Review
Received: 17-05-2010
Accepted: 05-07-2010

The Himalayas and a Survey of Determining the Height of Mt. Everest

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Abstract: *The introduction to this article describes the Himalayan mountain range, while the next chapter outlines its formation. The article then goes on to describe the early use of trigonometric networks in Europe and India, and the important achievements of Sir George Everest. When his successor, A. S. Waugh, extended the trigonometric network to the foot of the Himalayas, he determined the height of the highest peak of Mt. Everest trigonometrically, by measuring vertical angles only in the direction of Mt. Everest. Later, it became possible to determine the height of the highest peak in the world more precisely, using modern surveying means. The peak was named Mt. Everest in 1865, at the proposal of A. S. Waugh. It is known by other names by the indigenousl populations in China and Nepal. Finally, the earliest attempts to climb Mt. Everest are described.*

Key words: *trigonometric network, Great Survey of India, Himalayas, height of Mt. Everest, Sir George Everest*

1. Introduction

The Himalayas are the highest mountain range not only in Asia, but in the world (Fig. 1). The name derives from the Sanskrit words *him-alaja* and means 'abode of the snows'. The range is also known as the 'abode of the gods' and the 'Lama's snow monastery'.

The Himalayas are located in Asia, north of the Indian plains and the River Ganges, and south of the Tibetan plateau. They stretch west to east, from Nanga Parbat peak (8125 m) in India (in the federal states of Jammu and Kashmir) to Namcha Barwa peak (7756 m) on the eastern border of India with China, 280 km west of the point at which the borders of India, China and Myanmar conjoin. The Himalayas are 2500 km long and the average width of the range is 300 km (Šentija 1977, vol. 3, p. 425). However, in his book *Everest – die Geschichte seiner Erkundung*, Stephen Venables (2003) claims that the Himalayas are in fact longer and wider – 3200 km long and 480 km wide.

The Himalayas are situated in the territories of five countries: India, Pakistan, Nepal, Bhutan and China (Tibet). The range consists of three parallel ridges that plunge steeply towards the Indian Ganges plains. The most northerly belt, which is also the oldest, is known as Greater Himalaya. It includes the highest peak in the world, Mount Everest, which is 8848 m above sea level, though today there are many differing results of attempts to measure its height. Its horizontal coordinates have also been determined:

- latitude: 27° 59' 17''
- longitude: 86° 55' 31''

Pregledni rad
Primljeno: 17-05-2010.
Prihvaćeno: 05-07-2010.

Himalaja i pregled određivanja visina Mt. Everesta

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Sažetak: *U uvodu članka opisan je planinski masiv Himalaja, a u sljedećem poglavlju njegov nastanak. U nastavku su opisani počeci uporabe trigonometrijskih mreža u Europi te uporaba tih mreža u Indiji, gdje je G. Everest ostvario veliko djelo. Kad je A. S. Waugh, nasljednik G. Everesta, došao s trigonometrijskom mrežom do Himalaje, odredio je i visinu najvišeg vrha, Mt. Everesta, trigonometrijskim načinom, mjerenjem vertikalnih kutova samo u smjeru prema Mt. Everestu. Poslije se nastojalo što točnije odrediti visinu toga najvišega vrha na Zemlji uvođenjem suvremenih mjerenja. Ime Mt. Everest uvedeno je 1865. godine na prijedlog A. S. Waugha. Za taj vrh postoje i drugi nazivi domicilnog stanovništva u Kini i Nepalu. Na kraju su opisani počeci alpinističkih uspona na Mt. Everest.*

Ključne riječi: *trigonometrijske mreže, geodetska izmjera Indije, Himalaja, visina Mt. Everesta, George Everest*

1. Uvod

Najveći planinski masiv u Aziji, ali i na Zemlji, nazvan je Himalaja (sl.1). Naziv potječe od indijskih riječi *himalaja*, što na sanskrtskom jeziku znači *boravište snijega.* Često se naziva i *boravište bogova* te *Lamin samostan snijega*.

Himalaja je smještena u Aziji sjeverno od nizina Inda i Gangesa i južno od tibetskog visočja. Pruža se od zapada, od vrha Nanga Parbat, visokog 8125 m, u indijskim saveznim državama Jammu i Kašmir, prema istoku do vrha Namcha Barwa, visokog 7756 m, na istočnoj indijsko-kineskoj granici, 280 km zapadno od tromeđe Indije, Kine i Mianmara. Himalaja je duga 2500 km s prosječnom širinom 300 km (Šentija 1977, sv. 3, str. 425). Međutim, u knjizi *Everest die Geschichte seinere Erkundung* (Venables 2003) navodi se da je Himalaja duža i šira, tj. da je duga 3200 km i da je široka 480 km.

Himalaja je smještena na prostorima čak pet država: Indije, Pakistana, Nepala, Butana i Kine (Tibeta). Sastoji se od tri paralelna bila, koja se strmo spuštaju prema Indo-gangeškoj nizini. Najsjeverniji pojas, a ujedno i najstariji dio Himalaje, čini takozvana Visoka Himalaja. Ondje se nalazi i najviši vrh na Zemlji Mount Everest, visok 8848 m, a danas već ima više rezultata određivanja njegove visine, koji se međusobno razlikuju. Određene su i horizontalne koordinate njegova položaja:

- geografska širina: 27° 59’ 17’’ i
- geografska dužina: 86° 55’ 31’’.

U Atlasu svijeta Leksikografskog zavoda tiskanom 1966. godine piše da je visina Mt. Everesta 8882 m, što nije u skladu s većinom drugih starih ni novih izvora.

Da je riječ o velikom i visokom planinskom lancu najbolje govori činjenica da se na Himalaji nalazi čak 14

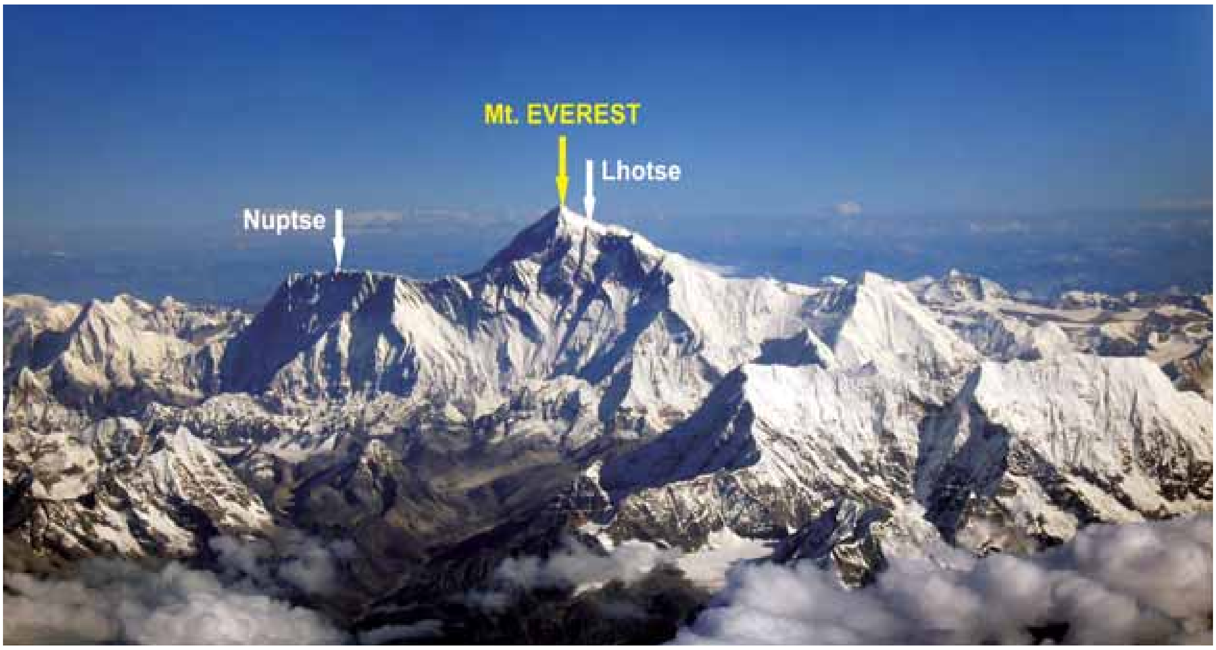


Fig. 1. View from the Nepali side towards the part of the Himalayan mountain range with the highest peak in the world, Mt. Everest (8848 m), with Lhotse (8516 m) and Nuptse (7861 m) (Scrimpol 1967, URL 32)

Slika 1. Pogled s nepalske strane na dio planinskog masiva Himalaje s najvišim vrhom na Zemlji Mt. Everestom (visokim 8848 m), vrhovima Lhotse (8516 m) i Nuptse (7861 m) (Schrimpo1967, URL 32)

In *Atlas svijeta* (*Atlas of the World)* published by the Croatian Leksikografski Zavod in 1966, it is stated that Mt. Everest is 8882 m high, but this conflicts with most other findings, whether older or more recent.

