Is Mount Everest higher now than 155 years ago?'

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All human works are subject to error, and it is only in the power of man to guard against its intrusion by care and attention. (George Everest)

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Foreword

One day in the Spring of 1852 at Dehra Dun, India, in the foot hills of the Himalayas, the door of the office of the Director General of the Survey of India opens. Enters Radanath Sikdar, the chief of the team of human computers who were processing the data of the triangulation measurements of the Himalayan peaks taken during the Winter. "Sir I have discovered the highest mountain of the world…….it is Peak n. XV". These words, reported by Col. Younghausband have become a legend in the measurement of Mt. Everest.

Introduction

The height of a mountain is determined by three main factors. The first is the sea level that would be under the mountain if the water could flow freely under the continents. The second depends on the accuracy of the elevations of the points in the valley from which the measurements are performed, and on the mareograph taken as a reference (height datum). The third factor depends on the amount of snow on the summit. This changes from season to season and from year to year with a variation that exceeds a metre between spring and autumn. Optical measurements from a long distance are also heavily influenced by the refraction of the atmosphere (due to the difference of pressure and temperature between the points of observation in the valley and the summit), and by the plumb-line deflections.

Geodetic studies have been performed since the beginning of the 19th century to determine which was the highest mountain of the Karakorum-Himalaya chain and its exact height. The Prussian geographer Alexander von Humboldt in 1816 reported the first tentative measurements of the Himalayan peaks when the elevation of the points in the valley were measured with barometers.

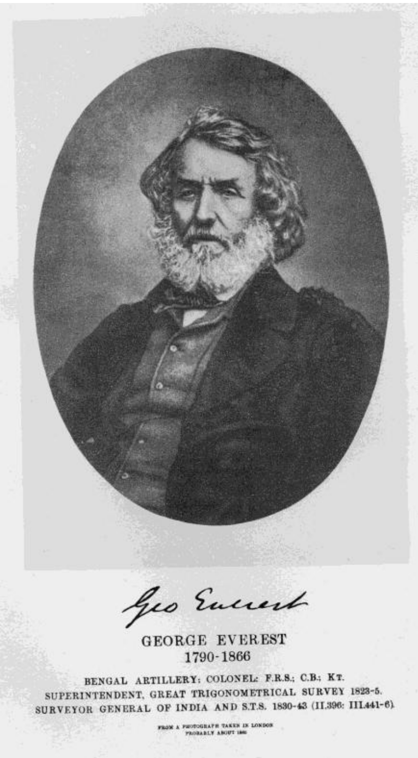

Fig. 1.- Col. George Everest Director General of the Survey of India.

William Lambton and George Everest (Fig. 1), the founders of the Survey of India, carried out the measurement of the Great Trigonometric Arc from Cape Comorin to Dehra Dun in the foothills of the Himalayas between 1799 and 1838 providing the base lines for surveying the mountains. From seven stations of a profile along the India-Nepal border, measurements to the snow covered peaks were made "discovering" that Mt. Everest (at that time called Peak XV) was the highest mountain in the world. This was announced by Andrew Waugh the new Director General of the Survey of India after George Everest, in 1856 and the height was determined to be 29,002 feet (8840 metres).

New measurements of Mount Everest were performed by the Survey of India between 1880 and 1904 under the direction of Sydney Burrard who brought the value of the height to 8882 metres (Fig. 2).

TABLE IX.—Height of Mount Everest.

Station of observation.	Year of observation.	Height of station of observation.	Distance from Mount Everest.	Values of height, if no correction for refraction be applied.	Resulting height as determined by Waugh with coefficients of refraction varying from 0·07 to 0·08 from stations in the plains.	Resulting height from computations in 1905 with coefficient of refraction 0·05 from stations in the hills.	Resulting height with assumed coefficient of refraction 0·0645 from stations in the plains.
		Feet.	Miles.	Feet.	Feet.	Feet.	Feet.
Jarol	1849	220	118·661	30366	28991·6	..	29141
Mirzapur	1849	245	108·876	30165	29005·3	..	29135
Janipati	1849	255	108·362	30141	29001·8	..	29117
Ladnia	1849	235	108·861	30171	28998·6	..	29144
Harpur	1849	219	111·523	30221	29026·1	..	29146
Minai	1850	228	113·761	30282	28990·4	..	29160
Suberkum	1881	11641	87·636	29576	..	29141	..
Do.	1883	11641	87·636	29572	..	29137	..
Tiger Hill	1880	8507	107·952	29860	..	29140	..
Sandakphu	1883	11929	89·666	29620	..	29142	..
Phallut	1902	11816	85·553	29589	..	29151	..
Senchal	1902	8599	108·703	29941	..	29134	..
Mean	..	..	..	..	29002	29141	29141
Range of variation in values*	..	..	..	794	Misleading.†	17	43

Fig. 2.- Computation of the height of Mt. Everest in 1852 and 1904 (Burrard & Heyden 1908).

