

Abstract

We proposed an alternative method to determine the height of Mount Everest (HME) based on the shallow layer method (SLM), which was put forward by Shen (2006). We use the precise external global Earth gravity field model (i.e., EGM2008 and EIGEN-6C4 models) as input information, and the digital topographic model (i.e., DTM2006.0) and crust models (i.e., CRUST2.0 and CRUST1.0 models) to construct the shallow layer model. There are four combined strategies: (1) EGM2008 and CRUST1.0 models, (2) EGM2008 and CRUST2.0 models, (3) EIGEN-6C4 and CRUST1.0 models, and (4) EIGEN-6C4 and CRUST2.0 models, respectively. We calculate the HME by two approaches: first approach, the HME is directly calculated by combining the geoid undulation (N) and geodetic height (h); second approach, we calculate the HME by the segment summation approach (SSA) using the gravity field inside the shallow layer determined by the SLM. Numerical results show that for four combined strategies, the differences between our results and the authoritatively released value 8848.86 m by the Chinese and Nepalese governments on December 8, 2020 are 0.448 m, -0.009 m, -0.295 m, and -0.741 m using first approach and 0.539 m, 0.083 m, -0.214 m, and -0.647 m using second approach. The combined calculation of the HME by the terrain model and gravity field model is more accurate than that by the gravity field model alone.

Model

➤ Shallow Layer Model

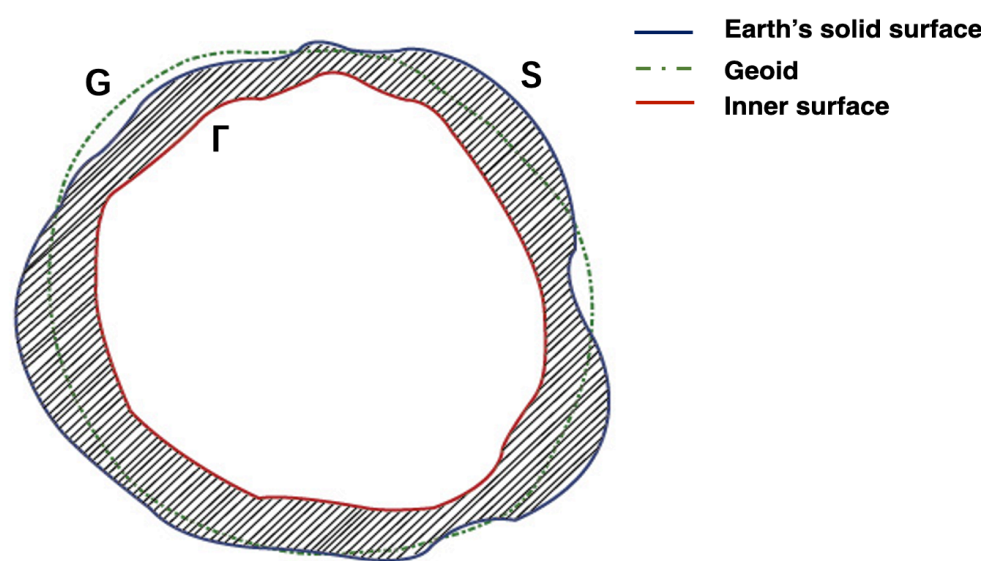


Fig. 1. Definition of the shallow layer, redrawn after Shen and Han (2013). The closed thick solid black curve denotes the Earth's surface S; the closed dotted green curve denotes the geoid G; and the thin solid red curve denotes an inner surface Γ below the geoid. The mass volume bounded by Γ and S is referred to as the shallow mass layer.

We use the external global Earth gravity field models (EGM2008、EIGEN-6C4 and XGM2019e), the digital topographic model (DTM2006.0) and crust models (CRUST2.0 and CRUST1.0 models) to construct the shallow layer model. The top and bottom boundaries of the shallow layer model are the Earth's nature surface and a surface below a reference geoid for a certain depth.

