Measure the Height of Mount Everest

Subjects: Geology
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Mount Everest is the highest mountain in the world. First, we should know where is Mt. Everest located on the plateau of Tibet map (https://www.greattibettour.com/tibet-travel-tips/plateau-of-tibet.html). It is on the border of Nepal and Tibet(the Autonomous Region of China). The determination of the height of Mount Everest(HME) is one of the focuses of the geodetic community. The shallow layer method (SLM) based on the definition of the geoid can determine the gravity field inside the shallow layer. The orthometric height of Mount Everest (HME) is calculated based on SLM, in which the key is to construct the shallow layer model. The top and bottom boundaries of the shallow layer model are the natural surface of the Earth and the surface at a certain depth below the reference geoid, respectively.

Keywords: Geology

1. Previous measurements of Mount Everest

The determination concerning a unified orthometric height system from which the HME is referred has not been solved. Over the last century, the HME has been measured many times by various countries. The first measurement of HME was 8839.2 m, which was observed by Sir George Everest (British geodesist) from 1847 to 1850 [1]. On July 23, 1975, the Xinhua News Agency (China) announced that the new HME was 8848.13 m referring to the 1956 Yellow Sea elevation system. In May 1999, the Millennium Mountaineering Team of Mount Everest used GPS to measure the rock surface height as 8850 m, and a snow-depth radar detector measured the average snow depth as 1 m, making the snow-covered height equal to 8851 m [1]. This number has been frequently cited in social media.

On October 9, 2005, China's StateBureau of Surveying and Mapping reported that the rock surface elevation at the summit of Mount Everest was 8844.43 m referred to the 1985 national elevation datum, and the accuracy of this measurement was ±0.21 m, and the depth of snow at the summit reached 3.50 m. On December 8, 2020, the Chinese and Nepalese governments announced that the HME was 8848.86 m referred to as a gravimetric geoid that is calculated based on the International Height Reference System (IHRS). The so-called AME refers to the height from the top of Mount Everest to the geoid. There are different kinds of methods for determining the geoid, such as the traditional Stoke's method, Monodensky's method, and the shallow layer method (SLM) proposed by Shen (2006) . The advantage of the SLM is that it is based on the definition of the geoid, thereby it avoids boundary-value problems and the mass adjustment that needs to be carefully addressed in traditional methods. Compared with ortho-metric height derived from the GPS leveling data in Xinjiang, China, Shen, and Han (2013) showed that the results of the determined geoid undulation based on SLM are better than those determined by other methods.

2. The Advantages of SLM

The so-called HME refers to the height from the top of Mount Everest to the geoid. There are different kinds of methods for determining the geoid, such as the traditional Stoke's method, Monodensky's method, and the shallow layer method (SLM) proposed by Shen (2006) [2][3][4][5][6]. The advantage of the SLM is that it is based on the definition of the geoid, thereby it avoids boundary-value problems and the mass adjustment that needs to be carefully addressed in traditional methods. Compared with ortho-metric height derived from the GPS leveling data in Xinjiang, China, Shen, and Han (2013) showed that the results of the determined geoid undulation based on SLM are better than those determined by other methods [7].

Furthermore, one important feature of SLM is that it can determine the gravity field inside the shallow layer. In general, it is difficult to determine the gravity field inside the Earth because the inner gravity field below the Earth's surface cannot be directly observed [12]. However, many high-precision models (e.g..EGM2008, EIGEN-6C4, CRUST2.0, CRUST1.0, DTM2006.0, andDNSCO8) enable SLM to determine not only the geoid but also the gravity field inside the shallow layer. For instance, the EGM2008and EIGEN-6C4 models provided a global 5'x5' gravity model with an accuracy- of centimeters |13,14- Compared with the constant density of 2.67 g/cm3 in the shallow layer, the CRUST2.0and CRUST1.0 models provided more detailed density information[15,16]. The digital terrain/elevation model (DTM2006.0) and the Danish National Space Center data set of the mean sea surface(DNSC08) provided high-resolution and high-precision information on the Earth's surface. All of these data sets (or models) provided an opportunity to construct a well-defined shallow layer model.

3. Geoid Undulation and Gravity Field Determined by SLM

Given the advantages of SLM, we calculate the HME by two approaches based on the geoid undulation (N) and gravity field inside the shallow layer. The first approach, which is also referred to as the direct approach, determines the geoid undulation at Mount Everest by SLM directly, and then the orthometric height (H) is calculated in combination with the geodetic height (h) observed by GPS. The second approach, which is referred to as the segment summation approach (SsA), divides the gravity potential difference between the peak of Mount Everest and the geoid into a number of segments. Then the height of each segment can be calculated by combining the gravity and geopotential numbers. Finally, the HME is obtained by summing all of them up.

Generally, the geoid lies beneath the Earth's natural surface on the continents. The geopotential on the geoid cannot be directly obtained by observation. Shen (2006) proposed the SLM to solve this problem. The shallow layer extends from the Earth's natural surface to an inner surface, and the surface below a reference geoid for a certain depth is to ensure that the whole geoid is well defined in the domain outside the inner surface. Then, we solve the geoid equation W(P) = Wo to determine the geoid, where Wo is the geopotential constant defined on the geoid. Due to the construction of the shallow layer, the gravitational potential V(P) of the whole Earth can be divided into two parts. One part is the potential field Vo (P) generated by the mass enclosed by 1 (referred to as the inner mass), and another part is the potential field V1(P) generated by the shallow layer mass. We can obtain the gravitational potential of the two parts by New ton integral and natural continuation in the domain outside I.

Based on the innovation of using SLM to determine the gravity field from the Earth's surface to the inner surface, we calculated the orthometric HME by two approaches. The first approach ignores the inconsistent direction difference between the geodetic height(h) and orthogonal height and directly determines the HME by combining h and the geoid undulation (N). Then, we use the second approach the SSA, which is more consistent with the actual condition. In this approach, the gravity field inside the shallow layer determined by SLM is used. The gravity potential is stratified into equipotential planes, and the calculated orthometric height is closer to its true trajectory. The comparison of the results shows that the difference between the two approaches increases with increasing altitude, and the difference is about 0.09 m at the top of Mount Everest.

References

1. Y.Q. Xue, Three hundred years of mapping of Mount Everest (in Chinese), The 12020 Academic Annual meeting of China Measurement Society, 2020. https://mp.weixin.qq.com/s/120WP17RnznEj4xopoC2uQ.
2. G.C. Stokes, On the variation of gravity on the surface of the Earth, Trans CambPhil Soc 8 (672-95)（(T84) .
3. B. Hofmann-Wellenhof, H. Moritz, Physical Geodesy, Springer Science andBüsiness Media, 2006.
4. M. MoTodenski, V. Eremeev, M. Yurkina, Methods Tor Stüdy of the ExternalGravitation Field and Figure of the Earth, Translated from Russian, IsraelProgram for Scientific Translations, Jerusalem, 1962.
5. W.8. Shen, An Approach for Determining the Prease Giobal Geoid; Proceedings of the Ist International Symposium of the GFS, F,2006.
6. W.A. Heiskanen, H. Moritz, Physical geodesy, Freeman and Company. SanFrandisco, 1967.
7. W.B. Shen, J.C. Han, Improved geoid determination based on the shallow-layer method: a case studying FC.M08 - ndrRIIST? 0 in the Xinjiang and Tibetan regions Terrestrial, Atmospheric Oceanic Sciences 24 (4) (2013).