An indication of the size and height of this mountain range can be gleaned from the fact that it includes 14 peaks over the height of 8000 m and 30 over 7620 m. To the northwest of the Himalayas, the Karakora range continues, where K2, the second highest peak in the world, is to be found. The highest peaks in the world are (Times Atlas of the World, 1990):

- Mt. Everest (8848 m)
- K2 (8611 m)
- Kangchenjunga (8586 m)
- Lhotse (8516 m)
- Makalu (8481 m)

The first successful ascents of the highest peaks of the Himalayas were as follows:

Annapurna (8091 m), in 1950 (this was the first peak over 8008 m to be conquered)

- Mount Everest (8848 m), in 1953
- Kangchenjung (8586 m) and Makalu (8481 m), in 1955
- Lhotse (8516 m), in 1956

2. Formation of the Himalayas

Two hundred million years ago, there was only one continental mass, known today as Pangea. Over the course of time, according to Alfred Wegener's theory, it divided into several parts, thus forming the continents. The Indian Plate, during a period of 40 to 50 million years, shifting at the rate of 15 cm per year, travelled 6,000 km before colliding with the Eurasian Continent (Fig. 5, URL 14). The collision of these huge continental masses resulted in the deceleration of the Indian Plate towards the Eurasian Continent to a speed of about 5 cm per year. Thus, the Indian Plate was driven about 1000 km into the Eurasian Continent (Asia). As the masses of the Eurasian Continent and the Indian Plate pushed against each other, forces at the collision point resulted in the Earth's crust being thrust upwards in the area of the Himalayas (Fig. 4). Today, the Himalayas are continue to move northwards at the rate of 6 cm per year, and rise by 6–8 mm per year (URL 2). According to other sources, these numerical values vary. This is understandable, since they are based on assumptions and numerical data which cannot be determined or proven precisely (for example, relative speed in relation to particular constants). In fact, the entire Earth is composed of plates which are moving at different speeds. Nonetheless, the Indian Plate was driven into the Eurasian Continent and the Himalayas were the result (Figs. 5 and 6). It can be asserted that the Himalayas consist of an older core, covered by Mesozoic and Triassic sediments.

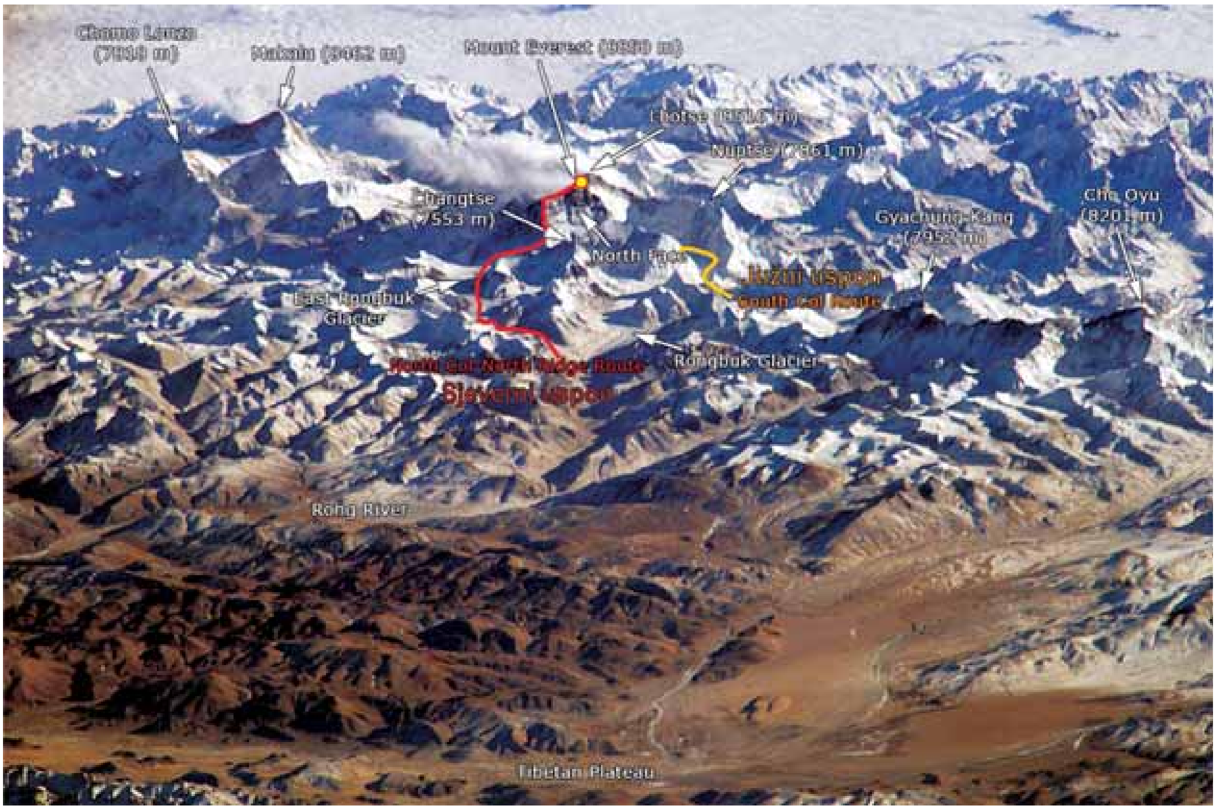


Fig. 2. View of the north and south ascents of Mt. Everest and part of the Himalayas. Photographed from the north from the International Space Station. The north route is marked in red and the south route in yellow (URL 28)

Slika 2. Pogled na sjeverni i južni uspon na Mt. Everest i dio Himalaje. Snimljeno je iz smjera sjevera s Međunarodne svemirske postaje, a na slici je crvenom bojom označena sjeverna ruta i žutom bojom južna ruta (URL 28)

vrhova viših od 8000 m i 30 vrhova viših od 7620 m. Na sjeverozapadu se na Himalaju nastavlja planinski lanac Karakoram, na kojem se nalazi drugi najviši vrh na Zemlji K2. Najviši su vrhovi svijeta (The Times Atlas of the World 1990):

- Mt. Everest (visok 8848 m)
- K2 (visok 8611 m)
- Kangchenjunga (visok 8586 m)
- Lhotse (visok 8516 m)
- Makalu (visok 8481 m) itd.

Prvi uspješni usponi na najviše vrhove Visoke Himalaje ostvareni su:

- na Annapurnu (visoku 8091 m) (prvi osvojeni vrh iznad 8008 m) 1950. godine,
- na Mount Everest (visok 8848 m) 1953. godine,
- na Kangchenjungu (visoku 8586 m) i na Makalu (visoku 8481m) 1955. godine,
- na Lhotse (visok 8516 m) 1956. godine itd.

