

Precise topography assessment of Lop Nur Lake Basin using GLAS altimeter

Longfei Wang^{1,2}, Huaze Gong^{1,3}, Yun Shao^{1,3}

¹ Institute of Remote Sensing Applications, Chinese Academy of Sciences, Beijing, 100101, China

² University of Chinese Academy of Sciences, Beijing, 100049, China

³ State Key Laboratory of Remote Sensing Science, Beijing, 100101, China

E-mail: wanglf@irsa.ac.cn

Abstract. Lop Nur is a dried-up salt lake lying in the eastern part of Tarim basin, which used to be the second largest lagoon in China. The “ear” rings in Lop Nur attract many interests and are regarded as the lake shorelines during its recession. The topography of the lake basin is important in understanding the formation of the “ear” rings. In this paper, elevation data along three transects obtained from laser altimeter were taken as the basic material of the topography in Lop Nur. Elevation data of laser altimeter show great consistency between adjacent passes. Orthometric height (OH) derived from altimetry data and the geoid model are used to analyze the elevation characteristic along “ear” rings. The result shows the “ear” rings are basically identical in elevation, supporting the statement that “ear” rings are former lake shorelines. A discrepancy of approximately 1 meter in OH is observed on the same “ear” ring, lower in the north and higher in the south, which is found for the first time. Possible explanations could be deformation of ground surface due to earthquake or tectonic movement after the “ear” rings are formed, or tilt of water surface due to wind stress or lake current during the formation of the rings.

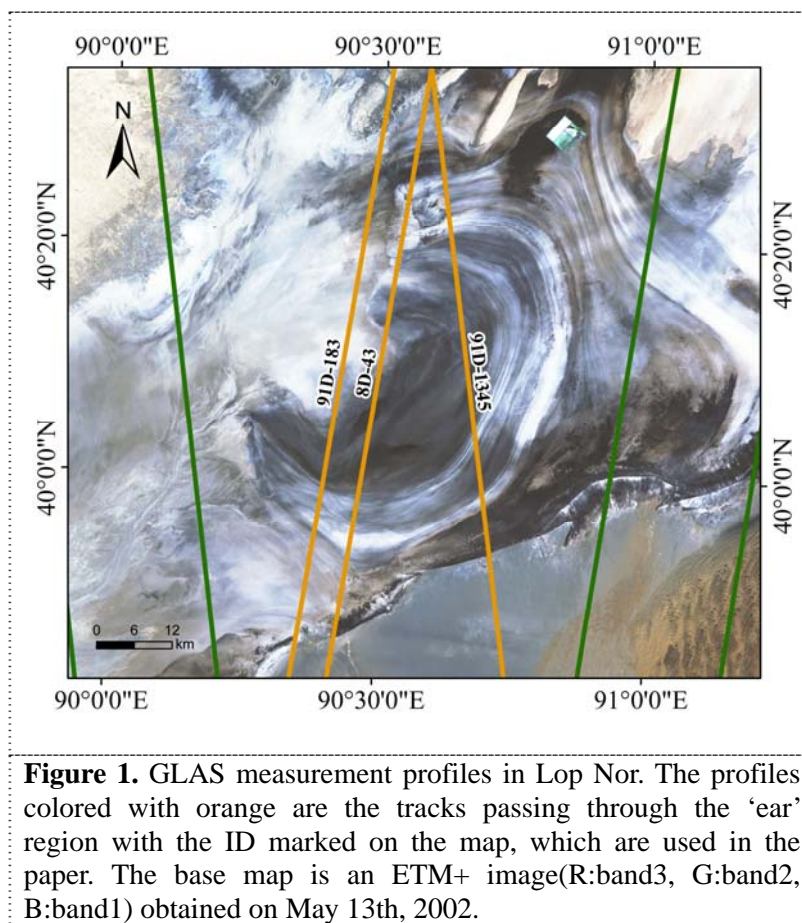
1. Introduction

Lop Nur Lake Basin, located in the innermost part of Eurasia continent, is surrounded by the Altun Mountain and Kum Tagh Desert to the south, Kuruk Tagh Mountain and Beishan Mountain to the north and northeast, and Lop desert to the west. The basin covers an area of more than 10,000 km², used to be the ending lake of Tarim river and Konche river, which plays an essential role in the ancient civilization evolution. In the 20th century, Lop Nur dried up and finally became a desolated lakebed covered with cracked salt crust. The area is extraordinary arid. According to the weather records in Ruoqiang county which is close to Lop Nur, the annual precipitation is only 17.4mm, while annual evaporation reaches as high as 2902mm [1]. The water storage of Lop Nur greatly rely on the inpouring of Tarim and Kongche rivers, and consequently sensitive to the climate change around Tarim Basin. The retrieve of climate change of Tarim Basin according to evolution of Lop Nur using various methods became popular in recent years.