➤ model combined strategy

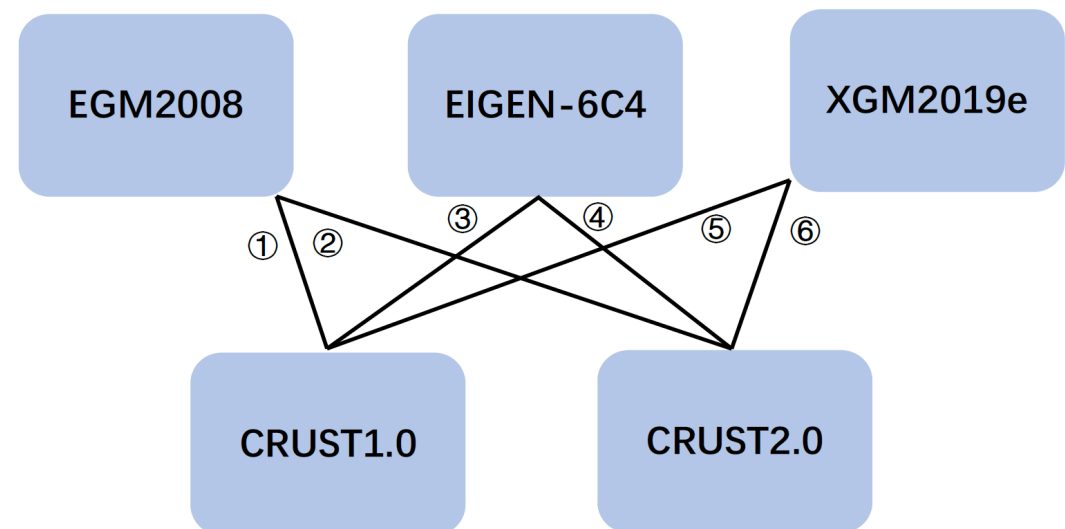


Fig. 2. Six combined strategies among the global gravity field models and crust models. Strategies ①、②、③、④、⑤ and ⑥ use the EGM2008 and CRUST1.0 models, EGM2008 and CRUST2.0 models, EIGEN-6C4 and CRUST1.0 models, EIGEN-6C4 and CRUST2.0 models, XGM2019e and CRUST1.0 models and XGM2019e and CRUST2.0 models respectively.

Method

➤ **Direct approach** : The orthometric height H is calculated in combination with the geodetic height h observed by GNSS.

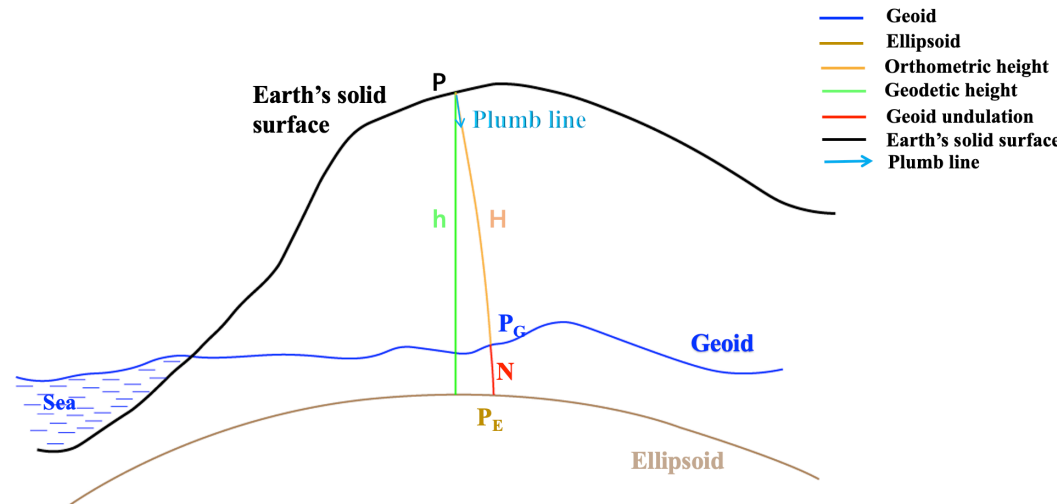


Fig. 3. The black curve denotes the Earth's solid surface, and P denotes the top of Mount Everest. The blue curve denotes the geoid G. The brown curve denotes the ellipsoid. The green straight line denotes geodetic height h from P to the reference ellipsoid along the normal direction of the reference ellipsoid. The deep yellow curve denotes the orthometric height H from P to the geoid G along the plumb line. P_G and P_E are the points at which orthometric height H intersects the geoid and ellipsoid, respectively.

$$H_{QF} = h_{QF} - N_{QF} \quad (1)$$

➤ **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, HME is obtained by summing all of them up.