2. Nastanak Himalaje

Prije 200 milijuna godina na Zemlji je postojao samo jedan prakontinent, koji je nazvan Pangea. Tijekom vremena on se, prema teoriji Alfreda Wegenera, podijelio na nekoliko dijelova. Od tih dijelova nastali su kontinenti. Pritom je Indijska ploča tijekom 40 do 50 milijuna godina, gibajući se brzinom od 15 cm u godini, prešla put od 6000 km prije sudara s Euroazijskim kontinentom (sl. 5) (URL 14). Kad je došlo do sudara tih velikih Zemljinih masa, smanjena je brzina približavanja Indijske ploče prema Euroazijskom kontinentu na oko 5 cm na godinu. Tako je došlo do uvlačenja Indijske ploče u Euroazijski kontinent (Aziju), čak više od 1000 km. Zbog međusobnoga guranja masa Euroazijskoga kontinenta i Indijske ploče pojavile su se sile na području njihova sudara, koje su izazvale uzdizanje Zemljine kore na području Himalaje (sl. 4). Danas se Himalaja kreće u smjeru sjevera oko 6 cm na godinu, a podiže 6 do 8 mm na godinu (URL 2). Prema nekim drugim izvorima te su numeričke vrijednosti različite. To je i razumljivo, jer je riječ i o nekim pretpostavkama i numeričkim podacima, koji nisu najbolje (najtočnije) provjereni ni determinirani, kao što je na primjer relativna brzina. Naime, čitava je Zemlja sa-

Fig. 3. Location of the Himalayas in Pakistan, India, Nepal, Bhutan and China (Tibet), with the highest peaks marked (heights given in metres)

Slika 3. Smještaj Himalaje u Pakistanu, Indiji, Nepalu, Butanu i Kini (Tibetu) s označenim najvišim vrhovima (visine su izražene u metrima)

3. The First Trigonometric Networks in Europe

The earliest traces of trigonometry are to be found in the works of the famous Alexandrian astronomer and scientist, Aristarchus of Samos (310-230 BC). Trigonometry developed in Indian and Arabic mathematics, and was introduced to Europe in the 15th century (Gusić 1995, p. 239). During the 17th, 18th and 19th centuries, it became increasingly important to produce precise charts and maps, both for military and commercial purposes. Therefore it was necessary to find a way of determining as precisely as possible distances between points on the Earth's surface.

In the Middle Ages, and indeed in the modern age, until the arrival of modern electronic means of measuring distances, it was easier to measure angles precisely, rather than distances between points on the Earth's surface. Johannes Regiomontan (1436-1476), whose real name was Johann Müller, laid a solid foundation for resolving this problem (Šentija, 1981, vol. 7, p. 42). In the mid 15th century, he published *De triangulis omnimodis libri quinque*, in which he elaborated trigonometric knowledge to date, thus influencing the development of this branch of science in the whole of Europe. This in turn affected the development of technical knowledge.

The first proposal for using trigonometric networks as a precise method of determining locations on the Earth's surface was made by the Flemish mathematician, cartographer, physician and astronomer, Regnier Gemma-Frisius (1508–1555), in *Libellus de locarum,* published in Apian's Cosmographia in 1533 (Šentija, 1977, vol. 3, p. 125).

The well known astronomer Tycho Brahe (1546–1601) first surveyed a trigonometric network in Öresund (between Sweden and Denmark), but unfortunately did not make calculations (Solarić M. and N. 2009, p. 112). The Dutch mathematician, physicist, astronomer and, one might add, surveyor, Willebrord Snell van Royen (known by the Latin name Snellius) (1580–1626), first used a trigonometric network (chain of triangles) between 1615 and 1617, in order to determine the distance along the meridian between the south point of Bergen op Zoom ($\varphi = 51°30'$, $\lambda = 4°17'$) and Alkmaar ($\varphi = 52°38'$, $\lambda = 4°44'$) (Šentija 1981, vol. 7, p. 543; Macarol 1977, p. 14). A picture of Snellius'

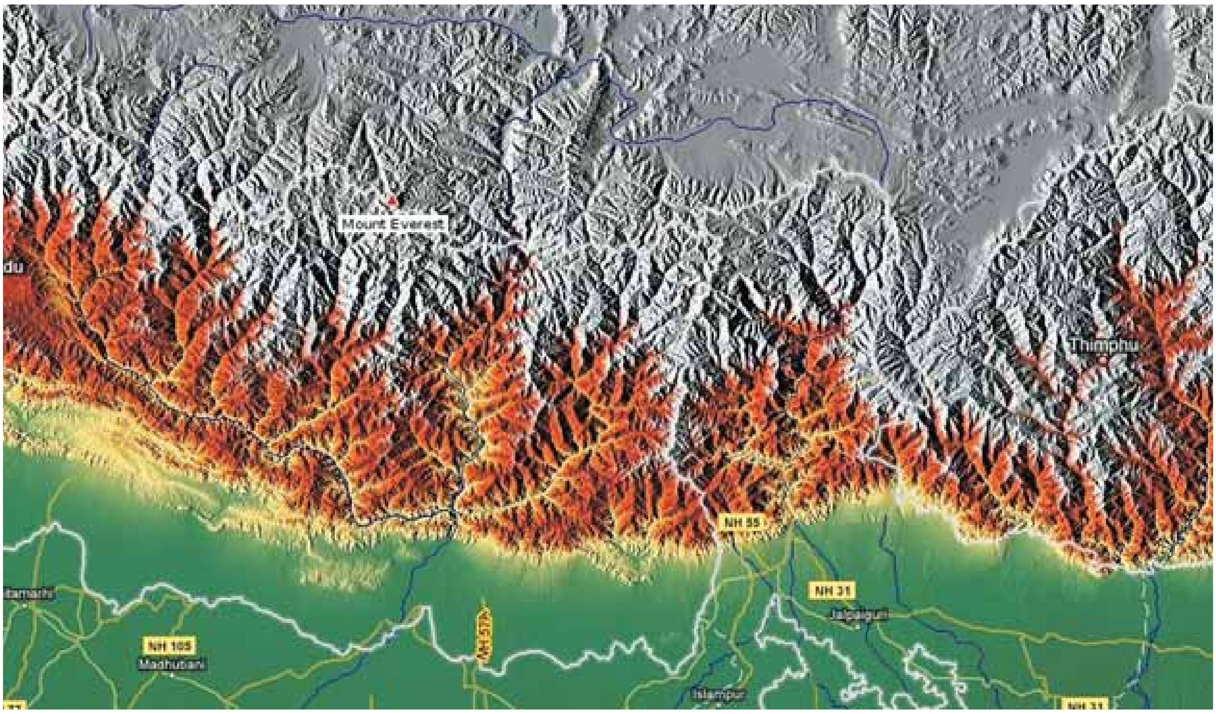


Fig. 4. Part of the Himalayas with Mount Everest (NASA, Janderk Jan Derk URL 28)
Slika 4. Prikaz reljefa dijela Himalaja s Mount Everestom (NASA, Janderk Jan Derk URL 28)

stavljena od raznih ploča koje se pomiču različitim brzinama. Indijska ploča uvlačeći se pod Euroazijski kontinent podiže Himalaju (sl. 5 i 6). Može se kazati da je Himalaja građena od stare jezgre, pokrivene mezozojskim i tercijarnim sedimentima.

3. Prve trigonometrijske mreže u Europi

Prvi tragovi trigonometrije javljaju se u radovima slavnog aleksandrijskog astronoma znanstvenika Aristarha sa Samosa (310–230. pr. Kr.). Nakon njezina unaprjeđenja u indijskoj i arapskoj matematici, trigonometrija je u 15. stoljeću prenesena u Europu (Gusić 1995, str. 239). Za potrebe vojske, ali i gospodarstva, u 17., 18. i 19. stoljeću pojavila se potreba za točnim kartama. Za to je trebalo na neki način odrediti što točnije udaljenosti između pojedinih točaka na Zemljinoj površini.