On the remote sensing images of Lop Nur, a set of concentric rings in the basin is the most distinct pattern, and highly resembles a huge human ear (see figure 1), for which Lop Nur is called “ear” lake by the researchers. Many interpretations were suggested to explain the formation and physical or chemical features of the “ear” rings [1-3], and most of which believe the ring is the former shorelines



left during the shrinking of Lop Nur and represent the water levels at certain period. That means the same ring should have the same elevation. If we ignore the impact of water flow in the lake and other forces act on the water body except gravity, such as wind stress and barometric force, the points along the same ring should be identical in elevation. Although widely accepted, the hypothesis is poorly demonstrated. The main reason is, as the Lop Nur is extraordinary large (~50km in horizontal scale) with very small elevation discrepancy (less than 5 meters in depth) [4, 5], it is still a rough task to explicitly describe the topography in the basin and consequently difficult to validate whether the “ear” rings are identical in elevation.



Large amount of specific field survey was conducted by the Chinese government around 1960 and in 1980s [6], unfortunately, little attention was paid to the precise topography in the basin. In 2000, the Shuttle Radar Topography Mission (SRTM) produces a 90 meters horizontal resolution Digital Elevation Model (DEM) for the world (30 meters for the US) using Interferometric Synthetic Aperture Radar (InSAR), with vertical accuracy of 16 meters. In 2009, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on Terra satellite yields global DEM of 30 meters horizontal resolution by stereophotogrammetry with vertical accuracy of 20 meters. However, these high precision DEMs are still insufficient to resolve the elevation difference between “ear” rings, because of the topographic smooth in Lop Nur. In 2005, an elevation profile from leveling measuring was published, showing 3.02 m elevation difference in 50 kilometers distance [5]. In 2006, an integral and carefully designed topographic measurement using Differential Global Positioning System (DGPS) method with nominal vertical error of 20 mm was performed [4]. The measurement shows a more reliable result with new insight to the topographic feature of Lop Nur basin, yet it is sparse in sampling and lack of affirmance from other data sources. In this paper, we will introduce topographic data in

Lop Nur basin from the Geoscience Laser Altimeter System (GLAS), and discusses the topographic features of along the “ear” rings.

2. Materials and Method

The GLAS on the Ice, Cloud and Land Elevation Satellite (ICESat) aimed to provide global information on ice sheet elevations as well as land elevations and other aspects. GLAS emits laser pulses at wavelength of 1064nm to measure the range from satellite to the surface, by combining precise orbital control system and laser pointing system, and after applying corrections based on an alternate wavelength laser. The transmitted pulse has a divergence of approximately 110 mrad, which will illuminate a spot on the Earth’s surface with a diameter of about 60 m. The 40 Hz rate of laser pulses producing a separation of illuminated footprints on the Earth’s surface of 172 m. The overall altimetric error for GLAS is designed to be 13.8cm [7], however, analysis on the performance of GLAS show a more preferable result, with accuracy of 3cm [8-10].

This paper collects GLAS land surface altimetry data product (GLA14) in Lop Nur “ear” region (90°10'E-90°55'E, 39°50'N-40°30'N) distributed by national snow and ice data center (NSIDC) of release number 33 [11], and the product retrieve land elevation using algorithm developed using waveforms acquired by the Shuttle Laser Altimeter and the airborne Laser Vegetation Imaging Sensor. Each regional product is processed with algorithms specific to that surface type after instrument corrections, atmospheric delays and tides have been applied. Three ground tracks numbered 8D-43, 91D-183, and 91D-1345 were prescribed in this area during the lifetime of GLAS (figure 1). As the off-nadir pointing will normally not be used to avoid saturation, tracks on repeat cycles will vary within about 1 km [7]. Actually, a total of 36 passes were measured along in the “ear” region, of which 15 passes with data losses in the region due to cloud sheltering or anomaly in on-board instrument are not considered in this paper. The remaining 21 passes used are listed in table 1. The GLAS elevation product adopts the reference ellipsoid of TOPEX/Poseidon, which is slightly different from WGS-84 ellipsoid. For latitudes north/south of 40 degrees, most applications could simply assume that TOPEX/Poseidon elevations are 0.71 meters higher than WGS-84 elevations. The conversion from TOPEX/Poseidon to WGS-84 ellipsoid is applied to GLAS data as a pretreatment.