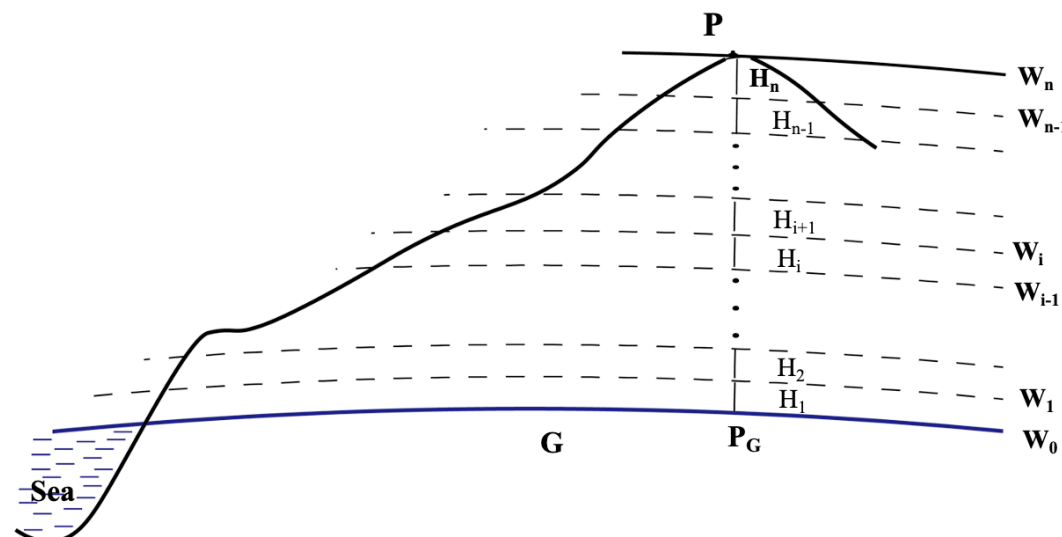


Fig. 4. Equipotential plane stratification. The black curve denotes the Earth's solid surface, and P denotes the top of Mount Everest. The blue curve denotes the geoid G. W_0 represents the geopotential constant on the geoid. The dotted line denotes the other equipotential plane. W_i represents the geopotential on the i-th equipotential plane. H_i is the orthometric height between the i-th and (i-1)-th equipotential planes. P_G represents the point at which orthometric height H intersects the geoid.

$$dH_i = \frac{dW_i}{\bar{g}_i}, i = 1, 2, 3, \dots, n \quad (2)$$

$$H = \sum_{i=1}^n dH_i \quad (3)$$

Conclusions

- We proposed an alternative method to determine the height of Mount Everest (HME).
- The combined calculation of the HME by the terrain model and gravity field model is more accurate than that by the gravity field model alone.
- Among all the results in Table 1, the accuracy of the result obtained of the SLM(2) by direct approach is the highest.

Results

- The experimental results are displayed in Table 1.

Table 1 Determined heights based on two different approaches; the heights are different from H_{20} . (1)–(6) represent the four combined strategies (unit: m).

Type	(1)	(2)	(3)	(4)	(5)	(6)
HME (direct approach)	8849.308	8848.851	8848.565	8848.119	8848.522	8848.065
HME (SSA)	8849.399	8848.943	8848.646	8848.213	8848.618	8848.169
HME (direct approach) - H_{20}	0.448	-0.009	-0.295	-0.741	-0.338	-0.795
HME (SSA) - H_{20}	0.539	0.083	-0.214	-0.647	-0.242	-0.691
HME (SSA) - HME (direct approach)	0.091	0.092	0.081	0.094	0.096	0.104

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References

W.B. Shen. An approach for determining the precise global geoid; proceedings of the 1st International Symposium of the IGFS, F, 2006 [C].

W.A. Heiskanen, H. Moritz. Physical Geodesy, 1967 [J]. Freeman and Company, San Francisco, 1999.

W.B. Shen, J.C. Han. Improved Geoid Determination Based on the Shallow-Layer Method: A Case Study Using EGM08 and CRUST2. 0 in the Xinjiang and Tibetan Regions [J]. Terrestrial, Atmospheric Oceanic Sciences, 2013, 24(4).

N.K. Pavlis, S.A. Holmes, S.C. Kenyon, et al. The development and evaluation of the Earth Gravitational Model 2008 (EGM2008) [J]. Journal of geophysical research: solid earth, 2012, 117(B4). <https://doi.org/10.1029/2011JB008916>.

C. Förste, S. Bruinsma, O. Abrikosov, et al. EIGEN-6C4: the latest combined global gravity field model including GOCE data up to degree and order 2190 of GFZ Potsdam and GRGS Toulouse; GFZ Data Services (2014) [M]. 2015.

C. Bassin. The current limits of resolution for surface wave tomography in North America [J]. EOS Trans AGU 81: Fall Meet Suppl, Abstract, 2000.

G. Laske, G. Masters, Z. Ma, et al. Update on CRUST1. 0—A 1-degree global model of Earth's crust; proceedings of the Geophys Res Abstr, F, 2013 [C].

.Zingerle, R. Pail, T. Gruber, et al. The combined global gravity field model XGM2019e [J]. Journal of Geodesy, 2020, 94(7): 1-12.