U srednjem vijeku, a i novom vijeku, pa sve do suvremenih elektroničkih daljinomjera, bilo je lakše točnije izmjeriti kutove nego udaljenosti između pojedinih točaka na Zemljinoj površini. Podlogu za rješenje toga problema dao je Johannes Regiomontan (1436–1476), pravim imenom Johann Müller (Šentija 1981, sv. 7, str. 42). On je sredinom 15. stoljeća objavio rad *De triangulis omnimodis libri quinque*, u kojem je sabrao dotadanja znanja iz trigonometrije, koja su utjecala na razvoj te grane znanosti u cijeloj Europi te na razvoj tehničkih znanja.

Prvi prijedlog uporabe trigonometrijskih mreža, kao točne metode određivanja položaja točaka na Zemlji, opisao je flamanski matematičar, kartograf, liječnik i astronom Regnier Gemma-Frisius (1508 –1555) u radu *Libellus de locarum* u Apianovoj *Cosmographia* 1533. godine (Šentija 1977, sv. 3. str. 125).

Slavni astronom Tycho Brahe (1546–1601) prvi je izmjerio trigonometrijsku mrežu u Öresundu (između Švedske i Danske), ali ju nažalost nije izračunao (Solarić, M. i N. 2009, str. 112). Nizozemski matematičar, fizičar, astronom, a može se reći i geodet Willebrord Snell van Royen (latinski Snellius) (1580–1626) prvi je primijenio od 1615. do 1617. godine trigonometrijsku mrežu (lanac trokuta) za određivanje udaljenosti po meridijanu između južne točke *Bergen op Zoom* (φ = 51°30', λ = 4°17') i *Alkmaara* (φ = 52°38', λ = 4°44') (Šentija 1981, sv. 7, str. 543; Macarol 1977, str. 14). Slika Snelliusove trigonometrijske mreže može se vidjeti u (Solarić, M. i N. 2009, str. 118). Snellius je objavio svoj postupak 1617. godine u radu *Holandski Eratosten* (*Eratostenes Batavus: De terrae ambitus vera quantitate*) (URL 19), koji predstavlja početak znanstvene geodezije. Godinu dana nakon njegove smrti, 1627, objavljen je rad o trigonometriji *Doktrina triangulorum*.

U mreži trokuta, odnosno trigonometrijskoj mreži, u kojoj su trokuti naslonjeni jedan na drugi, dovoljno je što točnije izmjeriti duljinu samo jedne stranice trokuta u čitavoj mreži, i to na mjestu gdje je to najlakše učiniti. U ostalim trokutima treba izmjeriti samo dva kuta između stranica trokuta, a zatim računskim putem postupno prelazeći s trokuta na trokut izračunati duljine svih ostalih stranica trokuta u mreži. Međutim, najčešće se izmjere

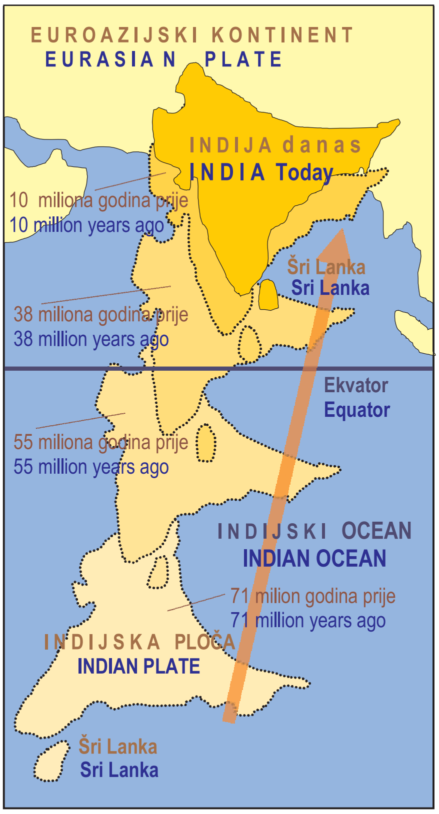


Fig. 5. Movement of the Indian Plate during the past (URL 14)

Slika 5. Pomicanje Indijske ploče tijekom prošlosti (URL 14)

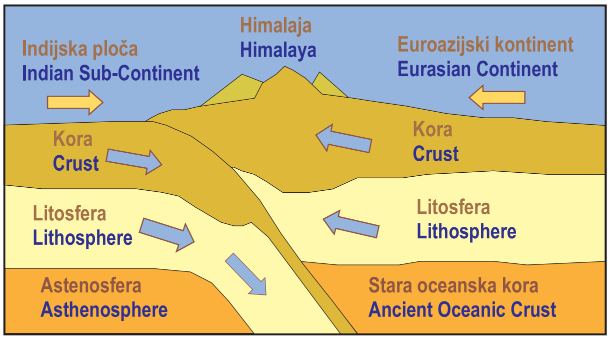


Fig. 6. Graphic presentation of the collision between the Indian Plate and the Eurasian Continent – the formation of the Himalayas

Slika 6. Grafički prikaz sudara Indijske ploče i Euroazijskoga kontinenta – nastanak Himalaje

trigonometric network can be seen in Solarić M. and N. 2009, p. 118. Snellius first published his method in 1617 in *Eratostenes Batavus: De terrae ambitus vera quantitate*) (URL 19). This work is considered to represent the birth of scientific geodesy. In 1627 he published a work on trigonometry entitled *Doctrina triangulorum*, printed a year after his death.

It should be emphasised that, in a network of triangles, i.e. a trigonometric network, in which the triangles border each other, it is sufficient to measure as accurately as possible only one side of a triangle in the entire network, at the point at which it is easiest to do so. As far as the other triangles are concerned, it is only necessary to measure two angles between adjacent sides, then by process of calculation move from one triangle to the next, calculating the lengths of all the remaining sides of the triangles in the network. However, as a means of control, all three angles in the triangles are often measured.

Snellius used a trigonometric network to calculate the Earth's radius. He did this by determining the distance of one point on its surface from another along the meridian, by means of triangulation between Bergen op Zoom and Alkmaar, then by using astronomical means to determine their geographic latitudes φ_B and φ_A. These measurements enabled him to calculate the Earth's radius (*R*) using the formula

$$R = \frac{l}{\varphi_A - \varphi_B} \frac{180^\circ}{\pi},$$

where:

- φ_A and φ_B are the geographical latitudes of the first and last points of the trigonometric network, expressed in degrees
- *R* is expressed in measurement units for length which are also used to express the length of the arc *l* between points A and B.

If we compare Snellius' calculation for *R* with modern calculations of the Earth's dimensions, we will find that his margin of error was only 3.5% (Haasbroek 1968).

Beginning with Snellius, trigonometric networks gradually become the basis for cadastral and cartographic measurements of land in all European countries. This continued to be the case until the introduction of Global Positioning System (GPS) artificial satellites.

At the end of the 18th and beginning of the 19th century, Jean Baptiste Joseph Delambre (1749–1822) and Pierre François-André Méchain (1744–1804) completed the taking of many measurements to survey the Parisian meridian from Barcelona (Premia der Mar) in Spain to Dunkirk in Flanders (URL 20). These measurements were used to establish the length of the metre as the basic international unit of length. The repeating circle instrument with two telescopes, built by Borda and Lenoir, was used to measure the angles of triangles.