Table 1. Passes without data loss in “ear” region

Track Number	Date of Pass
Track 8D-43	02/27/2003; 03/07/2003; 10/01/2003;
Track 91D-183	03/05/2004; 06/04/2004; 10/21/2004; 03/08/2005; 11/08/2005; 11/11/2006; 03/29/2007; 10/20/2007; 03/05/2008; 12/01/2008;
Track 91D-1345	05/23/2004; 10/09/2004; 05/25/2005; 02/27/2006; 10/30/2006; 03/16/2007; 10/09/2008; 03/13/2009;

The GLAS elevation product refers to ellipsoid rather than geoid, which is not suitable for analysis on water level. In order to compare water level along the same “ear” rings, OH (denoted by H_{OH}) must be introduced to represent height from geoid with correlation

$$H_{OH}=H-h_g \quad (1)$$

where H is geodetic height provided by the laser altimeter, and h_g is height anomaly from ellipsoid to the geoid. In this paper, EGM2008 released by the U.S. National Geospatial-Intelligence Agency (NGA) is adopted for the geoid model, which gives the parameter h_g . The model benefits from solutions of the latest gravity satellite GRACE (Gravity Recovery and Climate Experiment), and combines the improved altimetry-derived gravity anomalies as well as regional gravity anomaly measurement. The EGM2008 gravitational model is complete to spherical harmonic degree and order 2159, which means horizontal resolution is 5 second, or approximate meridionally 9 kilometers and zonally 7 kilometers in Lop Nur region.

Lop Nur Lake Basin is covered with cracked salt crust which is several meters in size and 10-80cm in height [5]. Laser altimeter measurement could be affected by these undulations but is substantially averaged by the 60-meters-diameter laser footprint, however, reflectance center could be slightly different over the basin and random errors are inevitable. So a lowpass filter with threshold length of 1.5km is applied to the GLAS data, the filtering section is exactly within the Lop Nur basin where no abrupt change in elevation exists to avoid impact of Yardangs, river terraces or mountains, which is section between 39°50'N to 40°27'N for track 8D-43 and 91D-183, and 39°55'N to 40°23'N for track 91D-1345 explicitly. To the threshold length, a smaller one couldn't filter out noises while a larger one could substitute the measured ground elevation with a smooth but biased one. As a result, the threshold length must be carefully chosen. The 1.5km threshold length is adopted for its filtering performance, and the standard deviation of elevation difference between the original and filtered ones is typically less than 7 centimeters, which is comparable with the error level of GLAS.

3. Result and Discussion

Track 8D-43 was implemented during the early time of ICESAT, while which GLAS finished ground calibration and validation. A total of 3 passes obtained during this time are selected in this paper. OH along the Track 8D-43 of section between 39°50'N to 40°27'N derived from GLAS altimetry and latest geoid model are shown in figure 2(a). The grey dotted lines are original elevation derived from GLAS land elevation product and EGM2008, and the red lines are filtered OH from each passes. Profiles of different passes are quite similar, with small OH in the center and larger OH at the edge of the basin. Small discrepancies at the scale of 10cm between different passes could be observed from the profiles. We can ascribe the discrepancies to measurement errors, but as different passes of the same track could be different in location for as many as 2 kilometers or even more, another explanation that the discrepancies respond for the real topography is preferable. OH along the track 91D-183 (39°50'N to 40°27'N) and in 91D-1345(39°55'N to 40°23'N) in “ear” region are shown in figure 2(b) and figure 2(c) respectively.

