), and comparison of our study with related previous studies is shown in Table 1.

Table 1. Comparison of this study with previous studies

Reference	No. of Lakes	Period	Data Source	Dataset Public or not
Jiang et al. (2017)	70	2003-2015	IceSat-1, Cryosat-2	N
Zhang et al. (2017)	68	1989-2015	IceSat-1, Landsat	N
Li et al. (2017)	167	2002-2012	IceSat-1, Envisat	N
Hwang et al. (2019)	59	2003-2016	Jason-2/3, SARAL, IceSat-1, Cryosat-2	N
Li et al. (2019)	52	2000-2017	Jason-1/2/3, Envisat, Cryosat-2, IceSat-1	Y
Zhang et al. (2019)	62	2003-2018	IceSat-1/2	N
Luo et al. (2021)	242	2003-2019	IceSat-1/2	N

Hydroweb	36	1993-2022	ERS-2, Envisat, T/P, IceSat-1, SARAL, Jason-1/2/3, Cryosat-2, Sentinel-3A	Y
DAHITI	62	2003-2022	ERS-2, Envisat, SARAL, Sentinel-3A, Cryosat-2, IceSat-1, Jason-2/3,	Y
This Study	361	2002-2021	Envisat, SARAL, IceSat-1, Cryosat-2, Jason-1/2/3, Sentinel-3A	Y

2 Study area and data

2.1 Study area

The TP is in the southwest of China and covers about 27% of the total area of China (Zhang et al., 2002), and its location and details are shown in Fig.1. There are more than 1000 lakes of >1 km^2 (Wan et al., 2016) in the TP, most of which belong to inland drainage systems. Based on coverage by altimeter data, 361 lakes of >10 km^2 in the TP were selected as the objects of study. Among these lakes, there were 13 lakes of > 500 km^2, 79 lakes of 100-500 km^2, 69 lakes of 50-100 km^2, and 200 lakes of 10-50 km^2. Most of these lakes are inland lakes with surface runoff, precipitation, snow and ice melting, springs, and underground runoff as their main sources of water recharge. Due to minimal impact by human activity, changes in the water levels in the lakes in the region are driven mainly by natural factors such as precipitation and temperature, which are important indicators of changes in the regional climate and the ecological environment.

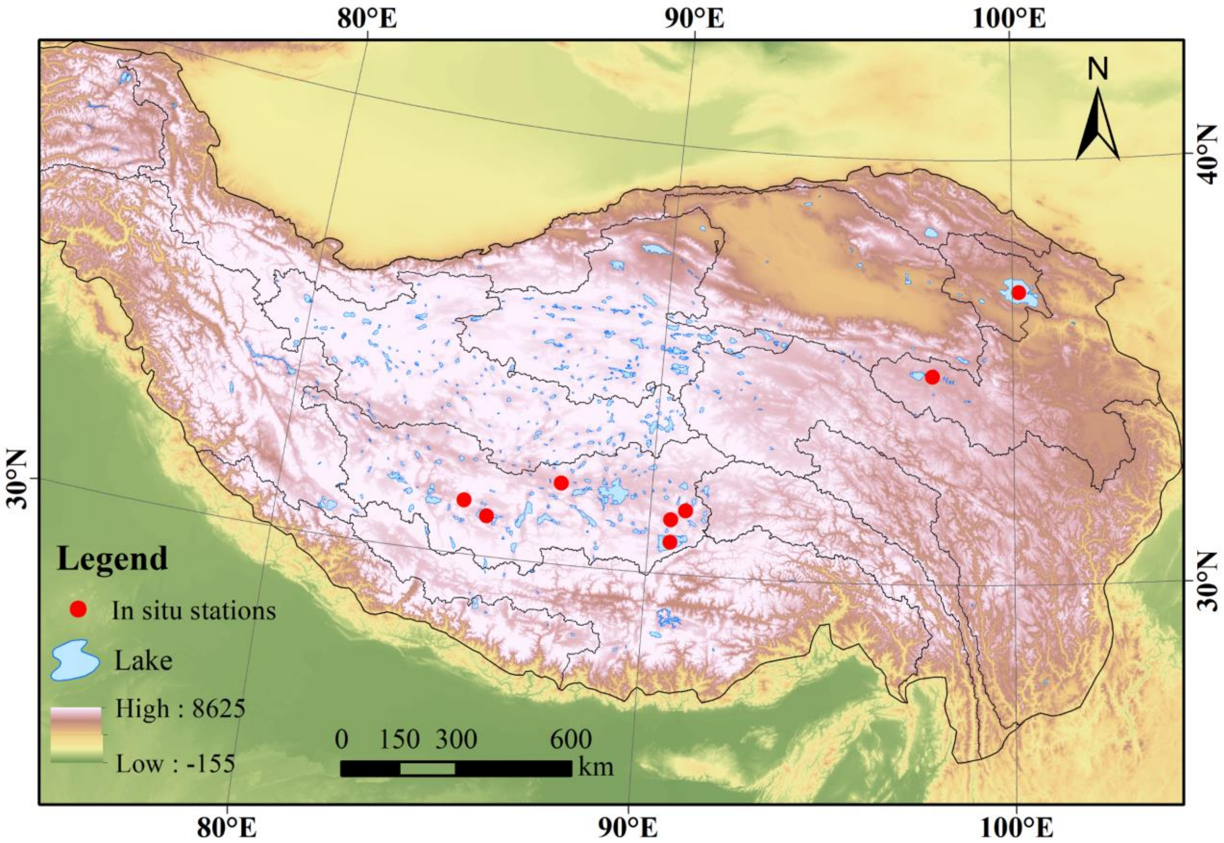

Fig 1. Location and distribution of lakes in the TP （The DEM of the base map is from the Global Multi-resolution Terrain Elevation Data 2010（GMTED2010）(GMTED: https://topotools.cr.usgs.gov/gtmed_viewer/)

2.2 Data

2.2.1 Multi-altimeter data

Eight sets of altimeter data from Envisat, ICESat-1, CryoSat-2, Jason-1, Jason-2, Jason-3, SARAL, and Sentinel-3A were used to extract the water levels of the lakes in the TP to obtain the lake level time series with high-space coverage. The details of the multi-altimeter data are given in Table 2. Envisat, CryroSat-2, and Sentinel-3A data provided by the European Space Agency (ESA) were available for 121, 352, and 106 lakes, respectively. Jason-1, Jason-2, and Jason-3 data provided by the Centre National d'Etudes Spatiales (CNES) and the National Aeronautics and Space Administration (NASA) were available for 48, 71 and 28 lakes, respectively, due to the relatively sparse ground tracks. Note that Jason-1/2 experience interlaced orbit (Jason-2 from Oct. 2016 to June 2017, Jason-1 after February 2009) which increasing the spatial coverage of Jason-1/2. ICESat-1 data provided by NASA were available for 124 lakes. SARAL is a joint mission of the Indian Space Research Organization (ISRO) and CNES and is a continuation of the Envisat mission. SARAL (Steunou et al. 2015) data were available for 135 lakes in the TP. ICESat-1 is a lidar altimeter, distinct from above radar altimeters. Its technique provides high spatial resolution and small footprint, but results in less measurements over time.

Table 2. Details of the multi-altimeter data used in this study

Mission	Sensor	Duration	No. of lakes	Repeat period （days）	Width[1] of footprint (km)
Envisat	RA-2	2002.05-2012.04	121	35	20
ICESat-1	GLAS	2003.02-2009.10	124	91	0.07
CryoSat-2	SIRAL	2010.07-2021.07	352	369 (30d sub-cycle)	1.6 (across), 0.3 (along)
Jason-1	Poseidon-2	2002.01-2012.03	48	9.92	30
Jason-2	Poseidon-3	2009.12-2017.05	71	9.92	30
Jason-3	Poseidon-3B	2016.02-2020.12	28	9.92	30
SARAL	Altika	2013.03-2016.05	135	35	8
Sentinel-3A	SRAL	2016.03-2019.09	106	27	1.75 (across), 0.33 (along)

[1] the footprint for SAR/SARin can be approximated by a rectangle given with the footprint width in across track and along track

In addition, a dataset on the shapes of the lakes generated by Wan et al. (2016) was selected to determine whether the altimeter data encompassed the lakes, and a buffer of 1 km around the shape of the lake was generated to determine the change in the boundary of the lakes during the past 20 years.

2.2.2 *In situ* data

In situ data on eight lakes were used to validate reliable information on the lake level time series from the multi-altimeter data. Table 3 lists details of the *in situ* data on the eight lakes. The *in situ* data for Qinghai Lake and Ngoring Lake were from the Hydrology and Water Resources Survey Bureau in Qinghai Province and from the Yellow River Commission of the Ministry of Water Resources, respectively, and the *in situ* data on Bamco, Dagzeco, Dawaco, Namco, Pungco and Zhari Namco were from the Institute of Tibetan Plateau Research, Chinese Academy of Sciences (Lei, 2018; Wang, 2018).

Table 3. Details of the *in situ* data for eight lakes as used for validation

Lake name	Date	Coordinates (°)	Reference	Mode[3]
Qinghai Lake	2010.05-2019.09	100.20, 36.89[1]	1985[2]	Absolution
Ngoring Lake	2010.01-2015.12	97.70, 34.90	1985	Absolution
Bamco	2013.06-2017.10	90.58, 31.27	Customize	Relative
Dagzeco	2013.06-2016.10	87.52, 31.89	Customize	Relative
Dawaco	2013.06-2016.10	84.96, 31.24	Customize	Relative
Namco	2007.04-2016.12	90.60, 30.74	Customize	Relative
Pungco	2014.05-2017.10	90.97, 31.50	Customize	Relative
Zhari Namco	2012.12-2017.10	85.61, 30.93	Customize	Relative

[1] the first figure is longitude, the second figure is latitude

[2] 1985 indicates the 1985 national height datum of China

[3] Absolute mode is the elevation relative to the geoid, and relative mode is the elevation relative to the average value (set to 0) of the *in situ* data

3 Methods

3.1 Extraction of lake water levels

With respect to the extraction of the water level data from the satellite altimetry, there is uncertainty as to whether there is a valid footprint falling on the lakes; this problem can be addressed by comparing the geographic coordinates of the footprints with the shape of the dynamic dataset for the lake. However, it would take considerable time to extract the dynamic shape file. A static shape dataset for the TP was used in this study (Wan et al., 2016); we also generated a 1 km buffer for the shape to solve the situation regarding the changes in the boundary of lakes during the past 20 years. After picking out the available footprints, the height of the lake surface height can be calculated based on using Eq. (1) for each footprint:

$$H = Alt - \left(R_{range} + \Delta R_{dry} + \Delta R_{wet} + \Delta R_{iono} + \Delta R_{tide} + \Delta R_{correction}\right) - N_{geoid} \quad (1)$$

where Alt is the satellite altitude, R_{range} is the distance between the altimeter and the lake surface, ΔR_{dry} is the dry troposphere, ΔR_{wet} is the wet troposphere, ΔR_{iono} is the ionospheric correction, ΔR_{tide} includes the solid earth tide and the pole tide, N_{geoid} is the geoid height with respect to the ellipsoid, for which the 2008 Earth Gravitational Model (EGM2008) was used in this study (Pavlis et al., 2012), and $\Delta R_{correction}$ stands for the retracking value $\Delta R_{retrack}$ for radar altimetry and the saturation correction $\Delta R_{saturation}$ for the laser altimetry. With the exception for $\Delta R_{retrack}$, all the corrections above are included in the altimetry data product.

3.1.1 Waveform retracking

The accurate measurement of the distance from the altimeter to the nadir points in inland water bodies presents a significant challenge due to the potential interference or submergence of water signals by those from adjacent land areas. Consequently, the implementation of retracking is of great importance in mitigating the influence of land signals when utilizing radar altimetry data for inland water body studies (Martin et al., 1983; Lee et al., 2008). In this study, we employed the automatic multiscale-based peak detection retracker (AMPDR) (Chen et al., 2021). The Jason-2/3, Sentinel-3A/B, and CryoSat-2 satellites are all suitable for providing precise measurements, with average accuracies of 0.18 m, 0.14 m, and 0.15 m when compared to gauges, respectively. However, sometimes there were biases for the retracking caused by the hooking effect or the scatter signal of the off-nadir point for Jason-1, Envisat, and SARAL. Therefore, some modifications for AMPDR were adopted for Jason-1, Envisat, and SARAL data in this study.

To ensure that the different typologies of multi-waveforms can be dealt with, we implemented a two-step process for the modified AMPDR here. The steps of the modified retracker are illustrated in Fig. 2. The optimal retracked range was determined using several criteria:

(1) The optimal retracked levels should be within the range $H_{DEM} \pm 20$ m.

(2) For periods with continuous data (where the gap between cycles is less ten days), the *DistanceThresh* in AMPDR was adjusted to minimize the median difference in water levels derived from neighboring cycles.

(3) For non-continuous data (where the gap between cycles exceeds ten days or several months), error filtering was applied to reduce the standard deviation of water levels in the current cycle, helping to minimize variability over time.

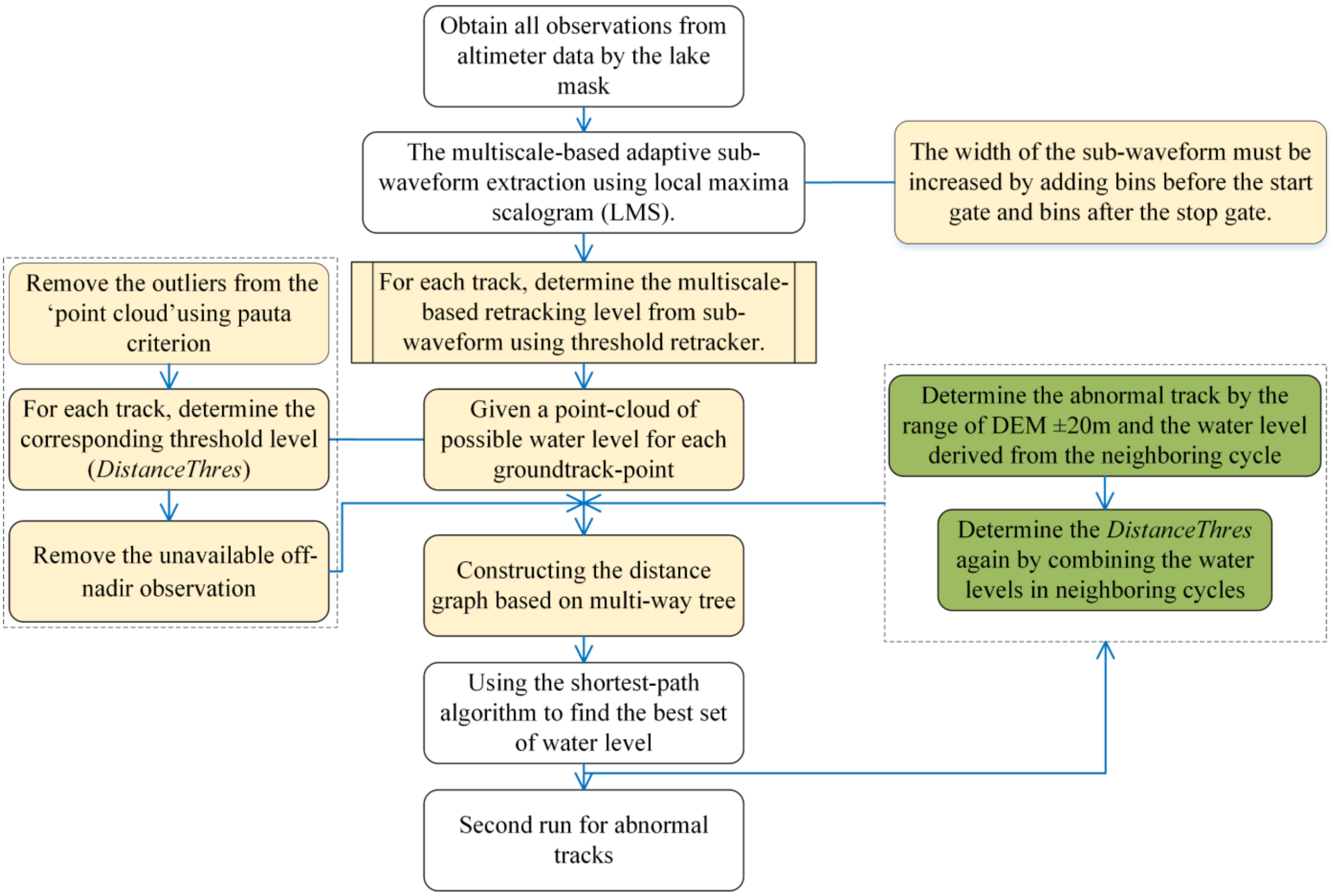

Fig. 2. Flowchart outlining the waveform retracking process. Steps with a yellow background are the preparation steps for using the shortest path algorithm. Steps with a green background are the retracking for the abnormal track by the selected DEM.