William Roy (1726–1790), the Scottish surveyor and military sketcher, first applied the new method of geodetic measurement using trigonometric networks to establish the foundation of the trigonometric network of Great Britain (URL 3). Between 1783 and 1853, basic trigonometric networks were set up (URL 4). Extremely precise theodolites of huge dimensions were used to measure angles (Fig. 9). These theodolites were made in 1785 by

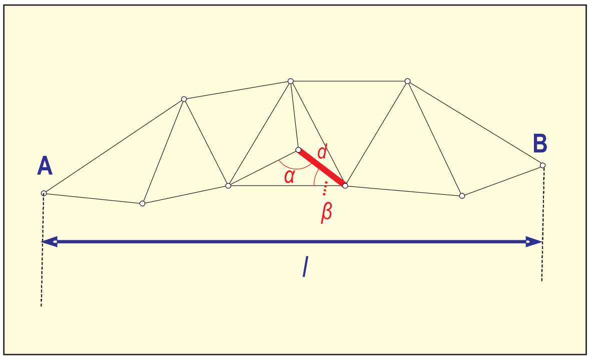


Fig. 7. Trigonometric network in which the base length d of one side and at least two angles in each triangle are measured. In this way, the distance l between the first and last points is determined for an arc of the meridian

Slika 7. Trigonometrijska mreža u kojoj je izmjerena duljina osnovne baze d jedne stranice i najmanje po dva kuta u svakom trokutu. Na taj je način određena udaljenost l između početne i posljednje točke postavljene na nekom luku meridijana

svi kutovi u trokutu (sva tri kuta), jer se na taj način postiže kontrola.

Snellius je iskoristio trigonometrijsku mrežu da bi odredio Zemljin radijus. On je tako odredio udaljenost *l* po meridijanu s pomoću trigonometrijske mreže između Bergen op Zooma i Almaara, a astronomskim načinom izmjerio je njihove geografske širine φ_B i φ_A. S pomoću tih izmjerenih veličina izračunao je Zemljin radijus *R* po formuli:

$$R = \frac{l}{\varphi_A - \varphi_B} \frac{180^\circ}{\pi},$$

gdje su:

- φ_A i φ_B geografske širine krajnje i početne točke trigonometrijske mreže izražene u stupnjevima
- *R* je izražen mjernim jedinicama za duljinu, kojima je izražena i duljina luka *l* od točke A do točke B.

Kad se usporedi njegov rezultat za *R* sa suvremenim određivanjima Zemljine veličine, vidi se da je odredio Zemljin radijus s pogreškom od samo 3,5 % (Haasbroek 1968).

Trigonometrijske mreže su, počevši od Snelliusa, postupno postale osnova za svu daljnju katastarsku i kartografsku izmjeru zemljišta u svim europskim državama. Tako je bilo sve do uporabe umjetnih Zemljinih satelita Globalnoga pozicijskog sustava (GPS-a).

Krajem 18. stoljeća i na početku 19. stoljeća Jean Baptiste Joseph Delambre (1749–1822) i Pierre François–André Méchain (1744–1804) završili su mnogobrojna mjerenja na izmjeri pariškog meridijana od Barcelone (Premia der Mar) u Španjolskoj do Denkerquea u Flandriji (na sjeveru Francuske) (URL 20). Ta mjerenja poslužila su za potrebe određivanja duljine metra, kao osnovne međunarodne jedinice za duljinu. Za mjerenje kutova u trokutima upotrijebili su instrument *repeating circle* s dva dalekozora, što su ga izradili Borda i Lenoir.

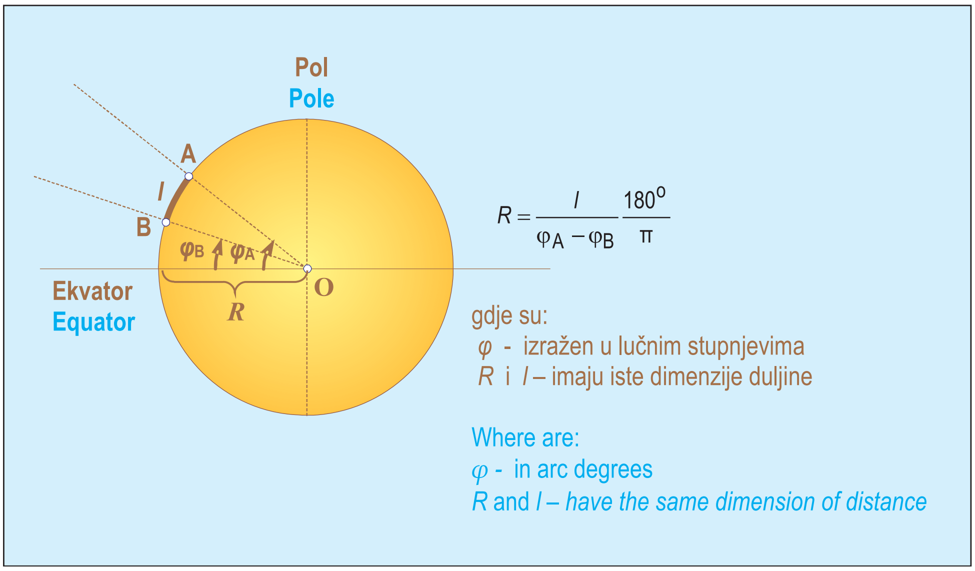


Fig. 8. Determining the Earth's radius R from a) the distance l between two points on the same arc of the meridian, determined by means of a trigonometric network and b) measuring geographical latitudes φ at points A and B using astronomical means.

Slika 8. Određivanje Zemljina radijusa R iz: a) udaljenosti l između dviju točaka koje se nalaze na luku meridijana određenih s pomoću trigonometrijske mreže i b) izmjerenih geografskih širina φ u točkama A i B astronomskim načinom.

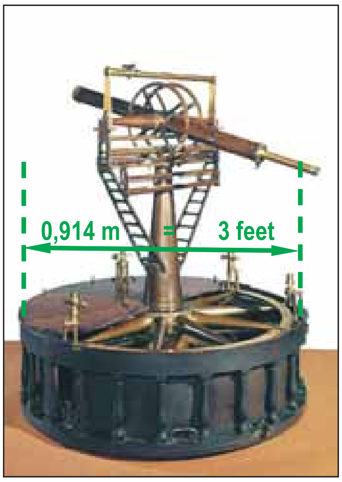


Fig. 9. Ramsden's Great Theodolite, with a diameter of 0.914 m (3 ft), built in 1791 (URL 6)

Slika 9. Ramsdenov veliki teodolit promjera horizontalnog limba 0,914 m (3 feeta) iz 1791. godine (URL 6)

Jesse Ramsdem (1735–1800), the English astronomer and maker of scientific instruments (URL 5). They had horizontal discs 0.914 m (3 ft) in diameter, with the graduations of the circle marked to a standard divergence of only one second (URL 6).

The team of experts which had been led by General William Roy began the Ordnance Survey using Ramsden's extremely precise Great Theodolites, a year after Roy's death, i.e. in 1791.

4. The Great Trigonometric Survey of India

As a great colonising power, Great Britain was anxious to exploit the natural wealth of her colonies. In order to do so, scientific research was carried out into the natural wealth of the colonies, along with exact maps of their territories. Good, precise maps were essential and necessary for military peacetime and wartime activities, and also formed a basis for planning commercial activities.

The trigonometric network of Great Britain covered the entire surface area of the British Isles, which comprise 122 000 square miles (1 square mile = 258.9939 ha). The surface area of India is 1 300 000 square miles, 10.6 times greater than that of Great Britain. Significant funds would have been required to survey India, so instead of setting up a trigonometric network, trigonometric chains (triangulation) were used. The same approach was adopted in France and Russia (URL 24), in order to cover the large territories of these countries.

William Lambton (1756–1823), a British officer, surveyor and geographer, began setting up trigonometric chains in 1802, in order to establish the trigonometric bases for creating precise maps of India (URL 7). His work on measuring the Great Arc made an important contribution to establishing the true contours of the Earth by geodetic and astronomic measurement.

He began taking measurements along a parallel from St. Thomas Mount (for which the latitude and longitude were known) in Madras, on the shore of the Bay of Bengal, and moved across the Indian peninsula to Mangalore, on the shore of the Arabian Sea. In 1806, he began latitudinal measurements 100 miles from Bangalore. He later surveyed southwards to Cape Comorin, then continued surveying northwards up to his death.