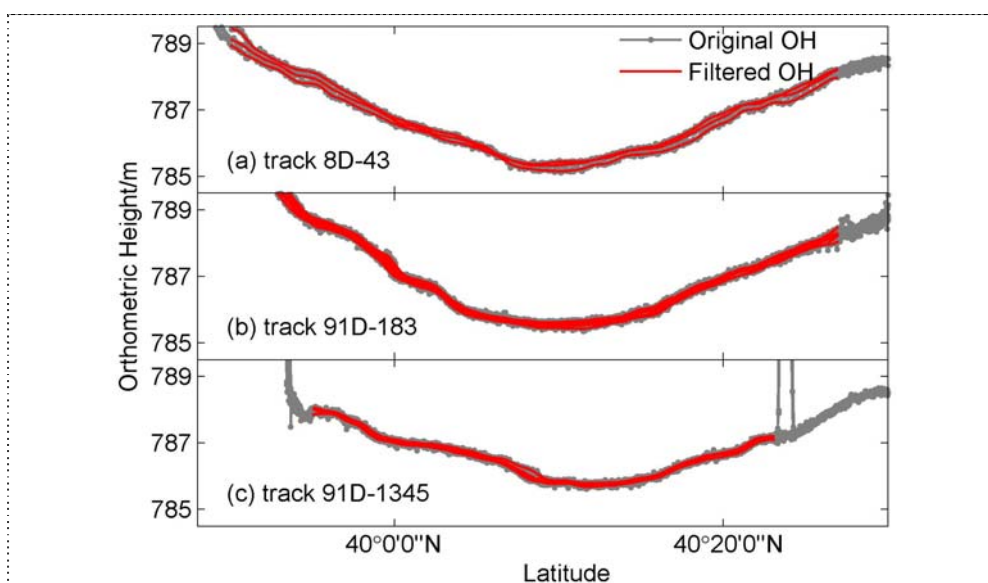


Figure 2 Elevation profile for the passes of GLAS track 8D-43(a), 91D-183(b) and 91D-1345(c). The grey lines indicate original elevation data obtained from GLAS land altimetry product and EGM2008, and the red ones are filtered elevation data using the scheme mentioned previously. Each track consists a number of passes vary within several kilometers apart, so the elevation profiles of the same track can differ from each other slightly.

To give a better understanding of the topography in this region, an plan-view of Lop Nur topography is shown in figure 3. The non-precisely repeated tracks provide extensive coverage of the region. Figure 3 shows clearly a shallow lowland of about 5 meters depth in the 2000 km² area of the “ear” region, with OH decrease gradually towards the central part.

Four distinct “ear” rings (lined in figure 3) are confirmed using precisely coregistered optical and radar images, naming ring A, B, C and D from outer to inner part of the region. OH along these rings are plotted in figure 4, with different color representing different rings. The OH of the rings are grouped in six regions from R1 to R6 for easily comparison. The result shows basically identical OH along the same ring in the northern part (R1-R3), while obvious larger OH along the same “ear” ring in the south (R4-R6). This characteristic can be recognized from each of the four “ear” rings. The discrepancy of OH from north to south on the same ring is approximately 1 meter, so that, considering the precision of these data sources, it's impertinent to attribute to the errors in elevation measurement, geographical location determination, or the geoid model. The phenomenon is quite interesting, as the “ear” rings regarded as former shorelines should be identical in OH, as discussed earlier, but data showing an unexpected case. If we believe in the fact that the “ear” rings represent the former lake shoreline at certain time, the reason for this could be (i) deformation of ground surface due to earthquake or tectonic movement after the “ear” rings are formed, or (ii) tilt of water surface due to wind stress or lake current during the formation of the rings. Both possibilities need further investigation.

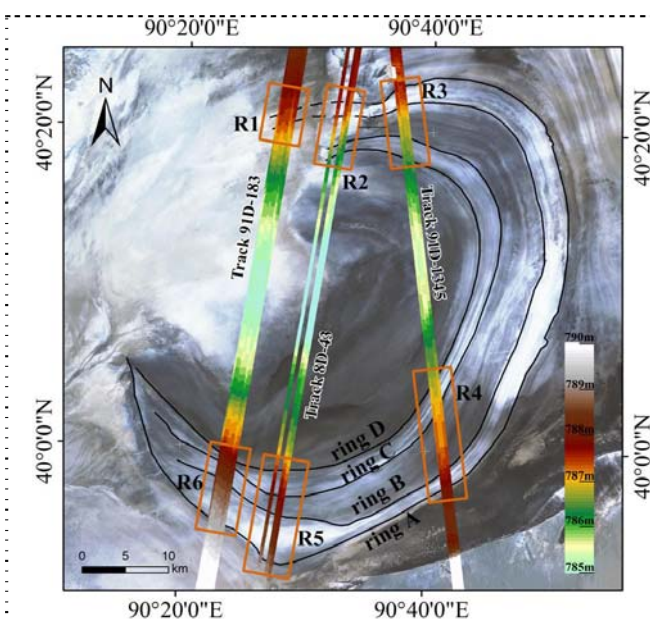


Figure 3 OH obtained by GLAS. Four rings of “ear” are depicted according to optical (solid rings) and radar (dashed rings) images, naming ring A, B, C and D, respectively, from outer to inner part of the region. The orange boxes labeled six intersect regions of GLAS tracks and “ear” rings with code R1 to R6, which are used in the analysis.