In the initial run, the standard AMPDR retracker was applied to calculate the lake level time series, with further details on the AMPDR's definition and implementation provided in Chen et al. (2021).

Following this, a second run of AMPDR was performed to retrack abnormal tracks identified by checking if the current cycle's water level fell within the range of the Digital Elevation Model (DEM) ± 20 m and by comparing it with water levels from neighboring cycles, particularly when a significant discrepancy or abrupt change was detected in current cycles. In this second run, the *DistanceThresh* parameter in AMPDR was defined using one of the three smallest second-order difference quotients of the cumulative distribution function (CDF) of the rounded water levels (smallest value was used in the initial run). This approach ensured that the *DistanceThresh* aligned with the median of the neighboring cycle water levels.

Additionally, a retracking point from the OCOG algorithm was incorporated into the AMPDR to assist in constructing the "point cloud" and CDF. This integration addresses specific cases where AMPDR's adaptive thresholding may encounter challenges. An example of the modified two-step retracker in operation is illustrated in Fig. 3.

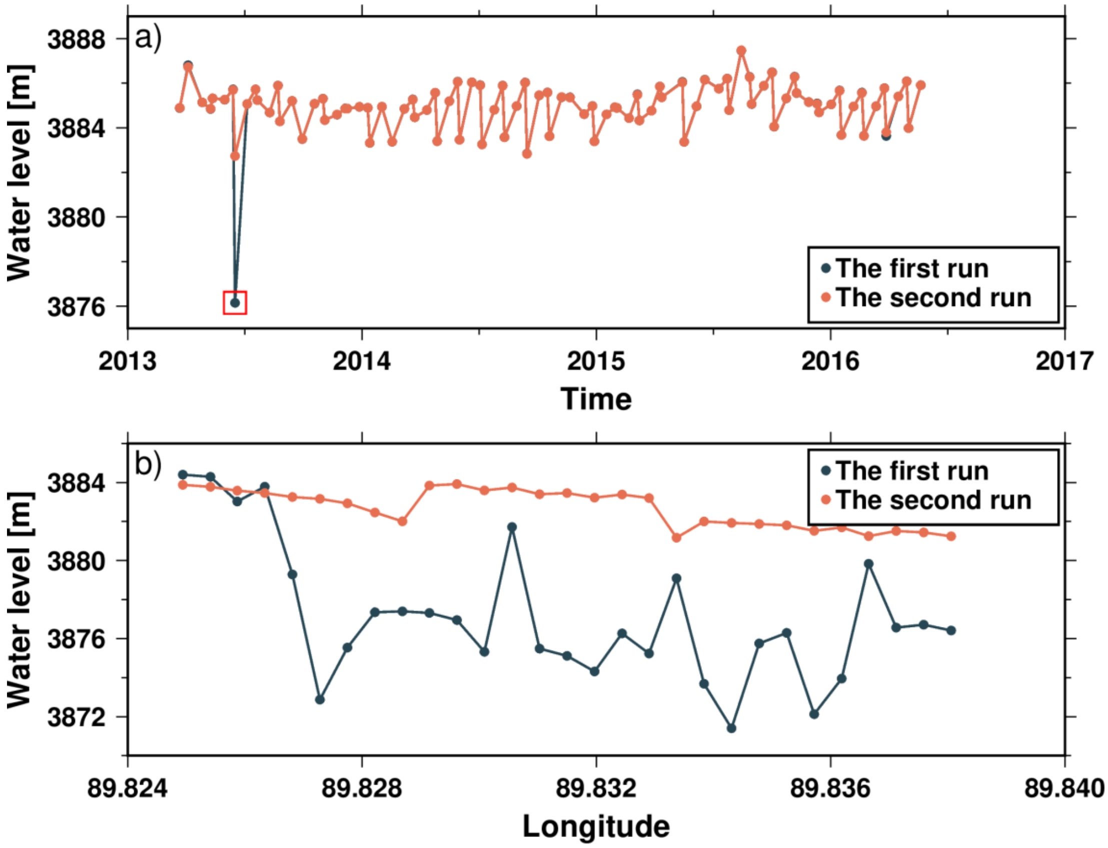

Fig. 3. An example of the operation of the modified two-step retracker. (a) shows the two water level time series for processing by the two-step retracker. (b) shows the along-track water level in the red rectangle from (a) when processing by the two-step retracker.

3.1.2 Waveform Selection

By selecting observations within a 1 km buffer around the lake boundary, we capture additional data points. However, this approach can also introduce uncertainty, as some observations may contain noisy waveforms that complicate the retracking process. Such noise may result from signals reflected off surrounding terrain or from off-nadir observations. To ensure accuracy in constructing the lake level time series, noisy observations should be removed before constructing the lake level time series. Waveform classification is an effective method for identifying the noise observations. Waveform classification has proven effective in identifying these noisy signals, and various methods have achieved strong results (Göttl et al., 2016; Lee et al., 2016; Marshall and Deng, 2016; Shen et al., 2017).

Different from the previous study that classify waveforms into multiple categories, this study focuses on separating waveforms into noise and non-noise categories using a random forest (RF) classifier. The RF classifier was trained on a dataset of approximately 300 waveforms per altimeter, using observations over inland lakes. Key features for classification included: the pulse peakiness (Strawbridge and Laxon, 1994), the mean value of the waveform, the skewness of the waveform, the kurtosis of the waveform, the amplitude of the waveform, the width of the waveform determined by the Offset Center of Gravity (OCOG) retracker (Bamber 1994), the bin position corresponding to the center of gravity determined by the OCOG retracker, and the peakiness of the left and right pulse (Ricker et al., 2014). After removing noisy observations, tracks with fewer than five valid observations were excluded from further analysis.

3.1.3 Construction of time series

Despite removing the noise footprints through waveform classification, outliers remain in the lake level time series for each cycle of certain altimeters. To address this, any point in each cycle with a difference exceeding three times the standard deviation (3σ rule) was removed. Then, the lake level time series was estimated using the R package tsHydro (https://github.com/cavios/tshydro). The core of tsHydro is a state-space model consisting of a process model and an observation model, providing a robust time series for altimeter observations.

$$H_i^{true} = H_{i-1}^{true} + \sqrt{t_i - t_{i-1}}\sigma_{RW} z_i, \qquad z_i \sim N(0,1) \tag{2}$$

$$H_{ij}^{obs} = H_i^{true} + \sigma_{obs}\varepsilon_{ij} \tag{3}$$

The process model is used to describe the relationship between the true water level $H^{(true)}$, and the observation model is described by the observed water level $H^{(obs)}$, with an error term ε_{ij}, being used to describe the relationship between $H^{(obs)}$ and $H^{(true)}$, t_i is the time of the i-th time step, j is the number of observations in given time, and z_i is a random noise term following a standard normal distribution. The scaling parameter σ_{RW} is defined as the standard deviation of the random walk in a time step. The model is described in detail by Nielsen et al. (2015). The predictions of the true heights $\hat{H}^{(true)}$ is the estimate of the water level of the lake for each cycle. Meanwhile, the standard deviation of each cycle was reserved to evaluate the uncertainty of the time series.

3.2 Fusion of multi-altimeter time series

It is not uncommon that the geoid between different altimeters should be different. Before merging the lake level from different altimeters, the geoid should be unified as WGS84/EGM 2008. The reference system of Jason-1/2/3 is the Topex/Poseidon (T/P) ellipsoid system instead of the WGS84 system, thus it was necessary to perform an ellipsoid system transformation from T/P to WGS84 by subtracting 0.71 m from the vertical height (Bhang et al., 2007).

Due to the variations in orbits and the disparities between instruments, systematic biases existed among the lake level time series extracted from the multi-altimetry, although they were corrected to the same reference system. In most studies (Li et al., 2019; Gao et al., 2013; Huang et al., 2016), the altimeters with the longest overlap period would be merged for the first time, but there may be some special situations whereby for some lakes the lake level time series for each altimeter cannot be merged. In this study, the dynamic reference time series was used to merge the lake-level time series. We first merged the two products with the longest period for the time series and chose the altimeter-derived water level with the longer time series as the baseline. Then systematic biases between another altimeter and the baseline will be removed by subtracting the mean discrepancy during the overlap period compared with the reference series (Lee et at., 2011; Kropáček et al., 2012) according to Eq. (4). To ensure consistency, we only merged time series when the average difference between the reference series ($\overline{Series1_{ref}}$) and current satellite series ($\overline{Series2_{ini}}$) was less than 10 meters. Then, the same process was applied to the remaining products and the merged products connecting the three altimeters. The result for the merged altimetry data when all sensors are available is shown in Fig. 4a and 4b.

$$Series2_{cor}(t_i) = Series2_{ini}(t_i) + \left(\overline{Series1_{ref}} - \overline{Series2_{ini}}\right) \tag{4}$$

where $Series2_{ini}(t_i)$ is the uncorrected lake level at time t_i, $\overline{Series1_{ref}}$ is the mean value of the water level time series from the baseline, and $\overline{Series2_{ini}}$ is the mean value of the other water level time series at the same time as $\overline{Series1_{ref}}$.

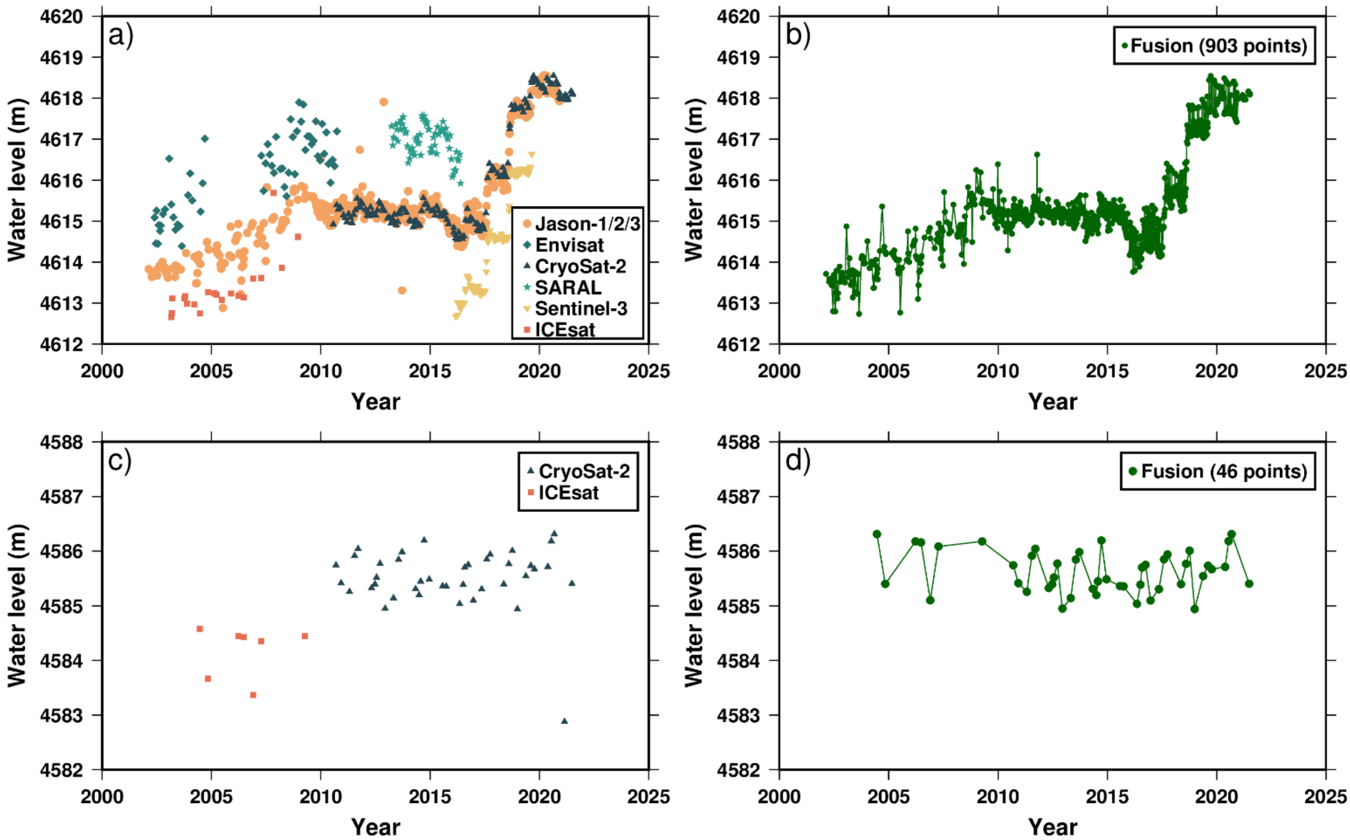

Fig. 4. The process of merging multi-altimetry data. (a) The water level data from eight altimeters in Zhari Namco; (b) The fusion water level data in Zhari Namco ; (c) The water level data from two altimeters in Cuona Lake; (d) The fusion water level data in Cuona Lake.

Nevertheless, not all the lake-level time series can be merged successfully following the steps outlined above. For instance, Cuona Lake, Xiasa'er Co, and Bei Hulsan Lake cannot be merged successfully because only ICESat and Cryosat-2 were available on these lakes before 2013, while there is no overlap period between ICESat and Cryosat-2. In this study, 18 lakes were found to have similar problems.