The British used enormous theodolites, known locally as Lambton's Theodolites, to measure the horizontal and vertical angles for triangulation. They were similar in size and shape to Ramsden's Great Theodolite, and had 500 kg each (Fig. 12). Each theodolite required 12 bearers to carry it (Venables 2003, p. 27). This meant that each man would have carried a load of 42 kg. However, according to another source, the theodolites were dismantled and carried by 27 bearers (URL 23). From today's perspective, when the largest theodolites had between 5 and 7 kg, the task seems unimaginably difficult.

The British paid particular attention to measuring the length of geodetic baselines (*d*), using Colby's compensation bar to determine them. Thomas Fredrick Colby (1784–1852), a British major-general and director of the Ordnance Survey, invented the compensation bar. It con-

Fig. 10. Jesse Ramsden (1735–1800), the English astronomer and maker of scientific instruments (URL 25)

Slika 10. Jesse Ramsden (1735–1800), engleski astronom i proizvođač znanstvenih instrumenata (URL 25)

Fig. 11. A large number of bearers were needed to carry the instruments, erect the pyramids and hold the geodetic targets (by permission of the Royal Geographical Society (with IBG))

Slika 11. Veliki broj pomoćnih radnika pomagao je u prenošenju instrumenata, podizanju piramida i držanju geodetskih značaka (uz dozvolu Royal Geographical Society (with IBG))

William Roy (1726–1790), škotski geodet i vojni crtač, primijenio je u Velikoj Britaniji tu, tada novu metodu geodetskih mjerenja s pomoću trigonometrijskih mreža za uspostavu osnovne trigonometrijske mreže Velike Britanije (URL 3). Na uspostavi te osnovne trigonometrijske mreže radilo se u razdoblju od 1783. do 1853 (URL 4).

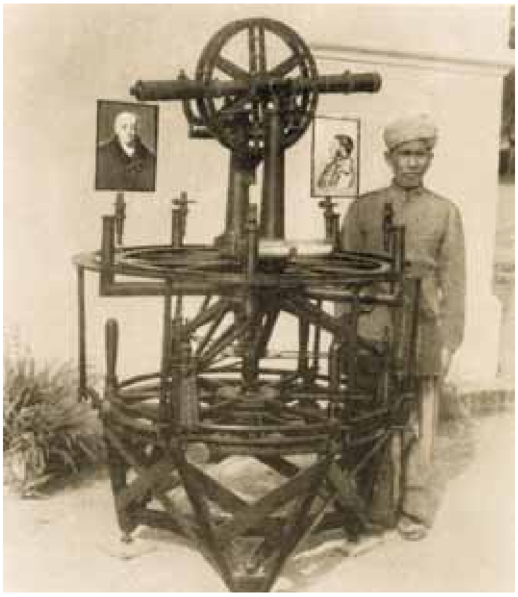


Fig. 12. Lambton's huge theodolite, having 500 kg (by permission of the Royal Geographical Society (with IBG))

Slika 12. Veliki Lambtonov teodolit mase 500 kg (uz dozvolu Royal Geographical Society (with IBG))

U izmjeri kutova korišteni su vrlo točni teodoliti velikih dimenzija (sl. 9). Te je teodolite izradio 1785. godine Jesse Ramsden (1735–1800) (sl. 10), engleski astronom i proizvođač znanstvenih instrumenata (URL 5). Imali su horizontalne krugove promjera 0,914 m (3 feeta) s ucrtanom podjelom kruga sa standardnim odstupanjem od samo jedne kutne sekunde (URL 6).

Ekipa stručnjaka koju je vodio W. Roy godinu dana nakon njegove smrti, tj. 1791. godine, počela je terenska mjerenja uz uporabu vrlo točnih Ramsdenovih teodolita velikih dimenzija.

4. Uspostavljanje velike trigonometrijske mreže Indije

Velika Britanija je kao velika kolonijalna sila željela iskoristiti prirodna bogatstva svojih kolonija. Kako bi to realizirala, organizirala je znanstvena istraživanja prirodnih bogatstava i točno kartiranje svojih kolonija. Naime, dobre i točne karte potrebne su za vojne aktivnosti u miru i u ratu, kao i osnova za planiranje u gospodarstvu.

Trigonometrijska mreža u Velikoj Britaniji postavljena je preko čitave površine njezinih otoka. Površina tih otoka je 122 000 kvadratnih milja (1 kvadratna milja = 258,9939 ha), a Indije 1 300 000 kvadratnih milja. Dakle, ta je površina oko 10,6 puta veća od britanske. Za tako

Fig. 13. Measuring the baseline using an apparatus which functioned on the principle of bi-metal temperature compensation, in 1828 (URL 30)

Slika 13. Mjerenje duljine baze 1828. godine s pomoću aparature, koja je djelovala na principu bimetalne temperaturne kompenzacije (URL 30)

sisted of six measuring poles set horizontally by placing beneath them smaller tripods. The apparatus was about 20 metres (63 ft) long. The poles were made of bronze and iron, to compensate for temperature expansion, as bronze and iron have different temperature expansion coefficients. Microscopes were located at the ends of the poles, for reading and defining distances. From time to time, the poles were compared with standard poles. In order to minimise the effect of the sun and temperatures on the length of the measuring poles, the measuring equipment was protected by tenting (Fig. 13).

The geodetic baselines were approximately 7 miles, i.e. 11 km long, and after establishing them, angles were measured using the theodolites, from the extreme points of the baselines to the third points of the triangles. Then the remaining triangles in the chain were laid against the side of the triangle of which one side had been previously calculated. Thus, a chain of connecting trigonometric points was formed. However, the trigonometric points could not always be fixed in high places, so pyramids made of bamboo were erected. The workers would then climb these pyramids and wave signal flags. In some places, tall permanent structures were built, as stable points in the trigonometric network.

The extremely demanding, exhausting task of establishing the basic trigonometric network in India, performed in difficult weather and terrain, progressed very slowly over a period of almost 40 years. Entire teams of experts and bearers died of malaria and other diseases, or from attacks by wild animals.

Lambton's surveying team arrived in central India in 1823, at which point he died. He was succeeded by his assistant, the Welsh surveyor and geographer, George Everest (1790–1866) (Fig. 15), who was himself weakened by malaria and dysentery at the time when he assumed this duty. Everest was appointed Surveyor-General of India, a post he held from 1830 to 1843. He suffered from fits of blindness and had some symptoms of paralysis, so that many in India considered he had a strange temper.

Everest continued work on the Great Trigonometric Survey of India along the arcs of the meridian from South India to Nepal and some paralels. He himself never set eyes on the highest peak in the world, which was later given his name, but when he retired, the measurement of the "Great Arc" had been completed. Dehra Dun, in the foothills of the Himalayas, north of Delhi, had been reached (Fig. 3). In addition, trigonometric points in the east arm of the "Great Arc" provided the exact locations and heights of points from which the locations and heights of the Himalayan peaks could be determined.

Based on the surveying and astronomical measurements taken in India, the dimensions of the Earth's reference ellipsoid were determined, also named after Everest (Everest 1830). The dimensions of this ellipsoid are given in Table 1. The dimensions of Bessel's ellipsoid are inserted for comparison. This ellipsoid was used in surveying the former Yugoslavia. The dimensions of the World Geodetic System WGS 84 are included, too.