Thirty years later the value of the elevation was calculated with respect to **sea level** and in 1954 a more accurate measurement was performed by B. L. Gulatee from triangulation points inside Nepal, taking into account new geoidal heights, refraction coefficients and deviations of the vertical. He determined the height to be 8848 metres and pointed out the errors in the previous measurements:

1) Adoption of an erroneous height of the observing stations: +2.4 m
2) Deviation of gravity from the normal: -9.1
3) Geoidal rise:+35.1
4) Atmospheric refraction: -36.6;

for a total amount of -8.2 metres (Gulatee B. L., 1954).

The New Determinations of the Geoid.

The measurements of elevation are referred to the **"mean sea level"** which is approximated by the **Geoid.**. This surface is determined from time to time by means of measurements of gravity and deflection of the vertical, by national (local Geoid) or international institutions (global Geoid). The Geoid is very well defined on the oceans, or in areas where gravity measurements are very dense, while it presents several gaps in mountain or remote areas where gravity determinations are sparse.

The co-ordinates of the points of the Earth are measured with reference to a geometrical surface called the **Ellipsoid,** and for every point the difference between the Geoid and the Ellipsoid named with the letters **N** or **ζ** and called **height anomaly**, must be known. On Earth the value of N reaches the amount of ±100 metres and in the Mt. Everest area it ranges between –25 and –35 metres.

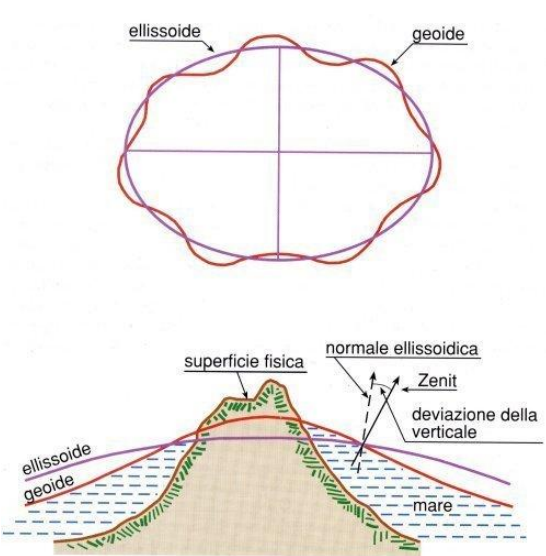

Fig. 3.- Geoid, Ellipsoid and deviation of the vertical.

Tab. 1: Height anomalies at some GPS stations in the Mt. Everest area

Station	Lat.	Long.	ζ(94)	ζ(99)	ζ(EGM96)
Base	28°08′10″	86°51′06″	1.0 m	–24.2 m	–25.1 m
III7	28°06′14″	86°52′49″	0.8 m	–24.3 m	–25.5 m
Summit Mt. Everest	27°59′17″	86°55′31″	–1.0 m	–26.2 m	–27.3 m

Fig.4.- Geoidal heights under the summit of Mount Everest.
(from Zeitschrift für Vermessungwesen 11/1999)

During the last 70 years new gravity measurements provided improved versions of global and of local geoids for the Mt. Everest area allowing the calculation of the elevation of the Himalayan mountains with different values of N.

Dr. De Graaf Hunter in 1929 calculated a value of –30.18, while in 1954 Gulatee applied a correction of –35.05 metres. In 1992, a Chinese determination gave -25.14 metres. Later on, in 1996, the new geoid EGM96 showed the value of -27.3 m while in 1999 a new calculation from the Chinese side rose to -26.2. The 1999 National Geographic measurement referred to a more recent value of -28.74 but in 2005 the Chinese NBSM announced a new calculation of -25.20. These values must be subtracted from the Ellipsoidal (e.g. GPS) heights to yield the orthometric (a.s.l.) height (Fig. 4).

The Depth of the Snow

In 1975 geodetic instruments (sight target for the theodolite) were carried for the first time to the summit. In 1992 an Italian expedition installed reflecting prisms and a Leica GPS 200 (Fig. 5).