A combined linear-periodic-residual model (Liao et al., 2014) was used to simulate and forecast the lake-level time series in the no-overlap period to merge the two altimeters with no overlap period. Numerous studies (Medina et al., 2008; Irvine et al., 1992; Kropáček et al., 2012; Lee et al., 2011) have indicated that the changes in the lake-level exhibited a clear linear trend and inter-periodic fluctuations at some scales such as 10 or 20 years in line with Eq. (5).

$$x_i = a + bt + \sum_{i=1}^{p}\left(\alpha_i cos\frac{2\pi}{T_i}t + \beta_i sin\frac{2\pi}{T_i}t\right) + \varepsilon_t \quad (5)$$

where a and b are the linear components of the lake-level time series, T_i indicates the ith periodic component, and ε_t is the remaining random component after removal of the linear and periodic components.

A result for the merged altimetry data of Cuona Lake is presented in Fig. 4c and 4d. First, singular spectrum analysis (SSA) algorithms are used to reduce the noise of the lake-level time series and to extract the effective fluctuating signal. Second, we decomposed the fluctuating signal into a linear component, a periodic component, and the remaining residuals using a simple linear fitting, wavelet analysis; then simple regression analysis, trigonometric function fitting, and the autoregressive-moving-average (ARMA) model were used to fit each component, respectively. Finally, we combined the modelling data of each component and obtain the simulated water level. The diagram for fusion processing is shown in Fig. 5.

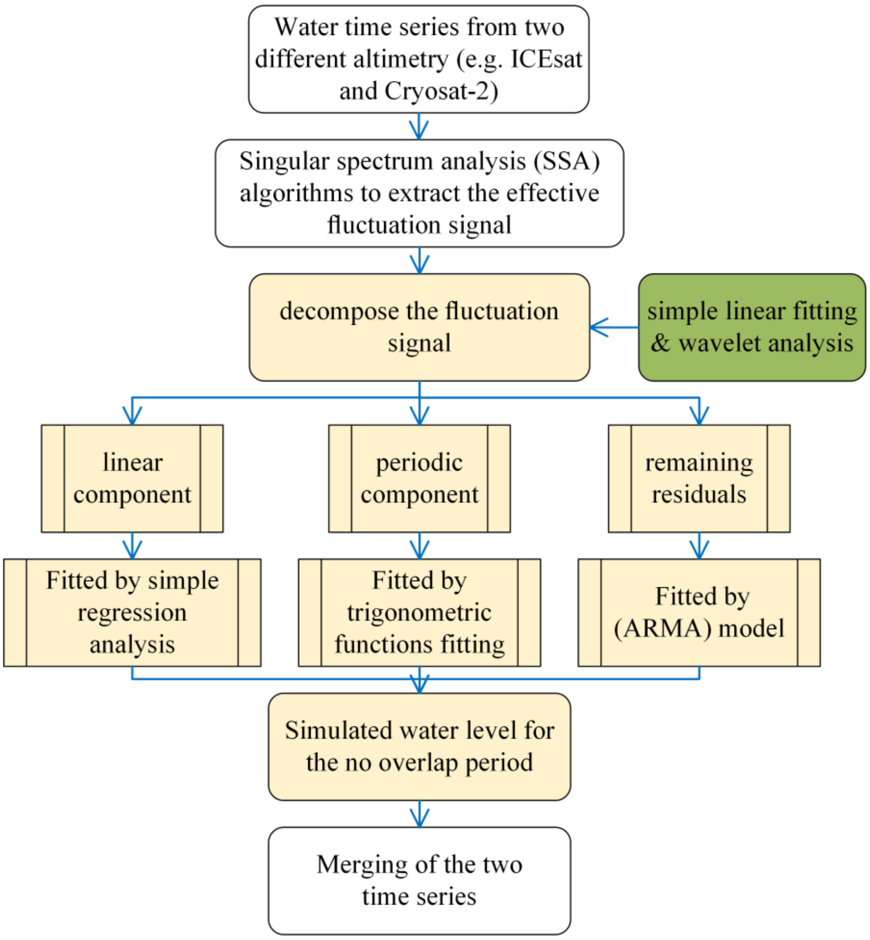

Fig. 5. Flowchart of fusion processing for the water level time series from different altimeters. Steps with a yellow background indicate preparation for merging the time series.

3.3 Lake level annual change rate

The trends of lake level change can be estimated from the dataset. The periodic changes in the water level were simplified as one-year and half-year periodic changes according to the following expression for the lake level change:

$$H(t) + v = a + bt + c\cos(2\pi t) + d\sin(2\pi t) + e\cos(4\pi t) + f\sin(4\pi t) \quad (5)$$

where t is the time relative to the mean time, v is the residual, a is a constant, b is the trend, and c, d, e, and f are the coefficients of the periodic terms for one-year and half-year cycles. All of the above parameters were determined by the least-squares method.

4 Validation of data quality

4.1 Validation and accuracy of lake level time series

Due to the lack of *in situ* for the water levels of lakes in the TP, only *in situ* data for eight lakes were collected to validate the accuracy of the lake level time series, and the datums of these *in situ* data were unknown, so the comparison of the water level anomaly between *in situ* data and lake level in this study was performed by removing the mean value over the validation period. Fig. 6 shows the comparison of the water level anomaly between *in situ* data and lake level extracted from altimetry data. It can be seen that there is good consistency between *in situ* data and lake level extracted from altimetry data. Table 4 gives the statistical results for a comparison between the lake level time series and the in-situ data for the eight lakes. The results show that the accuracy for all eight lakes was less than 0.35 m, and the average accuracy was 0.213 m. Dawaco had the lowest root-mean-square errors (RMSEs) (0.149 m), and Ngoring Lake had the highest RMSEs (0.335 m), indicating that the results of this study are reliable and the accuracy of the time series can reach the decimeter level with respect to the monitoring inland lakes. At the same time, except for Dawaco, the lake levels obtained in this study agreed well with those from the *in situ* gauges, showing a good correlation (the correlation coefficients >0.60). Furthermore, it can be seen from the comparison between the satellite-derived lake levels and the *in situ* water levels for the eight lakes that the satellite-derived lake level series followed the gauged data quite well, especially for Qinghai Lake, Bamco, and Pungco (correlation coefficients >0.90).

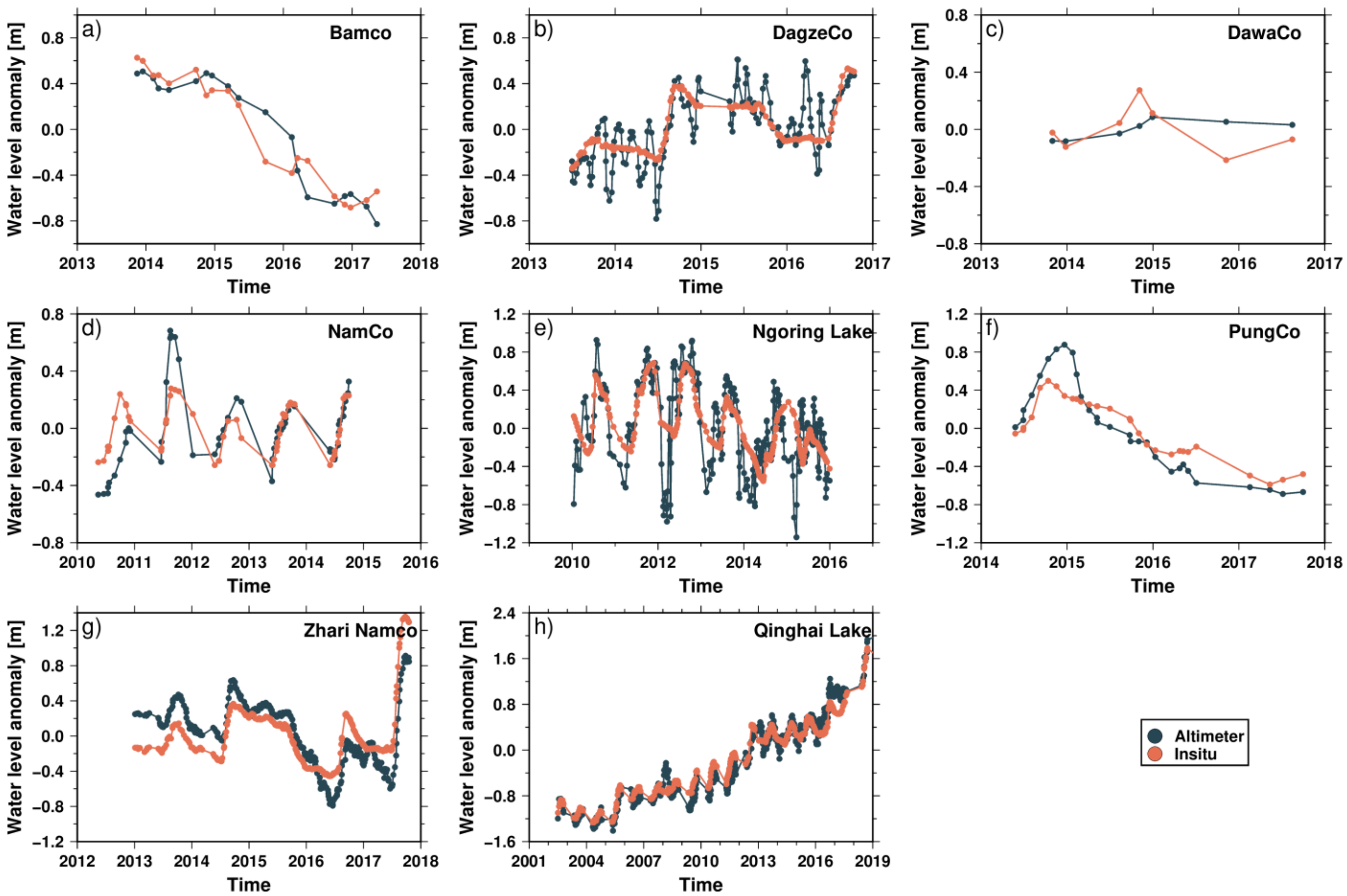

Fig. 6. Comparison of the water level anomaly between *in situ* data and lake level extracted from altimetry data

Table 4. Comparison between the lake levels in this study and the *in situ* water levels

Lake	Correlation coefficient	RMSE (m)	Number of validation points
Qinghai_Lake	0.977	0.190	570
Ngoring_Lake	0.635	0.335	284
Bamco	0.930	0.181	19
Dagzeco	0.744	0.199	156
Dawaco	0.209	0.149	7
Namco	0.738	0.179	60
Pungco	0.924	0.222	29
Zhari Namco	0.762	0.251	314

4.2 Cross-validation with similar products

We made a comparison of our product with three different lake level datasets provided by DAHITI, LEGOS Hydroweb, G-REALM (Global Reservoirs and Lakes Monitor), and Li et al.(2019). In Figure 7 and Appendix A, we compared the time series of water levels for 46 lakes from DAHITI, 40 lakes from LEGOS Hydroweb, 8 lakes from G-REALM, and 49 lakes from Li et al.(2019) against the lake levels from our study. The results indicate that the dataset in our study aligns consistently with the other three datasets. The median RMSEs are consistently below 0.30 m (with a value of 0.24 m for DAHITI, a value of 0.27 m for LEGOS Hydroweb, a value of 0.30 m for G-REALM, and a value of 0.26 m for Li et al.(2019), while the median correlation values consistently exceed 0.90 (with a value of 0.94 for DAHITI, a value of 0.96 for LEGOS Hydroweb, a value of 0.96 for G-REALM, and a value of 0.95 for Li et al.(2019)).

It should be noticed that occasional discrepancies in the statistics may arise from variations in the processing chain for different datasets. For example, Xuelian Lake exhibits an RMSE of 0.79 m when compared to data from DAHITI, whereas it demonstrates a markedly reduced RMSE of 0.29 meters when compared to LEGOS Hydroweb. Moreover, observations for Zhari Namco across all four datasets reveal that our study's results consistent closely with others, showing an RMSE of approximately 0.30 meters.

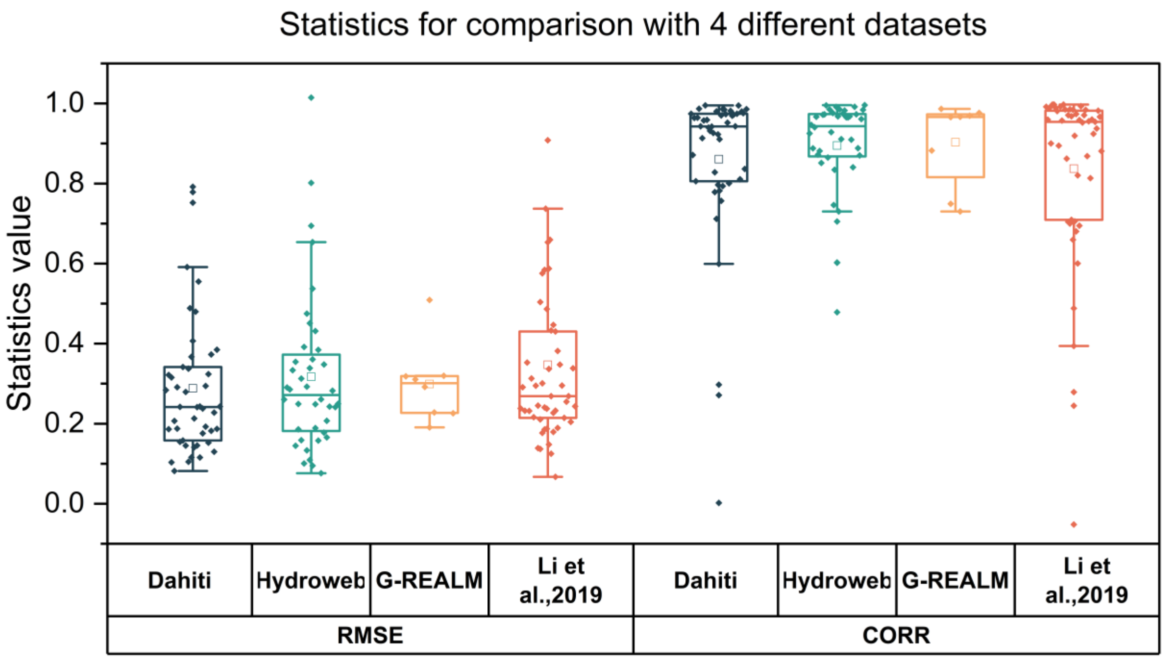

Fig. 7 Cross-validation of the lake levels in the TP derived from the present study with those provided by the DAHITI, LEGOS Hydroweb, G-REALM, and Li et al.(2019).

4.3 Potential source of error

A potential source of error in our dataset arises when the tracking window captures signals from nearby water bodies, such as other lakes or rivers, rather than the intended target lake. While the tracking window typically provides a valid waveform, the recorded signal may correspond to an unintended water body, leading to inaccuracies in lake level measurements. To mitigate this, we apply DEM-based height selection criteria, which filter lake level data to those within a defined range (e.g., $H_{DEM} \pm 20$ m). However, this approach is not fully correct, especially in regions where neighboring water bodies are within similar elevation ranges. Such cases could introduce inconsistencies in the time series for certain lakes, particularly where OLTC (Open Loop Tracking Command) DEM values have changed over time, affecting the tracking window's focus. Future improvements in the tracking algorithm and additional validation steps could help reduce these potential errors.