The semi-major axis of the ellipsoid a and its numerical eccentricity e can be determined from the calculated radius of curvature (R_1 in the southern section of the meridian, R_2 in the northern section of the meridian) and the calculated latitudes in the centres of the arcs measured φ_1 and φ_2, using curvature equations along the meridian M:

$$M = \frac{a\left(1-e^2\right)}{\left(1-e^2\sin^2\varphi\right)^{3/2}}.$$

Fig. 14. William Lambton (1756–1823) (by permission of the Royal Geographical Society (with IBG))

Slika 14. William Lambton (1756–1823) (uz dozvolu Royal Geographical Society (with IBG))

Fig. 15. The surveyor and geographer, Colonel Sir George Everest (1790–1866) Photo: Maull and Polyblank (by permission of the Royal Geographical Society (with IBG))

Slika 15. Geodet i geograf pukovnik Georg Everest (1790–1866) Foto: Maull and Polyblank (uz dozvolu Royal Geographical Society (with IBG))

veliku površinu trebala bi znatno veća financijska sredstva, pa se u Indiji nije pristupilo postavljanju trigonometrijske mreže, već postavljanju trigonometrijskih lanaca. Tako se postupilo u Francuskoj i Rusiji (URL 24), koje su trebale pokriti velike teritorije svojih zemalja.

Zbog toga je britanski časnik, geodet i geograf *William Lambton* (1756–1823) (sl. 14) 1802. godine počeo postavljati trigonometrijske lance za uspostavu trigonometrijske osnove za izradu točnih planova i karata Indije (URL 7). Osim toga, on je s pomoću tzv. velikog luka (*Great Arc*) geodetskim i astronomskim mjerenjima želio pridonijeti i utvrđivanju istinitog oblika Zemlje.

Započeo je mjerenja po paraleli od St. Thomas Mounta (kojega su geografska dužina i širina bile poznate) u Madrasu, na obali Bengalskog zaljeva, preko indijskog poluotoka do Mangalorea, na obali Arapskoga mora. U 1806. godini Lambton je počeo određivati geografske širine 100 milja od Bangalorea. Osim toga, mjerio je na jug prema rtu Comorin, a predložio je da se nastave mjerenja prema sjeveru nakon njegove smrti.

Britanci su horizontalne i vertikalne kutove u trigonometrijskoj mreži mjerili velikim teodolitima koje su u Indiji nazvali *Lambtonovim teodolitima*. Oni su po obliku i konstrukciji sasvim slični Ramsdenovim velikim teodolitima, a imali su masu čak oko 500 kg (sl. 12). Pojedini teodolit prenosilo je 12 pomoćnih radnika (Venables 2003, str. 27). To bi značilo da je svaki pomoćni radnik morao prenositi oko 42 kg toga instrumenta. Međutim, prema drugom izvoru teodolit je u dijelovima prenosilo 27 nosača – pomoćnih radnika (URL 23). Gledajući iz današnje perspektive, kad najveći teodoliti imaju masu samo oko 5 do 7 kg, geodetima je to gotovo nezamislivo.

Britanci su posvećivali posebnu pozornost mjerenju duljina osnovnih geodetskih baza (*d*), pa su ih određivali Colbyjevom kompenzacijskom aparaturom. Konstruirao ju je britanski generalmajor i direktor *Ordnance Surveya* Thomas Frederick Colby (1784–1852). Sastojala se od šest mjernih motki koje su postavljane u horizontalni položaj podstavljanjem ispod njih manjih stativa (podložaka), a aparatura je ukupno bila duga 63 feeta (oko 20 metara). Motke su bile izrađene od bronce i željeza tako da se može kompenzirati utjecaj njihova temperaturnog širenja, jer bronca i željezo imaju različite temperaturne koeficijente rastezanja. Na krajevima motki nalazili su se mikroskopi za očitavanje i što točnije određivanje duljina. Osim toga, motke su se povremeno uspoređivale sa standardnim motkama. Da bi se ublažio utjecaj Sunca i temperature na promjenu duljina mjernih motki, mjerni pribor je zaštićivan s pomoću šatorskih krila (sl. 13).

Duljine osnovnih geodetskih baza iznosile su oko 7 milja, tj. oko 11 km, a nakon njihova određivanja mjereni su kutovi s pomoću teodolita od krajnjih točaka osnovne baze prema trećoj točki trokuta. Zatim su ostali trokuti u lancu trokuta naslonjeni na stranice trokuta u kojem je prethodno izračunana duljina jedne stranice. Tako je nastalo polje trigonometrijskih točaka povezanih u lance. Međutim, te točke nisu uvijek mogle biti postavljene na vrhove uzvisina, pa su zato podizali piramide izrađene od bambusa na koje su se penjali pomoćni radnici sa signalnim zastavicama. Samo na nekim mjestima zidane su visoke zidane građevine, kao stabilne točke trigonometrijske mreže.

Vrlo težak i zamoran posao uspostave osnovne trigonometrijske mreže u Indiji pod lošim klimatskim i terenskim uvjetima napredovao je vrlo sporo, pa je tako izmjera trajala gotovo 40 godina. Čitavi timovi mjernika i pomoćnih radnika umrli su od posljedica malarije i drugih tropskih bolesti ili od napada divljih zvijeri.

Geodetska ekipa pukovnika W. Lambtona došla je do središnjeg dijela Indije 1823. godine, kada je on umro. Naslijedio ga je asistent, velški geodet i geograf Georg

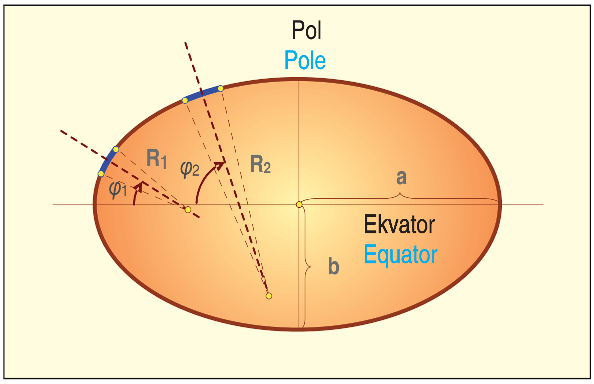


Fig. 16. Determining the dimensions of the Earth's rotational ellipsoid

Slika 16. Određivanje dimenzija Zemljina rotacijskog elipsoida

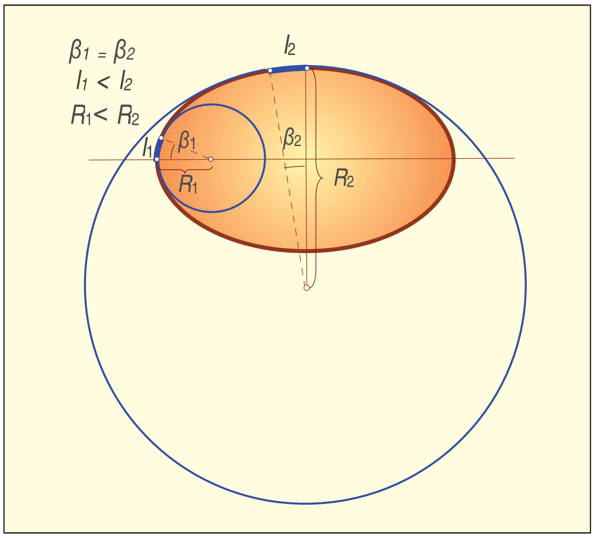


Fig. 17. Flattening of the Earth's poles. For equal values of the angles $\beta_1=\beta_2$ the radius of curvature near the poles (R_2) is greater than the radius of curvature near the equator (R_1)

Slika 17. Zemljina spljoštenost. Za jednake vrijednosti kutova $\beta_1=\beta_2$ radijus zakrivljenosti R_2 blizu pola veći je od radijusa zakrivljenosti blizu ekvatora R_1

By solving the two equations for $M_1=R_1$, $M_2=R_2$, with $\varphi = \varphi_1$ and $\varphi = \varphi_2$, from two unknowns, it transpires that

$$e^2 = \frac{R_2^{2/3} - R_1^{2/3}}{R_2^{2/3}\sin^2\varphi_2 - R_1^{2/3}\sin^2\varphi_1}$$

$$\text{and} \quad a = \frac{R_1(1-e^2\sin\varphi_1)^{3/2}}{1-e^2}.$$

From these two equations, the size of the semi-major axis a and the eccentricity of the Earth's ellipsoid e can be calculated. From e the degree of flattening of the ellipsoid f can be calculated according to the formula:

$$f = 1 - \sqrt{1-e^2}\,.$$

The extent of the trigonometric network for India can be seen in Fig. 18, where the triangulation links for the Great Trigonometric Survey of India are shown.