The surveys of Mt. Everest in 1975 (NBSM - National Bureau of Surveying and Mapping of China) and 1992 (EV-K2-CNR Committee of Italy) introduced another important concept: **the elevation of a mountain must be taken with respect to the rock surface,** and the depth of the snow layer was measured with a graduated avalanche probe.

This allows comparisons between the elevations of the mountains to be carried out using a reference system internationally recognised such as the ITRF (International Terrestrial Reference System) and which are not affected by an occasional snowfall.

In 1975 the depth of the snow was measured in 92 cm while in 1992 it was 2.55 metres.

Fig.5- 29 september 1992. Benoit Chamoux on the summit of Mt. Everest with the surveying instruments and the first Lreica 200 GPS.

For the Italian 2004 expedition to Mt. Everest, a new instrument was designed at the University of Trieste (Itly), using advanced technologies. It was a portable (4.05 kg batteries included) GPR (Ground Penetrating Radar) coupled with a GPS (Global Positioning System). The instrument (called "**snow radar**") was carried to the top and pulled across the summit (Fig. 6) along eight profiles recording the positions of the points and the depth of the snow (Fig.7).

Fig. 6- Climber operating the GPR on the steep slope along the South West ridge.

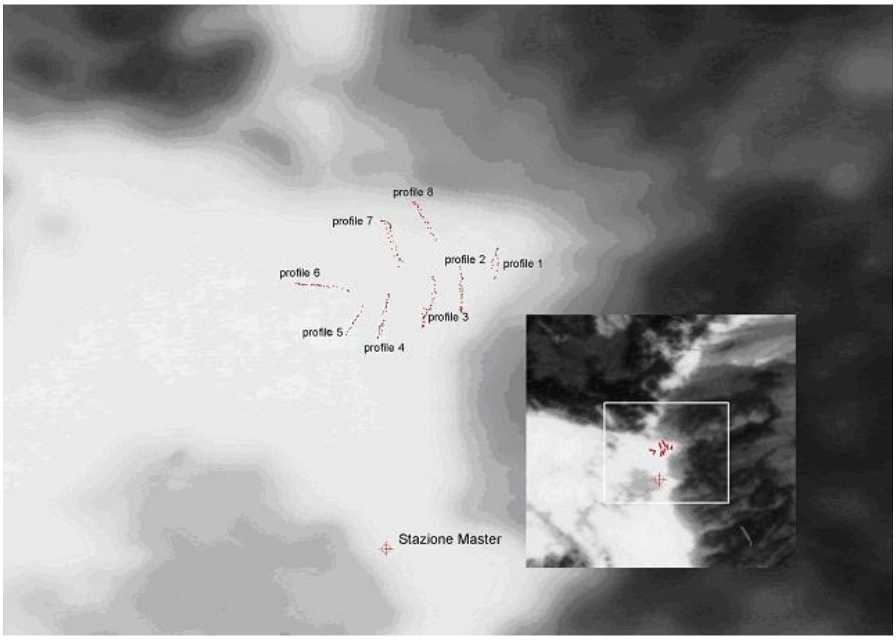

Fig.7.- Radar profiles on the summit (air photo enlarged).

From the processing of the snow radar and of the GPS data two surface models were computed one for the snow and one for the rock, which show that the two summits do not coincide. One must therefore distinguish a maximum elevation "**on the snow**" and a maximum elevation "**on the rock**". The two summits are at a distance of about one metre in the direction of the prevalent wind. The depth of the snow under the snow summit was 3.78 metres and 3.04 above the rock summit (Fig. 8).