4.4 Description of the data set

The lake-level change time series for 361 lakes (181 lakes for the time series from 2002 to 2021 and 180 lakes for the time series from 2010 to 2021) are available on the datasets. The water level time series for each lake are archived as 361 entities based on the names of the lakes, with a table describing all the information about each lake. The first part of each file describes the basic information of the lake-level time series, such as the geographic information, the start date of the time series, the end date of the time series, and the number of data points. Next is the main part for each file: the first row stands for the time, the second row records the water level, the third row is the uncertainty of the water level, and the final row stands for the source of the data. It should be noted that the uncertainty of the water level time series was calculated using the standard deviation for the processing in constructing the time series with the "R" package.

5 Spatio-temporal analysis of changes in lake levels in the TP

The spatio-temporal changes in lake levels across the TP can be analysed using this dataset. In summary, water level changes were monitored for a total of 181 lakes from 2002 to 2021, while the remaining 180 lakes were monitored from 2010 to 2021. Overall, lake water levels exhibited a clear upward trend from 2002 to 2021, with a weighted average annual change rate of 0.179 m/y (Table 5). Approximately 80% of the lakes showed rising water levels. The total area of lakes with increasing water levels (29930 km²) significantly exceeds that of lakes with decreasing levels (4197 km²), indicating a steady increase in water reserves across lakes on the TP.

Based on the changes in the water levels of the lakes (see Appendix B), the spatial patterns for the trends in the lake levels during 2010-2021 are shown in Fig. 8. Overall, the lake levels in the TP show a clear rising trend, and the overall average annual rate of change, weighted by lake size, is 0.111 m/y; further, the number of lakes with rising water levels accounts for 76% of all lakes. The total area of lakes with rising water levels (5501 km^2) is much larger than the total area of lakes with falling water levels (2233 km^2), indicating that the water storage of lakes on the TP is growing. From the distribution of the annual average rate of change of lake levels (Fig. 9), among the monitored lakes between 2010 and 2021, there are more lakes with rising water levels than those with falling water levels.

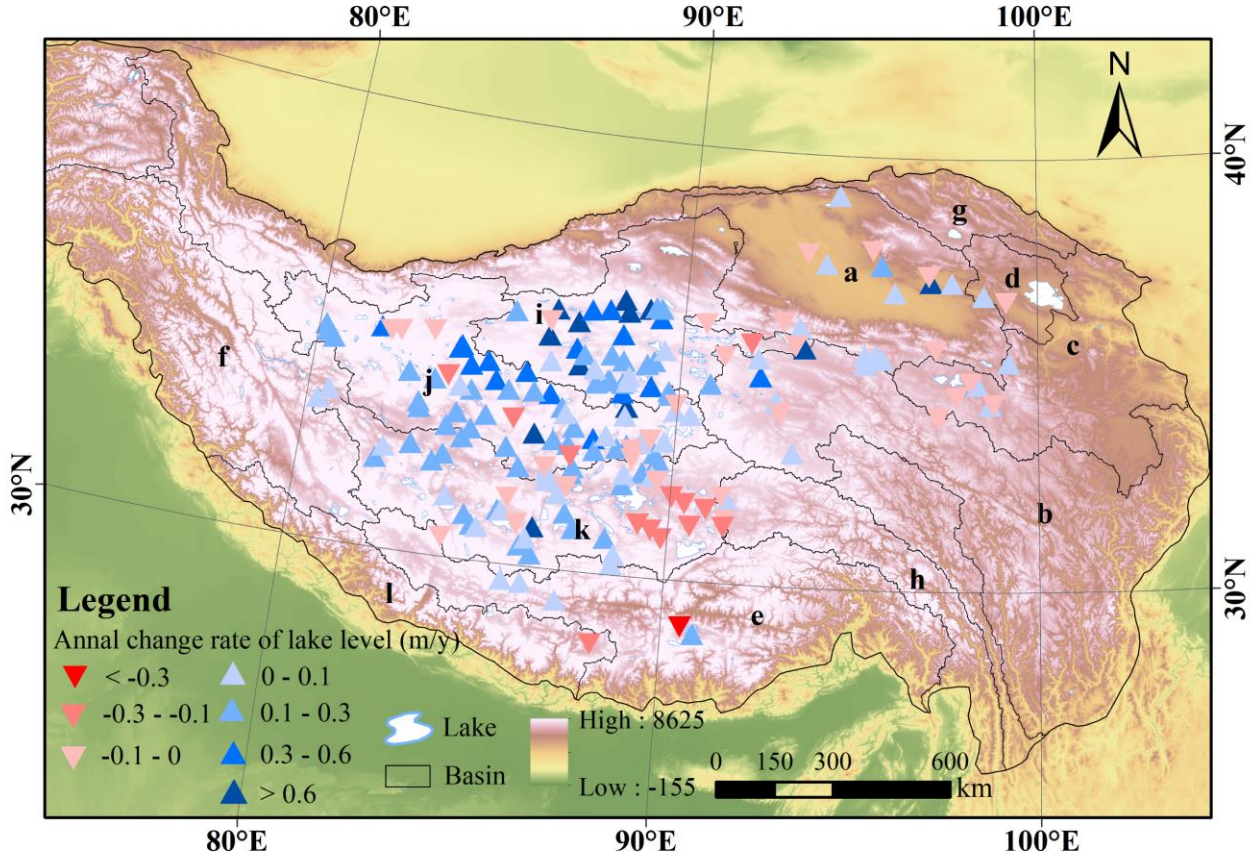

Fig. 8 Spatial distribution of trends in the changes in the water levels of lakes on the TP during 2010-2021. The black line shows the boundary of the basin of the TP (referred to Wan et al., 2016). The lowercase letters indicate different basins. The

DEM of the base map is from the Global Multi-resolution Terrain Elevation Data 2010（GMTED2010）(GMTED: https://topotools.cr.usgs.gov/gtmed_viewer/)

(a Qaidam; b Yangtze River; c Yellow River; d Qinghai Lake; e Brahmaputra River; f. Indus River; g Hexi Corridor; h Nu Jiang River; i Northern Inner Plateau; j Central Inner Plateau; k Southern Inner Plateau; l Ganges River)

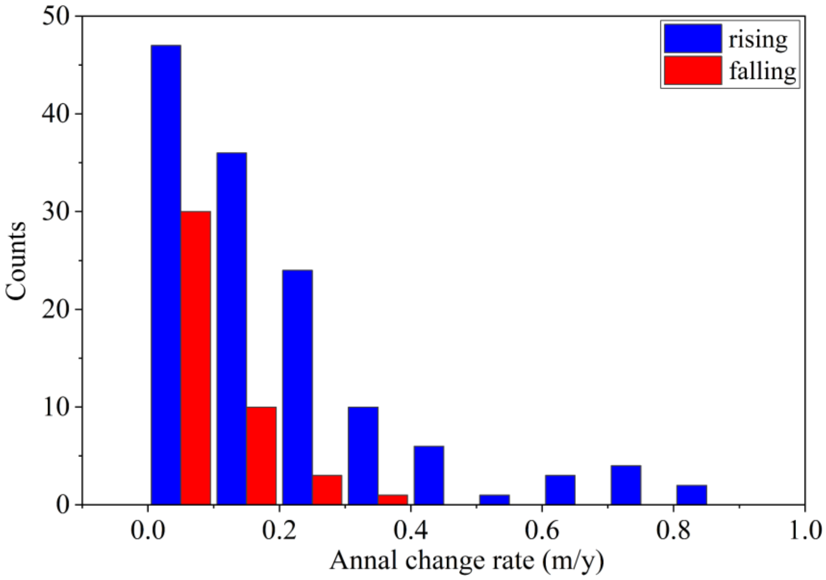

Fig. 9 Histogram of trends in the lake level changes on the TP during 2010-2021.

Analysis of the trends in the changes in the water levels based on the lake areas shows that there is a clear rising trend in the water level of lakes on the TP, the most significant trends in the case of rising water levels being for larger-size lakes (>500 km^2) and also for smaller size (<50 km^2) lakes, and intermediate size lakes showing significant rising trend (Table 6).

Table 5. The trends in the changes in the water levels of the lakes in the different basins of the TP during 2002-2021 and 2010-2021

Basin	No. of lakes	No. of lakes with rising water levels	Annual rate of rise (m/y)	Area of lakes with rising water levels (km^2)	No. of lakes with decreasing water levels	Annual rate of fall (m/y)	Area of lakes with decreasing water levels (km^2)
Qaidam	16 [6]	10 [3]	0.129 [0.064]	616 [369]	6 [3]	-0.014 [-0.055]	342 [342]
Yangtze River	7 [7]	5 [6]	0.089 [0.165]	357 [215]	2 [1]	-0.002 [-0.021]	29 [68]
Yellow River	8 [3]	4 [3]	0.074 [0.062]	131 [1153]	4 [0]	-0.019 [/]	82 [/]
Qinghai	2 [1]	1 [1]	0.058 [0.190]	43 [4348]	1 [0]	-0.005 [/]	115 [/]
Brahmaputra River	6 [7]	4 [3]	0.080 [0.274]	83 [141]	2 [4]	-0.179 [-0.081]	122 [925]

Indus River	1	1	0.086	21	0	/	/
	[7]	[3]	[0.054]	[740]	[4]	[-0.077]	[869]
Northern Inner Plateau	37	34	0.420	1032	3	-0.104	240
	[43]	[39]	[0.340]	[6257]	[4]	[-0.059]	[266]
Central Inner Plateau	56	45	0.225	1537	11	-0.055	385
	[49]	[41]	[0.247]	[4144]	[8]	[-0.042]	[634]
Southern Inner Plateau	44	31	0.122	1664	13	-0.121	860
	[54]	[44]	[0.148]	[11954]	[10]	[-0.057]	[605]
Nujiang River	2	1	0.003	17	1	-0.005	20
	[1]	[0]	[/]	[/]	[1]	[-0.011]	[191]
Ganges River	1	0	/	/	1	-0.152	38
	[2]	[0]	[/]	[/]	[2]	[-0.076]	[297]
Hexi Corridor	/	/	/	/	/	/	/
	[1]	[1]	[0.189]	[609]	[0]	[/]	[/]

* The trends in the changes in the water levels of the during 2002-2021 are shown inside square brackets.
* The trends in the changes in the water levels of the during 2010-2021 are shown without square brackets.

Table 6. The trends for changes in the lake water levels in the TP during 2010-2021

Lake area/km^2	No. of lakes	Annual rate of change (m/y)	No. of lakes with rising water levels	Mean rate of rise (m/y)	No. of lakes with decreasing water levels	Mean rate of decrease (m/y)
[200,500]	4	0.004	3	0.054	1	-0.147
[100,200)	14	0.289	9	0.486	5	-0.066
[50,100)	24	0.126	15	0.257	9	-0.094
[10,50)	138	0.148	109	0.205	29	-0.064

To better understand the spatial distribution pattern of the changes in the water levels of the lakes, the trends for the changes in the water levels of the lakes in each basin of the TP were analysed (Table 5). Overall, during the period 2010-2021, the water levels of the lakes in all basins increased significantly, except for the Brahmaputra River Basin. The area of lakes with rising water levels was larger than that for lakes with decreasing water levels (Fig. 10). The water level changes in lake for each basin can be summarized as follows:

Qaidam Basin. A total of 16 lakes were monitored in the basin, of which 10 lakes showed a rising trend, with an average rising rate of 0.129 m/y and a total rising lake area of 616 km^2. The other 6 lakes showed a falling trend, with an average falling rate of -0.014 m/y and a total falling lake area of 342 km^2. The fastest rising lake in the basin is Tuosu Lake with an average annual rate of 0.724 m/y and the fastest declining lake is Dachaidan Lake with an average annual rate of -0.036 m/y.

Yangtze River Basin. 7 lakes were measured in the basin, distributed in the upper reaches of the Yangtze River source area. 5 lakes exhibit a rising trend, predominantly located in the relatively lower-altitude regions upstream, with an average rising rate of 0.089 m/y and a total rising lake area of 357 km². The remaining two lakes show a downward trend, concentrated in the southern part of the basin, along the northern slopes of the Kunlun Mountains, with an average decrease rate of -0.002 m/y and a total falling area of 29 km^2. Telashi Lake has the fastest rising water level at 0.326 m/y. Yelusu Lake is the largest lake in the basin with an average annual rate of 0.034m/y.

Qinghai Lake Basin. Xiligou Lake, with an area of 43 km^2, exhibits a rising water level with an average annual increase rate of 0.058 m/y. Conversely, Caka Salt Lake, covering 115 km^2, shows a declining water level, with an average annual decrease rate of -0.005 m/y.

Yellow River Basin. The water levels of 8 lakes were monitored in the basin, of which 4 lakes showed a rising trend with an average rate of 0.074 m/y and a total rising lake area of 131 km^2, and the other 4 lakes showed a decreasing trend with an average rate of -0.019m/y. In this basin, Ayongwuerma Co has the fastest rising water level with a mean rate of 0.174 m/y, and Xinxin Lake has the fastest declining water level with a mean rate of -0.053 m/y. The largest lake is Kuhai Lake with a mean rate of 0.099m/y.

Brahmaputra River Basin. A total of 6 lakes were monitored in the basin, mainly in the upper and middle reaches of the Brahmaputra River. Of these, four lakes show an increasing trend, with an average rise rate of 0.080 m/y and a total rising area of 83 km^2. The remaining two lakes exhibit a decreasing water level trend, primarily concentrated in the upstream portion of the Basin, with an average decline rate of -0.179 m/y and a total falling area of 122 km^2. The lake with the fastest rising water level is Bajiu Co, at 0.230 m/y, while the fastest decline is observed in Chen Co, at -0.349 m/y. Sengli Co, the largest lake monitored with an area of 83 km^2, has an average annual water level change rate of -0.009 m/y.

Indus River Basin. The monitored lake in this basin is Aiyong Co, with an average annual increase rate of 0.086 m/y and a total rising area of 21 km^2.

Inner Plateau Basin. The basin contains the Qiangtang Plateau and the Cocosili region, with a harsh natural environment and dry climate, and is the largest endorheic area on the TP. The water levels of 137 lakes were monitored in the basin, and 110 lakes have a rising trend with an average rising rate of 0.257 m/y and a total rising area of 4229 km^2. The remaining 27 lakes have a declining trend, mainly in the centre and north parts of the basin, with an average falling rate of -0.093 m/y and a total falling area of 1480 km^2. The fastest rising lake in the basin is Yan Lake with an average rate of 2.384 m/y, and the fastest falling lake is Dongka Co with an average rate of -0.266 m/y.

In addition, since the number of lakes monitored in the Nujiang River, Ganges River and Hexi Corridor Basins is very small, their analysis have not be conducted.