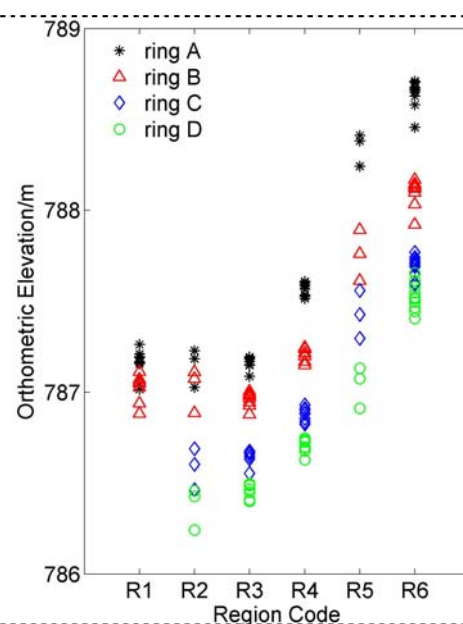


Figure 4 OH along Lop Nur rings. The region code is marked in figure 3. OH of a particular region shows a descending trend from ring A to ring D. The figure indicates higher elevation in the south (R4,R5,R6).

4. Conclusion

Elevation data in Lop Nur basin collected by GLAS is carefully checked and betaken to analyze the explicit topography of the lakebed. The precision of the laser altimeter GLAS is 13.3 cm generally and could be higher in flattened land without any vegetation such as Lop Nur. A total of 21 passes located along three tracks crossing the “ear” region indicates only 5 meters depth in the area. Careful

examination shows the “ear” rings are roughly identical in elevation, especially in the north part, supporting the statement that “ear” rings are former lake shorelines. Nonetheless, a discrepancy of approximately 1 meter in OH is observed on the same “ear” ring, lower in the north and higher in the south, which is never reported before due to lack of high precision data. The discrepancy could hardly be attributed to errors. The possible explanations for this could be deformation of ground surface due to earthquake or tectonic movement after the “ear” rings are formed, or tilt of water surface due to wind stress or lake current during the formation of the rings. The clarify of the reason for elevation discrepancy along the same rings would be important to understand the formation of “ear” rings, as well as the environment evolution in the area.

Acknowledgements

The authors thank NASA’s ICESAT Science Project and the NSIDC for distribution of the GLAS data. Thanks to U.S. NGA’s distribution of the geoid model. The work is supported by CAS Knowledge Innovation Program (KZCX2-EW-320), the fund of State Key Laboratory of Remote Sensing Science (Y1Y00201KZ), National Natural Science Foundation (41201346), and IRSA/CAS (Y1S01200CX).

References

- [1] Zhao Y, Xia X, Wang F, Cao Q, Gao W and You G 2006 *Arid Land Geogr.* **29**(6) 779-83
- [2] Shao Y, Gong H, Gao Z, Liu L, Li L and Zhang T 2012 *Can. J. Remote Sens.* **38**(03) 267-80
- [3] Ma L, Li B, Jiang P, Zhong J, Qiu H and Wu H 2007 *Chinese J. Geophys.* **50**(2) 651-4
- [4] Li B, Ma L, Jiang P, Duan Z, Sun D, Qiu H, Zhong J and Wu H 2008 *Chinese Sci. Bull.* **53**(06) 905-14
- [5] Zhao Y, Xia X, Cao Q and Lv Z 2005 *Arid Land Geogr.* **28**(6) 795-9
- [6] Xia X, Wang F *et al* 2007 *Lop Nor In China* (Beijing: Science Press) pp22-5
- [7] Zwally H, Schutz B, Abdalati W, Abshire J, Bentley C, Brenner A, Bufton J, Dezio J, Hancock D, Harding D, Herring T, Minster B, Quinn K, Palm S, Spinhirne J and Thomas R 2002 *J. Geodyn.* **34**(3) 405-45
- [8] Abshire JB, Sun X, Riris H, Sirota JM, McGarry JF, Palm S, Yi D and Liiva P 2005 *Geophys. Res. Lett.* **32**(21) L21S02
- [9] Fricker H, Borsa A, Minster B, Carabajal C, Quinn K and Bills B 2005 *Geophys. Res. Lett.* **32**(21) L21S06
- [10] Martin C, Thomas R, Krabill W and Manizade S 2005 *Geophys. Res. Lett.* **32**(21) L21S07
- [11] Zwally HJ, Schutz B, Bentley C, Bufton J, Herring T, Minster J, Spinhirne J and Thomas R 2003 GLAS/ICESat L2 Global Land Surface Altimetry Data Version 33 (*Digital Media*) (Boulder, CO: Nat. Snow Ice Data Center)