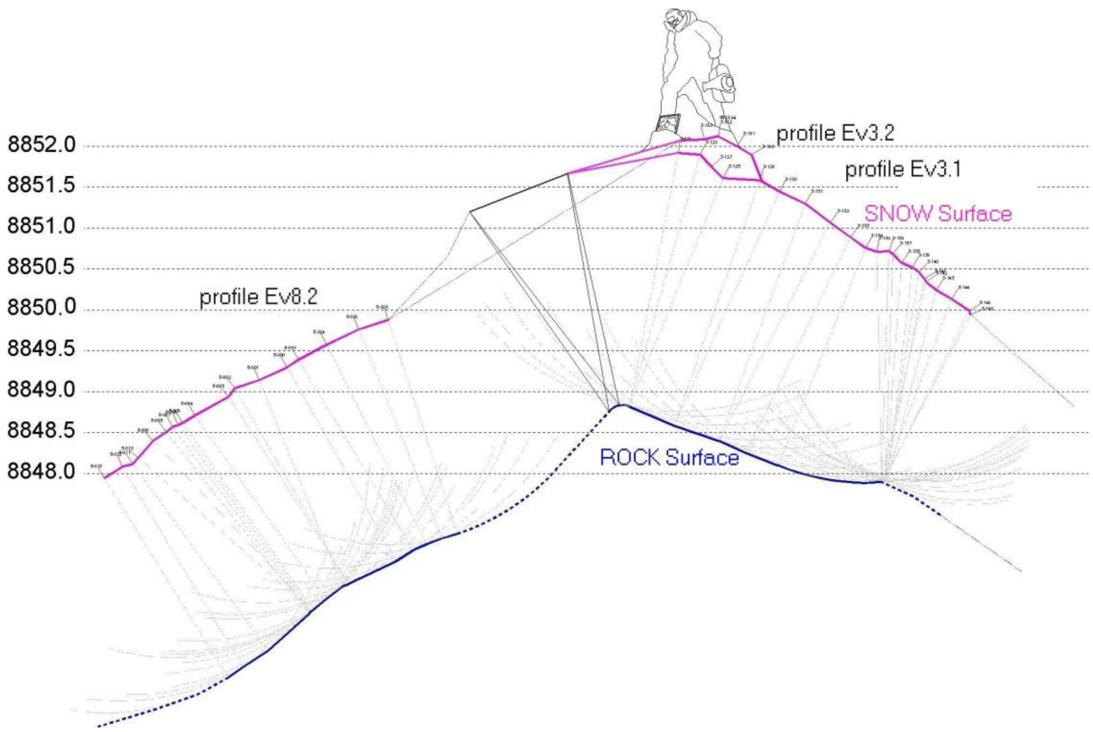

Fig. 8.- Section along two profiles crossing the summit.

The coordinates of the snow summit were determined from the GPS recordings while those of the rock summit were estimated on the digitised interpolation surface (Poretti & al. 2006).
Taking into account the most recent value of N (-25.199m) from the Italian data one obtains:

	Latitude	Longitude	Height
Snow Summit	27°59'16,963"	85°55'31,736"	8848,36
Rock Summit	27°59'16,998"	85°55'31,723"	8845,32

The last measurement was performed by Chinese topographers in May 2005. Using the Italian snow radar on the summit, they performed a circular profile around the summit reaching a value of 3.5 m for the depth of the snow, 8844,43 for the elevation of the rock and 8847.93for the elevation of the snow surface (Chen & al., 2006).

Conclusions

The height of Mount Everest was measured and calculated several times during the past two centuries. During this time the scientific knowledge and the technology employed for the measurements have greatly improved but the errors involved in the measurements were so large that it is impossible to know much (and even if) the height has increased.

Instead what can be considered as certain is that the summit has moved about 8 metres in a NNE direction and is still moving at a rate of 4-5 cm/year. The geodetic stations at the Pyramid Laboratory near Mt. Everest Base Camp confirm that the increase in elevation during the last 15 years might be in the order of 1 mm per year and still within the error margin of the measurements even after two centuries (Poretti et al. 2006)
The variations presented during the past 20 years are mainly due to the calculation of the sea level (the geoid) and to the amount of snow covering the summit.

	N	Geoid.El.Snow	Ellips.El.Snow	Geoid.El.Rock
Survey of India 1852		8840		
Sidney Burrard 1904		8882		
De Graaf Hunter 1930	-30,18	8854 ±5	8823,82	
B. L. Gulatee 1954	-35,05	8848	8812,95	
Desio & Caporali 1987	-39,00	8872	8833	
EV-K^2-CNR/NBSM 1992	-25,14	8848,65±0,35	8823,51	8846,1
J. Y. Chen 1999	-26,20	8849,71	8823,51	
EGM96	-27,30	8849,82	8822,52	
Washburn e Chen 1999	-28,74	8850±2	8821,26	
EV-K2-CNR 2004	-28,74	8852,12±0,12	8823,38±0,12	8848,44±0,23
EV-K2-CNR 2004	-25,14	8848,26±0,12	8823,38±0,12	8845,22±0,23
SBSM - China 2005	-25,20	8847,93±0,14	8821,47±0,14	8844,43±0,21

Table 1 The elevation of Mt. Everest with the geoid - ellipsoid separation N (values in metres).

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