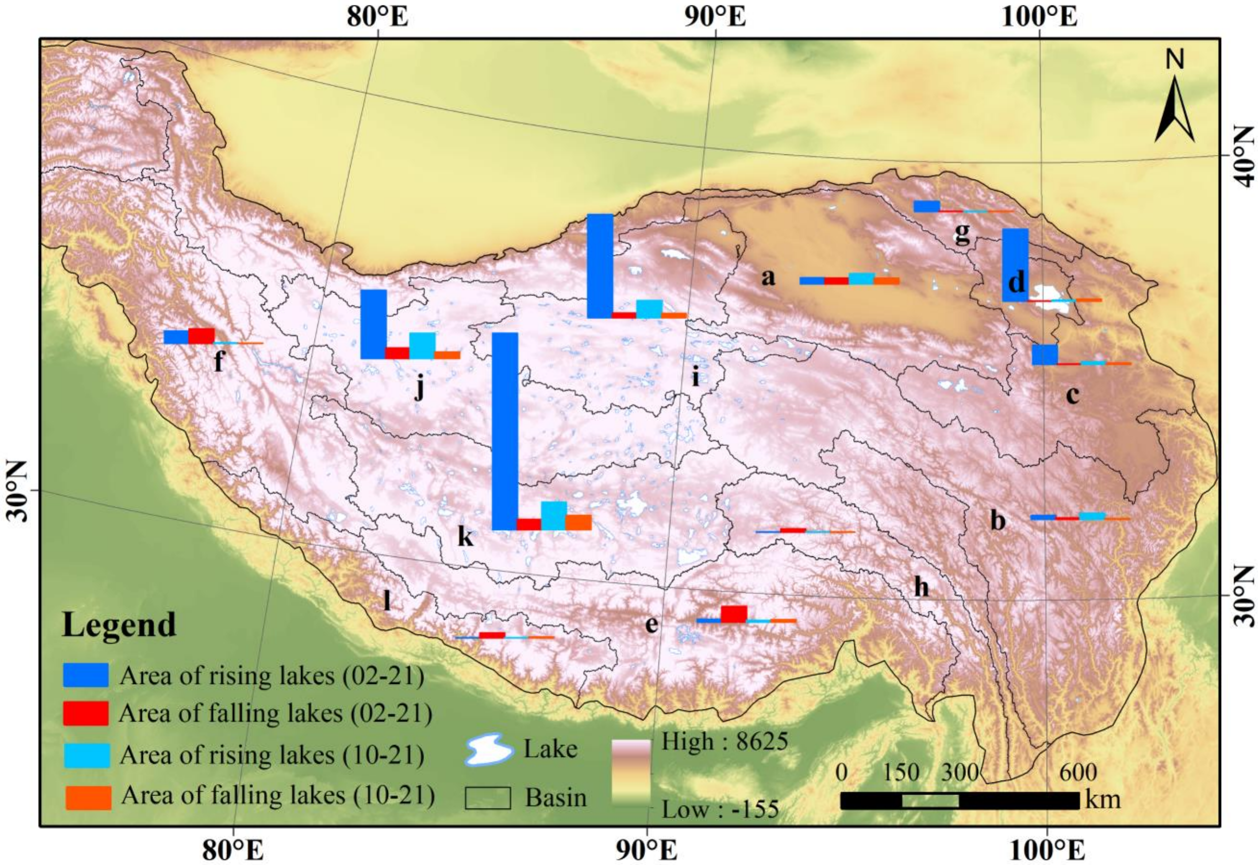

Fig. 10 Relative proportions of the trends in the lakes level changes in each basin. The boundary of each basin is referred to Wan et al. (2016). The DEM of the base map is from the Global Multi-resolution Terrain Elevation Data 2010（GMTED2010）(GMTED: https://topotools.cr.usgs.gov/gtmed_viewer/) (the lowercase letters indicate the different lake basins studied as in Fig. 8).

6 Data availability

The derived water levels in the lakes of the TP are archived and available at https://doi.org/10.1594/PANGAEA.973443 (Chen et al., 2021).

7 Conclusion

In this study, high-resolution datasets for changes in the water levels for 361 lakes on the TP during 2002-2021 and 2010-2021 were developed based on multi-altimeter data from Envisat, ICESat-1, CryoSat-2, Jason-1, Jason-2, Jason-3, SARAL, and Sentinel-3A. A two-step AMPDR retracker and a noise-footprint removal method were used to extract the water levels, and the lake level time series were then estimated using the R package tsHydro. The dynamic reference time series was then used to merge the lake-level time series from the multi-altimeter data. It was found that the merged water levels based on the altimetry increased the overall sampling frequency regardless of the lake size. The water levels derived from the altimeter data were validated with *in situ* data, and the accuracy of the time series for monitoring lakes reached the decimeter level. Based on comparison with the DAHITI, LEGOS Hydroweb, G-REALM and Li et al. (2019) datasets, the new product was found to be consistent with these products, and the median RMSEs are consistently below 0.30 m, while the median correlation values consistently exceed 0.90, indicating that the new dataset was reliable. In addition, the spatio-temporal changes in the water levels of the lakes on the TP during 2002-2021 were explored. Overall, the measured lake levels on the TP were indicative of a rising trend with an overall average annual rate of change of 0.175 m/y; moreover, the number of lakes with rising water levels accounted for 78% of the total examined. The lakes with the most significant rises in the water levels were those of large size (>500 km^2) and small size (<50 km^2), and the intermediate size lakes showed the significant rising trend in the water levels. The water levels of lakes in all basins have been increasing significantly over the period 2002 to 2021 except for the Brahmaputra River Basin. The lakes with decreasing water levels were distributed mainly in Brahmaputra River, Ganges River, and Nujiang River Basins. Further applications of the lake level dataset of the TP are anticipated.

Author contributions

Liao J and Chen J designed the research plan. Chen J developed the approaches and the dataset. Liao J, Lou Y and Ma S contributed to the analysis of the results. Shen G, Zhang L and Wu Y contributed to the data processing. Liao J and Chen J wrote the manuscript.

Competing interests. The authors declare that there are no conflicts of interest.

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Review statement

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Appendix A. Comparison of the lake levels in the TP derived from this study with those provided by the DAHITI, LEGOS Hydroweb, G-REALM, and Li et al., 2019 in RMSE and Correlation.

Lake Name	DAHITI ID	RMSE	CORR	NP*	Lake Name	DAHITI ID	RMSE	CORR	NP
Ake Sayi Lake	10445	0.48	0.94	83	Luotuo Lake	10538	0.32	0.84	44
Aqqujjik Kaje	11004	0.08	0.99	44	Ma'erxia Co	10986	0.21	0.92	49
Ayakkum Lake	10540	0.37	0.99	123	Meiriqiecuomari	10556	0.24	0.93	49
Bairab Co	11036	0.13	0.81	49	Mugqu Co	11018	0.19	0	5
Chabo Co	10543	0.14	0.91	36	Nam Co	345	0.15	0.94	110
Chibzhang Co	41056	0.16	0.8	11	Ngangla Ringco	10537	0.15	0.98	53
Dagze Co	10425	0.78	0.97	149	Ngangze Co	10404	0.28	0.96	387
Dangqiong Co	11019	0.37	0.78	73	Orba Co	11477	0.24	0.87	116

Daxiong Lake	11053	0.12	0.98	41	Pung Co	10975	0.41	0.97	83
Deyu Lake	11015	0.21	0.96	49	Qiagui Co	10989	0.49	0.3	72
Dulishi Lake	11126	0.1	0.98	50	Qinghai Lake	227	0.19	0.99	366
Garen Co	11030	0.24	0.83	38	Selin Co	233	0.19	1	153
Garkung Caka	11001	0.1	0.98	47	Serbug Co	11073	0.34	0.6	19
Goren Co	10536	0.34	0.8	79	Sugan Lake	11005	0.28	0.27	29
Gozha Co	10448	0.19	0.81	46	Tangra Yumco	10424	0.29	0.97	203
Har Lake	10419	0.23	0.98	155	Taro Co	10421	0.24	0.96	22
Heishi North Lake	11070	0.32	0.79	16	Tu Co	10973	0.15	0.99	87
Jieze Caka	10427	0.12	0.93	43	Wanquan Lake	11037	0.59	0.78	125
Jingyu Lake	10995	0.38	0.96	33	Xiangyang Lake	11012	0.55	0.97	48
Kyebxang Co	11025	0.24	0.76	37	Xuelian Lake	11040	0.79	0.71	92
Lagkor Co	11020	0.18	0.94	48	Xuru Co	10105	0.18	0.94	45
Longwei Co	11003	0.15	0.97	46	Yaggain Co2	11035	0.32	0.91	40
Lumajiangdong Co	10426	0.75	0.95	66	Zhari Namco	10423	0.29	0.97	443
Lake Name	**Legos ID**	**RMSE**	**CORR**	**NP**	**Lake Name**	**Legos ID**	**RMSE**	**CORR**	**NP**
Ake Sayi Lake	1300000001373	0.36	0.97	50	Lumajiangdong Co	1300000001399	1.01	0.84	71
Aqqujjik Kaje	1300000001352	0.09	0.99	22	Luotuo Lake	1300000014972	0.31	0.85	43
Ayakkum Lake	1300000001344	0.34	0.99	151	Mapam Yumco	1300000001454	0.35	0.73	56
Bairab Co	1300000001379	0.11	0.83	45	Nam Co	1300000000149	0.21	0.88	201
Bangong Co	1300000001403	0.25	0.60	72	Ngangla Ringco	1300000001431	0.35	0.48	88
Chabo Co	1300000015037	0.19	0.71	11	Ngangze Co	1300000001447	0.24	0.97	328
Chibzhang Co	1300000001404	0.25	0.99	291	Ngoring Lake	1300000001377	0.45	0.87	199
Cuoda Rima	1300000014898	0.29	0.91	46	Orba Co	1300000014959	0.33	0.75	73
Dagze Co	1300000001425	0.65	0.98	147	Pung Co	1300000001433	0.69	0.89	44
Dangqiong Co	1300000015180	0.13	0.97	29	Qinghai Lake	1300000000143	0.18	0.97	204
Dogai Coring	1300000001389	0.38	0.93	111	Selin Co	1300000000147	0.17	1.00	265
Dogaicoring Qangco	1300000001372	0.39	0.98	96	Tangra Yumco	1300000001450	0.28	0.97	205
Garkung Caka	1300000015010	0.10	0.97	36	Taro Co	1300000001445	0.29	0.87	34
Goren Co	1300000001439	0.26	0.86	21	Telashi Lake	1300000014940	0.24	0.94	50
Hoh Xil Lake	1300000001369	0.16	1.00	16	Tu Co	1300000001405	0.16	0.98	35
Huolunuo'er	1300000001370	0.14	0.93	41	Urru Co	1300000001428	0.47	0.60	47
Jieze Caka	1300000001401	0.08	0.97	32	Wulanwula Lake	1300000001386	0.43	0.96	126
Jingyu Lake	1300000001357	0.54	0.97	28	Xuelian Lake	1300000015002	0.29	0.89	43
Langa Co	1300000001452	0.19	0.91	310	Zhari Namco	1300000001449	0.25	0.98	496
Lexiewudan Co	1300000001366	0.80	0.97	109	Zige Tangco	1300000001422	0.26	0.95	202
Lake Name	**G-REALM ID**	**RMSE**	**CORR**	**NP**	**Lake Name**	**G-REALM ID**	**RMSE**	**CORR**	**NP**
Bangong Co	lake000121	0.23	0.73	341	Chibzhang Co	lake000171	0.23	0.99	448
Langa Co	lake000141	0.29	0.97	533	Orba Co	lake000177	0.32	0.75	290
Zhari Namco	lake000152	0.32	0.97	483	Dogai Coring	lake000189	0.19	0.98	389
Ngangze Co	lake000156	0.31	0.97	568	Ngoring Lake	lake000285	0.51	0.88	452
Lake Name	**Li et al., 2019**	**RMSE**	**CORR**	**NP**	**Lake Name**	**Li et al., 2019**	**RMSE**	**CORR**	**NP**
Ake_Sayi_Lake	Ake_Sayi_Lake	0.59	0.92	48	Memar_Co	Memar_Co	0.91	0.96	41
Aqqujjik_Kaje	Aqqujjik_Kaje	0.34	0.98	57	Nam_Co	Nam_Co	0.22	0.89	111
Ayakkum_Lake	Ayakkum_Lake	0.24	0.97	113	Ngangla_Ringco	Ngangla_Ringco	0.18	0.81	92
Bamco	Bamco	0.15	0.97	17	Ngangze_Co	Ngangze_Co	0.21	0.98	313
Bangong_Co	Bangong_Co	0.27	0.82	227	Ngoring_Lake	Ngoring_Lake	0.31	0.96	276
Chibzhang_Co	Chibzhang_Co	0.24	0.99	213	Paiku_Co	Paiku_Co	0.45	0.70	20
Co_Ngoin1	Co_Ngoin1	0.23	0.39	24	Puma_Yumco	Puma_Yumco	0.66	-0.05	30
Cuona_Lake	Cuona_Lake	0.30	0.24	15	Pung_Co	Pung_Co	0.25	0.99	22
Dagze_Co	Dagze_Co	0.23	0.96	112	Qinghai_Lake	Qinghai_Lake	0.23	0.92	196
Dogai_Coring	Dogai_Coring	0.19	0.97	228	Rola_Co	Rola_Co	0.07	1.00	31

Dogaicoring_Qangco	Dogaicoring_Qangco	0.21	0.99	78	Salt_Water_Lake	Salt_Water_Lake	0.27	0.95	29
Donggei_Cuona_Lake	Donggei_Cuona_Lake	0.38	0.86	50	Selin_Co	Selin_Co	0.14	1.00	141
Dung_Co	Dung_Co	0.25	0.71	68	Tangra_Yumco	Tangra_Yumco	0.35	0.94	64
Goren_Co	Goren_Co	0.35	0.66	39	Taro_Co	Taro_Co	0.20	0.90	56
Gozha_Co	Gozha_Co	0.49	0.68	40	Tu_Co	Tu_Co	0.23	0.98	53
Gyaring_Lake	Gyaring_Lake	0.30	0.71	48	Urru_Co	Urru_Co	0.58	0.28	51
Har_Lake	Har_Lake	0.43	0.95	93	Wulanwula_Lake	Wulanwula_Lake	0.19	0.99	125
Hoh_Xil_Lake	Hoh_Xil_Lake	0.12	0.98	62	Xijir_Ulan_Lake	Xijir_Ulan_Lake	0.43	0.97	93
Jingyu_Lake	Jingyu_Lake	0.65	0.97	68	Xuru_Co	Xuru_Co	0.34	0.69	11
Kusai_Lake	Kusai_Lake	0.30	1.00	204	Yamzho_Yumco	Yamzho_Yumco	0.50	0.96	86
Kyebxang_Co	Kyebxang_Co	0.19	0.60	16	Yelusu_Lake	Yelusu_Lake	0.29	0.70	43
Lexiewudan_Co	Lexiewudan_Co	0.58	0.98	63	Yibug_Caka	Yibug_Caka	0.24	0.49	24
Lumajiangdong_Co	Lumajiangdong_Co	0.74	0.96	53	Zhari_Namco	Zhari_Namco	0.24	0.88	293
Mapam_Yumco	Mapam_Yumco	0.18	0.87	56	Zige_Tangco	Zige_Tangco	0.14	0.99	197
Margai_Caka	Margai_Caka	1.45	0.99	6					

*NP indicates number of points for validation

Appendix B, Supplementary data

No.	Lake Name	Lat. (deg)	Lon. (deg)	Area (km^2)	Duration (yyyy/mm/dd)	Annual rate (m/y)	P-value	Altimeter type*
1	Ake Sayi Lake	35.2	79.86	258.25	2003/04/20-2021/07/17	0.1837	< 0.001	1,2,3,7,8
2	Amu Co	33.49	88.7	114.98	2007/03/23-2021/05/11	0.2746	< 0.001	1,3,5,7
3	Angrenjin Co	29.31	87.19	21.08	2016/04/29-2021/01/12	0.0540	< 0.001	3,8
4	Angshang Co	33.72	82.67	27.66	2007/10/13-2021/05/23	0.3547	< 0.001	2,3,8
5	Aqqujjik Kaje	37.07	88.4	350	2003/10/13-2021/07/27	0.5355	< 0.001	1,2,3,7,8
6	Argog Co	30.98	82.24	55.26	2003/09/16-2020/08/28	-0.0104	0.400	1,2,3
7	Aru Co	33.99	82.4	104.32	2003/10/06-2021/06/20	-0.0198	< 0.001	1,2,3,7
8	Ayakkum Lake	37.53	89.45	520	2003/01/02-2021/07/25	0.3262	< 0.001	1,2,3,4,5,7,8
9	Bangdag Co	34.94	81.56	142.92	2005/06/17-2021/05/28	0.6624	< 0.001	2,3,7
10	Bangkog Co	31.74	89.51	123.87	2003/03/11-2021/06/29	-0.1595	< 0.001	1,3,7,8
11	Bangong Co	33.68	79.23	671.2	2002/10/26-2021/06/27	0.0919	< 0.001	1,2,3,4,5,6,7,8
12	Bensong Co	33.21	86.43	15.27	2007/04/13-2016/03/14	0.2540	0.016	1,7
13	Bong Co	31.22	91.16	143.98	2011/03/28-2021/06/02	0.0153	0.222	1,3,7
14	Buergacuo Lake	33.66	84.38	10.01	2003/09/13-2019/11/22	0.2335	< 0.001	1,3,5,7
15	Cam Co	32.12	83.55	103.7	2009/08/27-2020/08/26	0.2116	< 0.001	3,4,5
16	Cedo Caka	33.17	89.04	74.96	2008/02/22-2021/07/02	0.3690	< 0.001	1,2,3,8
17	Cemar Co	33.55	84.59	49.42	2012/04/13-2020/09/19	0.1542	< 0.001	3
18	Chabo Co	33.36	84.19	49.47	2007/10/29-2020/06/06	0.1417	< 0.001	1,2,3,5,8
19	Changhu Lake1	35.02	84.48	10.35	2007/04/08-2021/06/17	0.1169	< 0.001	2,3
20	Changhu Lake2	34.71	89.04	51.08	2003/12/18-2021/07/25	0.1420	< 0.001	1,3,7
21	Chaxiabucuo Lake	31.93	87.88	11.53	2007/10/24-2021/05/13	0.1452	< 0.001	2,3
22	Chem Co	34.16	79.78	121.53	2007/03/24-2021/05/05	0.1460	< 0.001	2,3,5
23	Chibzhang Co	33.45	90.27	541.18	2003/03/03-2021/07/22	0.4185	< 0.001	1,2,3,4,5,6,7,8
24	Co Ngoin1	31.59	88.72	268.42	2007/11/02-2021/07/25	0.0135	0.090	1,2,3,8
25	Co Nyi	34.55	87.18	166.91	2005/06/15-2021/07/30	0.0988	< 0.001	1,2,3,7

26	Cuoda Rima	35.33	91.86	83.87	2005/03/21-2021/03/16	0.3154	< 0.001	3,4,5,6
27	Cuona Co	31.63	82.34	52.81	2007/03/23-2021/04/05	0.0374	0.066	2,3
28	Cuona Lake	32.03	91.48	191.46	2011/07/17-2021/06/25	-0.0117	0.051	3
29	Dabsan Lake	36.96	95.15	296.4	2009/08/06-2021/05/23	-0.0530	< 0.001	1,3,4,5,7,8
30	Daggyai Co	29.84	85.72	109.43	2005/11/08-2021/07/07	0.0622	0.016	1,2,3
31	Dagze Co	31.89	87.52	311.04	2003/02/24-2021/07/02	0.4180	< 0.001	1,2,3,5,6,7,8
32	Damazirang	30.95	85.99	32.98	2011/12/15-2021/06/12	-0.0124	0.323	1,3
33	Dangqiong Co	31.57	86.74	63.87	2010/01/04-2019/08/04	0.1480	< 0.001	1,7,8
34	Dangquezangbu	29.83	83.73	62.6	2005/02/26-2021/07/12	0.1130	< 0.001	1,2,3,7,8,37
35	Darab Co	32.47	83.22	25.66	2005/10/29-2020/10/15	0.1259	< 0.001	2,3
36	Dawa Co	31.24	84.96	118.2	2007/04/05-2021/06/15	0.2620	< 0.001	2,3
37	Daxiong Lake	34.05	85.61	42.93	2008/10/14-2021/05/20	0.3077	< 0.001	2,3,8
38	Deyu Lake	35.69	87.27	61.63	2004/05/28-2021/07/30	0.3648	< 0.001	1,2,3,4,5,7,8
39	Dogai Coring	34.58	88.96	492.4	2002/11/28-2021/07/23	0.2257	< 0.001	1,2,3,4,5,6,7,8
40	Dogaicoring Qangco	35.32	89.24	403.1	2003/03/14-2021/07/25	0.3900	< 0.001	1,3,7,8
41	Dong Co	32.18	84.74	105.43	2004/01/12-2021/04/03	0.1468	< 0.001	1,3,7
42	Donggei Cuona Lake	35.3	98.55	241.37	2003/02/04-2021/06/14	0.0651	< 0.001	1,3,7,8
43	Dulishi Lake	34.73	81.89	98.55	2003/11/28-2021/04/05	0.2853	< 0.001	1,3,7,8
44	Dung Co	31.71	91.16	151.44	2010/05/26-2021/06/02	0.0020	0.750	1,3,5,6,8
45	Duoqing Co	28.15	89.35	49.6	2003/07/10-2021/05/11	-0.0271	0.010	1,3,7,8
46	Finger Lake	33.72	85.12	15.18	2004/04/26-2021/07/10	0.3339	< 0.001	1,3,7
47	Gangnagema Co	34.32	98.66	32.03	2012/06/06-2020/07/01	0.0136	0.109	3
48	Gansenquan Lake	37.46	92.77	20.02	2008/03/08-2020/04/17	0.0293	0.003	2,3
49	Gaotai Lake	35.41	90.96	10.59	2006/03/24-2021/04/15	0.0066	0.335	2,3
50	Gasi Kule Lake	38.12	90.79	115.81	2003/11/10-2021/06/25	-0.0412	< 0.001	1,2,3,7
51	Gemang Co	31.58	87.28	62.28	2009/10/01-2021/07/27	0.1551	< 0.001	2,3
52	Gemu Caka	33.67	85.81	70.52	2003/10/16-2020/08/22	-0.0314	< 0.001	1,3,7
53	Gopug Co	31.86	83.18	61.63	2003/07/25-2020/06/09	0.0957	< 0.001	1,2,3,7

54	Goren Co	31.12	88.35	478.16	2003/06/27-2021/07/25	0.1081	< 0.001	1,2,3,5,7,8
55	Gouren Lake	34.6	92.45	31.3	2005/06/02-2021/05/31	0.2184	< 0.001	2,3,7
56	Gozha Co	35.02	81.07	245.34	2003/11/13-2021/07/15	-0.0027	< 0.001	1,3,7,8
57	Guboke Co	33.08	82.03	11.98	2004/01/18-2021/03/14	-0.0175	0.007	1,3,7
58	Guojialun Lake	31.99	88.69	88.19	2010/12/23-2021/07/25	0.2775	< 0.001	1,3,8
59	Gyarab Punco	32.2	87.78	51.9	2006/11/17-2021/03/28	0.0064	< 0.001	2,3,5,6
60	Gyaring Lake	34.93	97.26	526	2007/10/04-2021/07/10	0.0276	0.055	1,2,3,7,8
61	Gyesar Co	30.21	84.8	142.1	2007/06/07-2017/05/06	0.1694	0.003	1,4,5
62	Haidingnuo'er	35.57	93.17	67.59	2010/11/03-2021/07/17	-0.0977	< 0.001	3,5
63	Har Lake	38.29	97.59	609.04	2003/09/18-2021/07/10	0.1894	< 0.001	1,2,3,7,8
64	Heishi North Lake	35.56	82.74	112.4	2003/03/26-2021/04/28	0.3899	< 0.001	1,2,3,5,7,8
65	Hoh Xil Lake	35.59	91.14	350.38	2005/06/20-2021/07/22	0.4792	< 0.001	2,3,4,5,8
66	Hot Spring Lake	34.43	83.56	11.65	2008/03/08-2021/05/21	0.0033	< 0.001	2,3
67	Hulu Lake	34.42	91.03	36.91	2011/11/08-2021/07/22	0.1848	< 0.001	3,7
68	Jiamucheng Co	33.74	90.64	34.27	2007/03/11-2020/09/07	0.1651	< 0.001	2,3,8
69	Jiang Co	31.55	90.82	40.48	2007/10/24-2021/01/30	0.1349	0.063	2,3
70	Jiangchai Co	32.16	90.46	28.64	2003/07/10-2021/06/27	-0.0137	0.050	1,3,7
71	Jidaocuo Lake	32.52	83.22	12.76	2006/11/02-2020/12/02	-0.0742	0.033	2,3
72	Jieyue Lake	35.07	90.27	17.76	2008/12/06-2020/06/21	-0.0071	0.861	2,3
73	Jieze Caka	33.95	80.9	114.33	2003/12/18-2020/02/19	0.0725	< 0.001	1,2,3,7,8
74	Jingyu Lake	36.33	89.44	339.57	2003/08/01-2021/07/25	0.4282	< 0.001	1,3,7
75	Jiuru Co	31.01	89.92	39.95	2007/05/18-2020/12/03	0.0114	0.392	3,4,5,6
76	Katiao Co	33.96	82.97	61.09	2007/03/19-2021/04/07	0.7727	< 0.001	2,3
77	Kekao Lake	35.7	91.36	74.39	2004/05/22-2021/06/27	0.4040	< 0.001	1,2,3,4,5,7
78	Kongmu Co	29.01	90.45	36.94	2007/10/16-2021/04/15	-0.0412	< 0.001	2,3
79	Kunggyu Co	30.64	82.13	55.57	2004/05/18-2020/12/28	0.0600	< 0.001	1,2,3,7,8
80	Kunzhong Co	33.1	80.39	13.77	2009/08/07-2021/01/27	-0.0868	0.668	3,4,5
81	Kusai Lake	35.73	92.87	326.8	2002/09/29-2021/07/15	0.6215	< 0.001	1,2,3,4,5,6,7,8

82	Kushuihuan	35.99	90.12	34.7	2004/04/17-2020/10/24	-0.0234	< 0.001	1,2,3,7
83	Kyebxang Co	32.45	89.98	187.11	2005/11/03-2021/06/30	0.2350	< 0.001	2,3,8
84	Lagkor Co	32.03	84.13	95.62	2007/10/18-2021/04/26	0.1839	< 0.001	2,3,8
85	Langa Co	30.69	81.23	256.24	2002/07/18-2020/11/23	-0.1559	< 0.001	1,3,4,5,6,7,8
86	Langqiang Co	28.72	85.88	24.03	2004/04/05-2021/03/06	-0.0552	< 0.001	1,3,7
87	Laxiang Co	33.98	86.04	25.46	2011/08/06-2021/07/30	0.2270	< 0.001	1,3
88	Laxiong Co	34.34	85.23	66.92	2011/05/26-2021/07/07	0.3449	< 0.001	1,3,7
89	Lexiewudan Co	35.75	90.2	273.3	2004/01/03-2021/07/23	0.5863	< 0.001	1,2,3,4,5,7,8
90	Lianhu Lake	35.56	90.22	47.11	2007/04/03-2021/07/23	0.3035	< 0.001	2,3,4,5
91	Longmucuo Lake	34.66	80.69	10.85	2004/08/03-2021/05/28	0.1170	< 0.001	1,3,7
92	Longre Co	34.87	98.02	17.77	2003/09/03-2020/11/29	0.0227	< 0.001	1,3,7
93	Longwei Co	33.87	88.31	57.85	2008/03/18-2021/06/30	0.2201	< 0.001	2,3,7,8
94	Lumajiangdong Co	34.02	81.61	384.67	2003/07/12-2021/05/28	0.3865	< 0.001	1,2,3,4,5,7,8
95	Luotuo Lake	34.44	81.94	68.22	2007/03/14-2021/04/08	0.2726	< 0.001	1,2,3,4,5,8
96	Maindung Co	33.53	78.91	57.8	2006/02/26-2021/07/22	-0.0370	< 0.001	2,3,8
97	Mang Co1	29.53	98.84	18.28	2004/01/05-2016/05/18	0.4612	< 0.001	1,7
98	Mapam Yumco	30.68	81.47	412.69	2003/04/13-2021/07/15	-0.0130	0.029	1,2,3,7
99	Margai Caka	35.12	86.75	158.05	2006/03/13-2021/04/20	0.6346	< 0.001	2,3,8
100	Margog Caka	33.86	87.01	90.43	2009/01/22-2021/07/27	0.0328	< 0.001	3,4,5,6
101	Mazhangcuoqin	34.34	91.59	67.93	2008/10/11-2021/01/05	-0.0210	0.598	2,3
102	Meiriqiecuomari	33.64	89.72	97.18	2006/11/08-2021/05/10	0.2160	< 0.001	2,3,7,8
103	Memar Co	34.22	82.31	166.67	2003/10/06-2021/07/12	0.4979	< 0.001	1,2,3,7
104	Mingjing Lake	35.07	90.57	124.26	2003/09/01-2021/06/05	0.4452	< 0.001	1,3,4,5,7,8
105	Mudidalayu Co	30.58	88.59	24.01	2004/09/04-2021/07/25	0.1051	0.001	1,3,7
106	Mugqu Co	31.06	89	78.04	2007/10/19-2021/06/07	-0.0147	0.304	2,3,7
107	Mushicuo Lake	32.73	86.99	16.23	2004/04/05-2021/07/05	0.2426	< 0.001	1,2,3,7,12
108	Naka Co	31.86	89.79	29.6	2007/10/28-2021/03/24	0.0576	0.087	2,3
109	Nam Co	30.74	90.6	2024.21	2003/03/08-2021/07/22	0.0305	< 0.001	1,2,3,7,8

110	Nariyong Co	28.3	91.95	23.18	2013/09/26-2016/04/27	0.4404	0.115	7
111	Nawu Lake	32.93	82.08	20.06	2003/03/09-2020/04/15	-0.0448	< 0.001	1,3,7
112	Ngangla Ringco	31.54	83.08	492.8	2003/03/06-2021/06/19	0.0452	< 0.001	1,2,3,4,5,7,8
113	Ngangze Co	31.02	87.13	471.6	2002/07/30-2021/06/10	0.2209	< 0.001	1,2,3,4,5,6,7
114	Ngoring Lake	34.9	97.7	610	2002/06/10-2021/05/21	0.1363	< 0.001	3,4,5,6,7,8
115	Norma Co	32.38	88.04	90.05	2007/11/13-2021/07/03	0.2758	< 0.001	1,3,4,5,6,7
116	Orba Co	34.53	81.04	92.36	2003/04/17-2020/11/27	0.0093	0.275	1,3,4,5,6,8
117	Paiku Co	28.89	85.59	272.95	2005/11/08-2021/07/07	-0.0967	< 0.001	2,3,4,5
118	Palung Co	30.89	83.58	144.65	2004/05/15-2021/07/10	0.0676	< 0.001	1,3
119	Pipa Lake	34.2	87.8	16.86	2012/05/06-2021/04/21	0.1973	< 0.001	3
120	Pongyin Co	32.9	88.2	75.59	2010/03/21-2021/07/25	0.0934	< 0.001	1,3,5,6
121	Puma Yumco	28.57	90.4	290.43	2006/03/08-2021/05/10	-0.0568	< 0.001	1,2,3,7
122	Qiagang Co	33.23	88.39	47.54	2005/10/31-2021/06/30	0.1137	< 0.001	2,3,5,6
123	Qiagui Co	31.82	88.25	88.97	2004/01/22-2021/05/15	-0.0138	0.023	1,2,3,6,7
124	Qingche Lake	34.48	81.79	71.51	2004/01/03-2021/05/03	0.2690	< 0.001	1,3,7
125	Qinghai Lake	36.89	100.2	4348.25	2002/11/23-2021/07/02	0.1896	< 0.001	1,2,3,4,5,7,8
126	Qiongjiang Lake	36.02	88.52	37.06	2007/03/18-2020/12/06	0.5334	< 0.001	2,3,5,6
127	Qoiden Co	34.37	87.49	27.52	2003/10/13-2020/10/08	-0.0308	0.025	1,3,7
128	Quemo Co	33.89	91.19	98.48	2008/03/17-2021/06/27	0.1993	< 0.001	2,3,4,5,7
129	Rebang Co	33.03	80.58	46.22	2003/05/21-2021/05/05	0.0351	< 0.001	1,3,7,8
130	Rigain Punco	32.58	86.24	42.79	2003/08/22-2021/03/29	0.0996	< 0.001	1,3,7,8
131	Rijiu Co	34.2	91.7	13.26	2007/10/06-2021/05/05	0.0173	0.103	2,3
132	Ringco Kongma	30.93	89.67	138.48	2008/12/09-2021/07/23	-0.0072	< 0.001	2,3
133	Rinqin Xubco	31.28	83.45	186.55	2007/10/09-2021/04/30	0.1924	< 0.001	2,3
134	Rola Co	35.44	88.41	169.9	2003/05/06-2021/07/03	0.2018	< 0.001	1,3,7
135	Salt Water Lake	35.28	83.07	211.98	2008/02/28-2021/07/10	0.3751	< 0.001	1,2,3,8
136	Selin Co	31.81	88.99	2300.37	2003/03/23-2021/07/25	0.3045	< 0.001	1,2,3,4,5,7,8
137	Serbug Co	32	88.22	92.9	2003/08/01-2021/07/25	0.3072	< 0.001	1,2,3,7

138	Shibu Co	31.39	88.73	14.1	2008/12/15-2020/11/23	-0.0802	< 0.001	2,3
139	Shuanghu	34.47	83.16	14.47	2013/03/24-2021/07/13	0.1593	< 0.001	3
140	Shuanglian Lake	35.5	88.31	48.58	2011/04/05-2021/07/03	0.4009	< 0.001	3,4,5
141	Sugan Lake	38.87	93.88	107.54	2003/02/16-2021/06/24	0.1075	< 0.001	1,2,3,5,7
142	Suona Lake	33.92	86.69	27.03	2007/10/16-2021/05/15	0.0087	< 0.001	2,3
143	Tangra Yumco	31.07	86.61	848.96	2003/09/08-2021/07/30	0.2117	< 0.001	1,2,3,7,8
144	Taro Co	31.14	84.12	484.65	2007/10/18-2021/06/17	0.0439	0.048	2,3,4,5,7
145	terang Punco	33.06	89.07	32.52	2011/09/18-2021/07/02	0.0957	< 0.001	1,3
146	Tomgo Co	31.72	86.98	24.08	2011/07/28-2020/09/13	0.0008	0.653	1,3
147	Tso moriri	32.9	78.32	142.54	2007/04/10-2021/06/04	-0.1024	< 0.001	2,3,4,5
148	Tu Co	33.4	89.86	448.23	2006/11/08-2021/07/23	0.4267	< 0.001	2,3,4,5,7,8
149	Tuoheping Co	34.18	83.15	56.53	2003/04/30-2021/07/13	-0.0565	< 0.001	1,3,7,37
150	Urru Co	31.72	88	356.57	2003/05/23-2021/07/03	0.0314	< 0.001	1,2,3,7
151	Wanquan Lake	34.24	83.81	67.42	2003/07/25-2021/04/30	-0.1393	< 0.001	1,3,7,8
152	Weishan Lake	35.96	89.24	46.83	2007/03/26-2021/07/25	0.2201	< 0.001	2,3
153	Wulanwula Lake	34.8	90.48	651	2018/03/29-2021/07/27	0.2787	0.019	3
154	Xiaga Co	32.31	83.81	22.15	2008/02/28-2021/05/01	0.1346	< 0.001	2,3,8
155	Xiajian Lake	34.16	82.77	13.92	2018/09/21-2021/04/03	0.0784	0.168	3
156	Xiangyang Lake	35.8	89.42	121.01	2007/10/03-2021/06/30	0.4468	< 0.001	2,3,8
157	Xianhe Lake	36	88.07	50.71	2014/02/19-2021/05/13	0.4875	< 0.001	3,7
158	Xiaokusai Lake	36.09	92.79	20.05	2013/07/12-2020/09/19	-0.0069	0.002	3,8
159	Xiasa'er Co	31.58	80.99	13.83	2003/06/24-2021/07/23	0.0100	< 0.001	1,2,3,4,5,7,8
160	Xijir Ulan Lake	35.21	90.34	462.69	2014/05/13-2021/07/07	0.3289	0.003	3
161	Xuelian Lake	34.09	90.26	54.06	2013/02/09-2021/07/27	0.1273	< 0.001	3,7
162	Xuguo Co	31.95	90.34	35.07	2013/05/10-2021/07/30	0.0169	< 0.001	3,7,8
163	Yaggain Co	31.56	89.01	112.39	2006/11/08-2021/07/23	0.9582	< 0.001	2,3
164	Yamzho Yumco	28.96	90.71	548.29	2013/05/21-2021/06/24	-0.2006	< 0.001	3,8
165	Yanghong Lake	35.25	89.96	88.38	2007/04/08-2021/06/17	0.2879	< 0.001	2,3,5,8

166	Yanghu Lake	35.41	84.59	163.09	2003/10/06-2021/07/23	0.6811	0.053	1,3,7,8
167	Yangnapeng Co	32.33	89.77	17.41	2003/11/13-2021/07/25	0.0410	< 0.001	1,3,7
168	Yanjian Lake	34.77	89.03	18.19	2015/12/20-2020/01/02	0.5182	0.328	3
169	Yinbo Lake	36.19	88.14	50.01	2008/02/18-2021/06/05	0.4428	< 0.001	2,3,8
170	Yinlong Co	33.91	88.04	17.5	2007/03/06-2021/07/25	0.2017	< 0.001	1,3
171	Yinma Lake	35.6	90.63	105.23	2003/05/20-2021/06/05	-0.1593	< 0.001	1,3,7,8
172	Yishan Lake	35.24	90.91	27.61	2009/10/01-2021/07/20	0.2571	< 0.001	2,3
173	Yongbo Lake1	35.74	86.69	79.71	2004/03/07-2021/06/12	0.6614	< 0.001	2,3
174	Youyi Lake	34.46	88.74	10.64	2007/03/18-2020/05/27	0.0085	0.105	2,3
175	Yuan Lake1	34.81	89.29	17.22	2004/05/09-2021/07/02	0.1526	< 0.001	3,4,5,6
176	Yueliang Lake1	35.61	90.36	32.51	2007/10/28-2021/06/30	0.2762	< 0.001	2,3
177	Yulin Lake	35.97	88.47	12.82	2008/10/10-2020/10/30	0.4261	< 0.001	2,3
178	Yuye Lake	36.01	88.78	146.91	2003/10/29-2021/07/23	0.2125	< 0.001	1,2,3,4,5
179	Zhaliwa Co	34.42	92.45	7.09	2013/01/05-2021/05/28	0.1126	0.058	3,7
180	Zhamucuomaqiong	33.15	89.7	30.7	2010/07/15-2021/04/18	0.0523	0.054	3,4,5
181	Zhaoyang Lake	35.3	87.26	92.28	2007/10/24-2021/07/05	0.0408	< 0.001	1,2,3
182	Zhari Namco	30.93	85.61	1000.57	2002/08/02-2021/07/07	0.1671	< 0.001	1,2,3,4,5,6,7,8
183	Zhegucuo	28.68	91.68	55.8	2003/10/01-2019/11/03	0.2692	< 0.001	1,3,7
184	Zhenquan Lake	35.93	86.89	128.23	2004/06/06-2019/08/01	0.2616	< 0.001	2,3,7,8
185	Zige Tangco	32.08	90.86	238.31	2002/08/01-2021/07/22	0.2200	< 0.001	2,3,4,5,6,7
186	Zigu Co	31.37	87.9	76.17	2007/04/03-2021/07/03	0.0164	0.945	2,3
187	Qagong Co	34.44	82.33	30.73	2012/02/21-2021/06/20	0.3455	< 0.001	3
188	S63005	35.95	90.83	10.99	2013/12/05-2019/09/13	-0.0871	< 0.001	7,8
189	Shen Co	31.01	90.49	51.86	2014/06/17-2021/04/15	-0.1095	< 0.001	3,7,8
190	Yaggain Co1	33.01	89.8	158.75	2013/09/16-2020/11/23	0.1842	< 0.001	3,7,8
191	Zhangnai Co	31.54	87.4	43.98	2003/03/29-2021/03/26	0.1552	< 0.001	1,2,3,5,6,7
192	Zhaxi Co	32.2	85.12	49.56	2010/03/11-2021/06/15	0.0760	< 0.001	3,5,6,7
193	Aiyong Co	33.36	80.56	21.56	2015/02/19-2019/12/28	0.0862	< 0.001	3,7

194	Alake Lake	35.57	97.12	34.7	2014/04/08-2021/06/12	-0.0268	0.026	3,7
195	Amjog Co	29.63	86.25	22.01	2010/11/18-2021/04/23	0.0266	< 0.001	3
196	Angdar Co	32.71	89.58	66.05	2013/10/21-2021/06/04	0.1110	< 0.001	3
197	Ayonggama Co	34.78	98.29	14.38	2011/11/08-2021/06/10	0.0074	0.767	1,3
198	Ayongwu'erma Co	34.79	98.2	37.6	2016/07/16-2021/03/08	0.1736	0.004	3
199	Baibing Lake	35.9	86.42	21.87	2014/11/03-2021/05/15	0.6140	< 0.001	3
200	Baidoi Co	32.79	87.83	79.17	2013/10/26-2021/07/27	0.2175	< 0.001	3,7
201	Bairab Co	35.03	83.13	135.22	2012/03/21-2021/07/13	-0.0165	0.143	3,8
202	Baitan Lake	34.56	88.58	20.13	2016/08/07-2021/05/11	0.0305	0.005	3
203	Baitutang Lake	34.65	87.61	10.4	2017/06/20-2020/06/27	0.0890	< 0.001	3
204	Bajiu Co	28.79	90.85	30.2	2011/10/13-2018/11/30	0.2304	< 0.001	3
205	Bamco	31.27	90.58	255.29	2012/11/13-2021/07/22	-0.1468	< 0.001	3
206	Bandao Lake	34.17	88.44	48.78	2014/11/23-2021/06/09	0.3673	< 0.001	3,8
207	Bei Hulsan Lake	36.88	95.91	130.5	2012/08/06-2021/06/15	0.0026	0.161	3,7
208	Beilei Co	32.9	88.44	29.13	2018/06/17-2021/05/15	0.1563	< 0.001	3
209	Beiyu Lake	33.03	86.18	15.1	2016/12/28-2019/08/27	1.0599	< 0.001	8
210	Bengze Co	32.08	88.67	16.46	2010/11/10-2021/06/05	0.1052	< 0.001	3
211	Bero Zeco	32.43	82.93	35.99	2013/06/17-2021/07/13	0.2038	< 0.001	3,7
212	Biluo Co	32.9	88.84	35.12	2015/07/08-2021/07/25	-0.0168	0.600	3
213	Botao Lake	34.01	89.96	71.36	2013/09/23-2021/07/23	-0.0247	0.755	3
214	Caiji Co	31.21	85.44	33.05	2013/06/25-2021/04/25	0.1456	< 0.001	3,7
215	Caka Salt Lake	36.7	99.11	115.77	2012/08/26-2021/06/09	-0.0047	0.216	3,8
216	Chabyer Co	31.38	84.04	258.5	2012/08/07-2021/06/17	0.0256	0.021	3,7
217	Chacang Co	30.23	88.58	19.17	2014/07/08-2021/03/26	0.0254	0.005	3,7
218	Chamu Co	33.26	83.01	12.06	2016/04/02-2021/07/13	0.1501	< 0.001	3
219	Chanacuo Lake	33.28	84.02	10.98	2016/09/16-2021/07/12	0.1064	0.534	3
220	Chen Co	28.95	90.52	39.4	2018/09/08-2021/04/15	-0.3488	< 0.001	3
221	Co Ngoin2	31.47	91.5	84.86	2014/05/01-2021/04/13	-0.0841	0.005	3

222	Como Chamling	28.4	88.22	38.57	2014/10/28-2020/02/05	-0.1518	0.405	3
223	Cuoga Lake	33.1	80.29	10.06	2019/10/31-2021/07/17	0.0385	0.296	3
224	Cuojia Lake	31.99	91.37	20.79	2015/02/09-2021/05/08	-0.0052	0.346	3
225	Cuojiangqin	33.99	92.83	15.54	2012/11/07-2021/04/12	-0.0027	0.117	3
226	Cuolaba'e'eadong	35.43	95.42	13.88	2019/05/08-2021/06/20	0.0219	0.398	3
227	Dachaidan Lake	37.84	95.25	33.14	2017/02/09-2021/04/28	-0.0363	< 0.001	3
228	Dazadizha Co	32.87	87.12	19.87	2013/08/12-2020/07/25	0.2458	< 0.001	3,7,8
229	Derucuo Lake	32.69	88.88	10.61	2016/07/10-2021/03/26	-0.0456	0.005	3
230	Dingjiamang Co	29.65	85.74	10.01	2012/01/18-2021/07/07	0.0099	< 0.001	3
231	Dongmo Co	32.3	86.57	12.34	2013/10/04-2021/04/23	-0.0245	0.035	3,7
232	Dongyue Lake	34.38	89.21	29.37	2014/08/27-2021/07/02	0.3215	< 0.001	3
233	Duolangcuoguo Lake	32.23	85.86	11.15	2013/06/09-2021/05/18	0.1093	< 0.001	3,7
234	Duoma Co	32.96	84.46	14.84	2015/11/07-2020/09/19	0.1965	< 0.001	3
235	East taijiner Lake	37.49	93.92	101.8	2012/12/06-2021/06/19	0.0893	0.001	3
236	Ezong Co	32.86	89.47	14.75	2016/08/07-2021/05/13	0.1058	0.007	3
237	Fenxing Lake	34.39	88.42	12.41	2016/11/27-2021/06/09	0.1610	0.101	3
238	Gahai1	37.13	97.55	34.87	2016/05/21-2020/06/06	0.0820	0.003	3
239	Galala Co	34.49	97.73	22.43	2013/11/26-2021/04/26	-0.0056	0.040	3
240	Gangma Co	33.83	84.34	14.31	2016/08/19-2021/06/17	0.2253	< 0.001	3
241	Ganongcuo Lake	31.91	91.53	17.8	2015/12/20-2021/06/25	0.0029	0.022	3,8
242	Garen Co	30.77	84.95	65.48	2014/10/06-2021/05/20	0.0303	0.084	3,8
243	Garkung Caka	33.97	86.49	70	2013/10/01-2021/06/10	0.3461	< 0.001	3,8
244	Gomang Co	31.22	89.2	115.73	2020/12/15-2020/12/15	-0.1396	< 0.001	3
245	Guogen Co	32.4	89.19	57.9	2014/11/23-2021/07/23	0.1168	< 0.001	3,8
246	Haobo Lake	34.4	88	18.89	2017/11/07-2021/07/27	0.1476	0.015	3
247	Hehua Lake	36.14	88.99	29.49	2014/05/10-2021/06/29	0.8498	< 0.001	3,8
248	Heihai	35.99	93.26	38.16	2011/08/04-2021/05/26	0.0706	0.405	1,3,13
249	Hengliang Lake	34.88	89.05	23.66	2013/09/28-2021/07/25	0.2989	< 0.001	3,7

250	Huangshui Lake	34.33	87.7	31.29	2014/05/10-2019/12/13	0.2205	< 0.001	3,8
251	Huolunuo'er	35.56	91.93	160.15	2013/09/18-2021/07/17	-0.1708	< 0.001	3,8
252	Jiaomu Caka	33.27	87.22	25.52	2017/01/02-2019/08/04	0.2970	< 0.001	8
253	Jiaruo Co	32.19	86.6	13.15	2014/05/03-2016/05/06	0.0651	0.850	7
254	Kaba Niu'erduo	35.42	95.11	29.08	2013/07/17-2021/06/17	0.0034	0.831	3
255	Kahu Co	33.39	82.97	30.56	2016/01/06-2020/01/21	0.1124	0.002	3
256	Kanbakadong Co	35.21	95.13	20.6	2017/01/12-2020/03/14	0.0080	0.296	3
257	Kangru Caka	33.56	86.96	15.49	2016/05/03-2020/08/19	0.0902	< 0.001	3,8
258	Keluke Lake	37.28	96.89	54.55	2014/01/27-2021/05/23	-0.0011	0.277	3
259	Kong Co	30.82	88.35	13.8	2019/05/26-2019/05/26	0.1380	< 0.001	3
260	Koucha	34.01	97.23	17.5	2016/11/08-2019/11/18	-0.0120	0.028	3
261	Kuhai	35.3	99.18	47.32	2014/12/25-2021/02/06	0.1000	< 0.001	3
262	Labu Co	32.96	83.8	15.36	2017/07/23-2021/04/05	0.1938	0.905	3
263	Lingguo Co	33.85	88.6	125.8	2013/05/08-2021/05/15	0.6406	< 0.001	3
264	Ma'erxia Co	30.97	87.47	102.07	2014/02/16-2021/04/21	0.1358	< 0.001	3,8
265	Mang Co2	34.49	80.44	12.92	2016/09/22-2019/10/01	0.1572	0.002	3
266	meijuhu	36.02	88.41	17.48	2013/07/28-2021/07/03	0.7254	< 0.001	3,7,37
267	Merqung Co	31.02	84.58	60.27	2017/05/26-2021/07/08	0.1298	< 0.001	3
268	Monco Bunnyi	30.64	86.26	150.78	2014/01/02-2021/05/18	0.0834	0.007	3,7
269	Naiqam Co	32.32	88.69	45.99	2014/01/17-2021/02/03	0.0154	0.003	3,7
270	Nanzha Co	32.66	85.47	25.1	2013/01/19-2020/09/16	0.1950	< 0.001	3
271	Neri Punco	31.3	91.47	92.61	2013/02/03-2021/04/13	-0.1365	< 0.001	3,5
272	Ngoinyar Coqung	32.99	88.7	96.58	2013/10/24-2021/05/11	0.1414	< 0.001	3
273	Ningri Co	33.32	85.58	16.42	2013/11/28-2020/10/10	-0.1068	0.321	3,7
274	Niri Acuogai	33.09	93.21	35.29	2011/11/13-2021/07/15	0.0546	0.003	1,3
275	Niudu Lake	33.65	88.58	10.23	2010/12/03-2020/11/20	0.0498	0.014	3,5,6
276	Noname	33.16	89.34		2017/12/01-2021/06/29	-0.0583	0.325	3
277	Nyer Co	32.28	82.22	22.13	2019/01/17-2021/04/05	0.0852	0.276	3

278	Pa Co	31.91	90.04	13.43	2017/11/30-2020/07/19	-0.2014	0.002	3
279	Pozi Co	30.47	86.11	25.66	2016/06/18-2021/01/15	0.1312	< 0.001	3
280	Puga Co	31.11	89.55	43.43	2014/08/27-2020/08/15	-0.1463	0.022	3,8
281	Pur Co	34.88	81.96	40.64	2016/01/08-2020/04/14	-0.0078	0.136	3
282	Pusai'er Co	32.34	89.46	33.89	2013/07/20-2021/06/29	0.0591	0.103	3,7
283	Puxu Co	31.91	87.21	16.58	2016/11/04-2020/04/04	-0.0486	0.026	3
284	Qieli Co	31.68	90.97	12.92	2010/09/10-2021/05/08	-0.1155	< 0.001	3
285	Qige Co	31.2	85.53	20.29	2016/09/13-2021/07/07	0.0074	0.684	3
286	Qingwa Lake	34.71	86.4	25.22	2017/04/26-2020/10/08	0.0794	0.016	3
287	Qiuruba Lake	33.31	84.81	10.65	2018/04/02-2020/07/04	0.2911	0.169	3
288	Quanshui Lake	34.76	80.18	16.74	2016/03/05-2021/07/20	0.2077	0.002	3,8
289	Rejue Caka	33.69	86.85	33.12	2013/08/12-2021/04/20	0.1031	< 0.001	3,7
290	Rena Co	32.73	84.26	20.7	2016/05/18-2020/10/14	0.1002	< 0.001	3,8
291	Rige Co	34.33	98.75	16.45	2016/04/27-2021/04/25	-0.0039	< 0.001	3,8
292	Riju Co	33.8	90.36	26.12	2013/02/07-2020/10/24	0.0472	< 0.001	3
293	Ringco Ogma	30.93	89.84	66.92	2013/06/02-2021/06/30	-0.2125	< 0.001	3,7
294	S54001	36.19	89.16	13.21	2011/09/08-2020/08/16	0.2422	< 0.001	1,3
295	S63008	35.95	89.33		2016/10/29-2019/11/07	0.3496	< 0.001	3
296	S63022	35.23	91.21	13.75	2014/08/27-2021/03/21	-0.0015	< 0.001	3
297	Sandao Lake	34.73	83.88	32.81	2015/06/20-2020/08/26	0.4259	< 0.001	3,8
298	Sekezhi Co	32	82.05	19.15	2021/04/30-2021/04/30	0.2214	< 0.001	3
299	Sengli Co	30.44	84.06	83.29	2016/04/17-2020/09/19	-0.0087	0.497	3,8
300	Shengli Lake	35.29	86.27	36.78	2015/08/12-2021/07/07	0.7865	0.003	3
301	Shuangju Lake	34.94	87.3	10.82	2019/04/30-2021/03/04	0.1057	0.351	3
302	Shuixiang Lake	36.03	87.88	15.52	2013/08/31-2021/05/16	0.4641	< 0.001	3
303	Sijia Lake	34.04	82.61	24.62	2018/11/20-2021/05/23	0.2260	0.027	3
304	Songmuxi Co	34.61	80.25	30.8	2015/05/05-2020/02/24	0.1364	0.024	3
305	T54001	34.22	89.75	19.1	2018/07/12-2020/07/19	0.1441	0.014	3

306	T54024	34.92	81.69	17.99	2017/12/20-2021/04/30	0.3288	0.044	3
307	Taiping Lake	34.3	89.71	28.48	2018/07/12-2020/09/09	0.1672	< 0.001	3
308	Taiyang Lake	35.93	90.63	101.44	2013/10/11-2021/04/13	-0.0005	0.853	3,7
309	Tao Lake	36.17	89.33	32.49	2015/10/26-2020/11/23	0.2384	< 0.001	3
310	Taoxing Lake	33.88	84.02	10.52	2016/06/24-2021/04/02	0.0428	0.002	3
311	Tari Co	31.52	85.68	40.11	2014/04/17-2021/06/12	-0.0147	0.045	3,8
312	Telashi Lake	34.81	92.22	73.65	2010/06/07-2021/06/22	0.3263	< 0.001	3,5,6,8
313	Tungpu Co	31.31	87.23	32.95	2021/01/14-2021/01/14	0.2309	< 0.001	3
314	Tuosu Lake	37.14	96.94	150.65	2011/07/03-2021/06/12	0.7239	< 0.001	1,3
315	Tuzhong Lake	34.53	84.7	32.28	2015/03/24-2020/09/19	0.3202	< 0.001	3
316	Wan'an Lake	34.43	88.55	19.87	2013/08/29-2020/05/25	0.0894	< 0.001	3,8
317	Wandou Lake	34.56	90.85	22.81	2013/09/21-2021/04/15	0.1611	< 0.001	3,5
318	Wuga Co	32	86.65	11.56	2019/12/15-2021/04/23	0.0122	0.865	3
319	Wujiongcuo Lake	30.91	86.42	14.66	2003/09/01-2021/06/30	0.7219	< 0.001	1,2,3,4,5,7,8
320	Xiabie Co	32.22	87.27	20.71	2011/08/14-2021/05/21	0.1412	< 0.001	1,3
321	Xiangtao Lake	34.13	84.97	11.31	2004/02/27-2021/07/02	0.4246	< 0.001	1,2,3,7
322	Xiao Caka	33.06	87.78	28.2	2013/06/14-2021/07/13	0.3508	< 0.001	3
323	Xiaosugan Lake	39.07	94.21	11.87	2008/12/12-2019/08/31	0.0230	0.427	2,3,8
324	Xiligou Lake	36.84	98.46	43.31	2016/02/25-2021/07/02	0.0581	< 0.001	3
325	Xingbo Lake	35.68	87.04	12.06	2013/10/31-2021/03/11	0.8170	< 0.001	3
326	Xinhu Lake	34.39	84.25	61.04	2018/05/30-2020/11/02	0.3981	0.071	3
327	Xinxin Lake	34.83	98.11	26.28	2015/11/02-2020/01/06	-0.0529	< 0.001	3
328	Xuejing Lake	35.98	87.38	86.08	2003/10/06-2021/06/30	0.4701	< 0.001	1,3,4,5,8
329	Xuemei Lake	36.29	88.27	56.26	2005/05/20-2021/07/22	0.6780	0.148	2,3
330	Xuru Co	30.29	86.42	210.03	2016/05/25-2021/06/19	0.1013	0.002	3
331	Yadao Lake	33.96	83.32	19.5	2006/06/10-2021/06/07	0.2246	< 0.001	2,3,7
332	Yaggain Co2	32.35	87.31	48.78	2018/01/02-2021/03/01	0.2445	0.006	3
333	Yake Co	34.7	87.19	20.41	2003/03/28-2021/07/22	1.5657	< 0.001	1,2,3,4,5,7,8

334	Yan Lake	35.52	93.41	144.32	2003/11/30-2021/07/22	2.3845	< 0.001	1,3,7
335	Yanzi Lake	33.87	89.93	16.07	2016/06/02-2021/05/06	0.0199	< 0.001	3
336	Yaxi Co	34.25	92.68	25.17	2017/10/13-2020/10/10	0.0239	0.053	3
337	Woniu_Lake	35.73	85.27	15.78	2013/10/04-2021/06/10	0.2039	0.108	3,5,7
338	Yazi Lake	35.07	87.07	44.24	2014/05/15-2021/07/30	0.5351	< 0.001	3
339	Yelusu Lake	35.22	92.14	202.47	2011/11/08-2021/07/20	0.0342	< 0.001	3,7,8
340	Yibug Caka	32.94	86.71	178.36	2013/11/23-2021/05/15	0.1059	< 0.001	3,5
341	Yingtian Lake	34.43	88.06	16.93	2012/01/14-2021/03/28	0.1110	< 0.001	3
342	Yongbo Lake2	34.96	89.24	43.59	2010/04/25-2020/12/06	0.1208	< 0.001	3,5,6
343	Yoqag Co	30.47	88.61	68.19	2016/07/10-2021/03/26	0.0016	0.635	3
344	Youbu Co	30.8	84.8	64.15	2013/09/21-2020/03/13	0.2190	< 0.001	3,7
345	Yuan Lake2	33.95	85.34	14.04	2018/04/28-2021/06/15	0.1111	0.384	3
346	Yueliang Lake2	35.62	86.27	12.54	2013/05/13-2021/06/10	-0.0433	0.567	3
347	Yueya Lake	34.92	82.22	14.21	2019/12/21-2021/07/15	-0.0219	< 0.001	3
348	Yuhuan Lake	34.8	83.92	17.28	2017/09/18-2021/04/02	0.3645	0.132	3,8
349	Yupan Lake	34.9	88.39	21.11	2015/12/28-2020/10/04	0.2744	< 0.001	3
350	Zainzong Co	32.24	89.61	12.56	2016/02/16-2021/04/18	-0.0586	0.068	3
351	Zhangtoujiangmu Co	35.33	95.61	17.84	2016/01/05-2021/05/26	0.0041	0.034	3
352	Burog Co	34.4	85.77	92.95	2016/03/07-2021/04/23	0.4081	< 0.001	3,8
353	Dongka Co	31.78	90.4	72.5	2019/06/17-2021/07/22	-0.2658	0.503	3
354	Kongkong Caka	33.16	88.11	49.52	2013/04/08-2021/07/25	0.0535	< 0.001	3,8
355	West taijiner Lake	37.71	93.38	99	2014/02/01-2020/08/29	-0.0112	< 0.001	3
356	Xiaochaidan Lake	37.5	95.51	88.13	2009/06/24-2019/08/06	0.2674	0.001	3,4,5
357	Laorie Co	33.73	90.01	56.6	2007/04/21-2021/07/23	-0.0284	< 0.001	3,4,5,6
358	Pung Co	31.5	90.97	176.46	2003/07/25-2021/06/27	0.1797	< 0.001	1,3,7
359	Ciyijiare Lake	32.61	87.21	10.05	2019/02/03-2021/07/27	-0.1646	0.005	3,8
360	Ma'an Lake	35.23	89.51	18.55	2011/03/13-2021/06/07	0.0067	0.921	3,5,6
361	Xuehuan Lake	35.01	88.05	40.98	2012/02/09-2021/07/05	0.2427	< 0.001	3

*altimeter type; 1 - Envisat, 2 – ICESat-1, 3 - CryoSat-2, 4 - Jason-1, 5 - Jason-2, 6 - Jason-3, 7 - SARAL, 8 - Sentinel-3A.