Today, we can say that the shape of the geoid in the region of India certainly affects the accuracy of determining the Everest ellipsoid. Based on modern satellite determinations, it is now known that there is a large, indentation of the geoid in the Indian Ocean, below the reference ellipsoid WGS'84, and that it is about 107 m deep. On the other side, to the north, is the range of the Himalayas, with the highest peak in the world.

Sir George Everest did great things in India, but his health suffered. He retired in 1843 and returned to live in England. Paradoxically, he never reached the Himalayas himself, though the highest peak in the world was named after him (Smith 1999).

After Everest retired, the British officer and surveyor Andrew Scott Waugh was appointed to take his place. He pressed on with the final measurements (URL 11). It should be emphasised that determining the height of the Himalayan peaks depended on the Great Trigonometric

Table 1. Dimensions of several Earth reference ellipsoids (URL 10)

Tablica 1. Dimenzije nekoliko referentnih Zemljinih elipsoida (URL 10)

Name of ellipsoid Naziv elipsoida	Semi-major axis Velika poluos (m)	Inverse flattening of ellipsoid Recipročna vrijednost spljoštenosti elipsoida 1/f
Everest 1830	a = 6 377 276,34	300,80
Besselov 1841	a = 6 377 397,00	299,15
WGS' 84	a = 6 378 137,00	298,25

Fig. 18. Map showing triangulation links for the Great Trigonometric Survey of India of 1880, on the basis of which the height of the Himalayan peaks was determined, and Mt. Everest discovered to be the highest peak in the world (by permission of the Royal Geographical Society (with IBG))

Slika 18. Karta lanaca trigonometrijske mreže Velike izmjere Indije *iz 1880. godine na temelju koje su određene i visine vrhova Himalaje te najvišeg vrha na Zemlji Mt. Everesta (uz dozvolu Royal Geographical Society (with IBG))*

Everest (1790–1866) (sl. 15), koji je u trenutku preuzimanja dužnosti bio oslabljen od malarije i dizenterije. Pukovnik G. Everest bio je postavljen na mjesto glavnog mjernika (*surveyor-general*) Indije od 1830. do 1843. godine. Događalo mu se da povremeno oslijepi, a imao je i znakove paralize, pa su ga u Indiji često smatrali čovjekom loše ćudi.

Pukovnik G. Everest nastavio je rad na uspostavi velike trigonometrijske izmjere Indije uzduž lukova meridijana na potezu od juga Indije sve do Nepala i nekim paralelama. Nikada nije ugledao najviši vrh svijeta, koji je poslije dobio njegovo ime, a kad je otišao u mirovinu izmjera "velikog luka" bila je završena. S "velikim lukom" došlo se sve do Dehra Duna u prednjoj Himalaji sjeverno od Delhija (sl. 3). Osim toga, trigonometrijske točke u istočnom rukavu "velikoga luka" dale su točne položaje i visine stajališta s kojih su se mogli odrediti položaji i visine vrhova Himalaje.

Na osnovi izvedenih geodetskih i astronomskih mjerenja u Indiji određene su dimenzije Zemljina referentnog elipsoida, koji je dobio Everestovo ime (Everest 1830). Dimenzije tog elipsoida upisane su u tablici 1, a za usporedbu u nju su unesene dimenzije Besselova elipsoida, koji je korišten u geodetskoj izmjeri bivše Jugoslavije, i dimenzije elipsoida WGS 84.

Velika poluos Zemljina elipsoida a i njezin numerički ekscentricitet e mogli su se odrediti iz izračunanih radijusa zakrivljenosti (R_1 na južnom dijelu meridijana i R_2 na sjevernijem dijelu meridijana), i izračunanih geografskih širina sredina izmjerenih lukova φ_1 i φ_2 s pomoću jednadžbe za zakrivljenost po meridijanu M:

$$M = \frac{a\left(1-e^2\right)}{\left(1-e^2\sin^2\varphi\right)^{3/2}}.$$

Rješenjem dviju jednadžbi za $M_1=R_1$, $M_2=R_2$, s $\varphi = \varphi_1$ i $\varphi = \varphi_2$ s dvije nepoznanice dobije se da je:

$$e^2 = \frac{R_2^{2/3} - R_1^{2/3}}{R_2^{2/3}\sin^2\varphi_2 - R_1^{2/3}\sin^2\varphi_1} \quad \text{i} \quad a = \frac{R_1(1-e^2\sin\varphi_1)^{3/2}}{1-e^2}.$$

Iz tih dviju jednadžbi mogu se izračunati veličina velike poluosi a i ekscentricitet Zemljina elipsoida e. Zatim

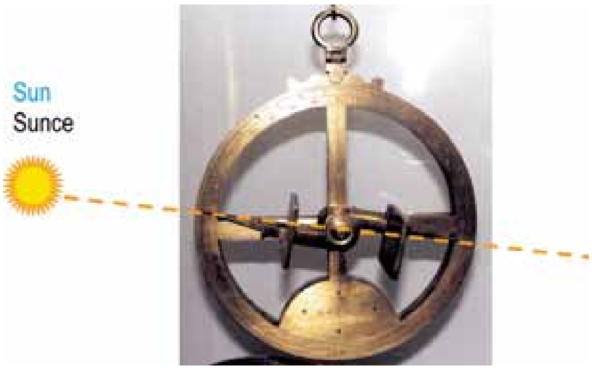


Fig. 19. Navigational astrolabe, such as was used by mariners to determine latitudes. The graduations of the circle are marked on the rim of the disc.

Slika 19. Pomorski astrolab kakvim su pomorci određivali geografske širine. Na obodu limba ucrtana je stupanjska podjela.

Survey of India, and that it was at the suggestion of A.S. Waugh that the highest peak of all was named after his eminent predecessor, Sir George Everest.

5. Determining the Heights of the Himalayan Peaks

In the early 18th century, the Andes were considered the highest mountain range on Earth, and the highest point of the "old known world" was Pico de Teide on the island of Tenerife in the Canary Islands (Atlantic Ocean). Measuring height was extremely difficult, even though the sea was relatively close by as a reference point. The summit of Pico de Teide was measured using a navigational astrolabe.

It is not known when the first astrolabe was made, but they certainly existed in the 7th century, and the Arabs developed them in the 8th and 9th centuries. They were introduced to Europe in the 12th century from Moslem Spain (Andalusia). They played an important role in determining the positions, particularly the latitudes, of ships at sea, and in the 15th and 16th century enabled the discovery of significant sea routes, and indeed, the discovery of America. The astrolabe, when being used for measuring, must hang freely, and the alidade must be set so that the rays of the sun pass through the upper and lower holes (Fig. 19). On the rim of the disc, the graduations of the circle are marked, as used by the ancient Babylonians. Today, we would say that the accuracy of measuring angles using an astrolabe is only satisfactory to within four or five degrees. Thus it was considerably less accurate than a theodolite. The height of the summit of Pico de Teide was overestimated by some thousand metres. Today, it is known that the correct height is 3718 m, (*The Times Atlas of the World* 1990), or 3712 m according to the Croatian *Atlas svijeta* (1966).

Later, many European experts presumed that the Andes were the highest mountain range in the world, and the highest peak Chimborazo in Equador. Its height (6310 m) was fairly accurately estimated (Abromeit 2008).

Jesuit missionaries arrived in Tibet via Kashmir and the western Himalayas at the beginning of the 18th century. Representatives of the British and East India Company, with its headquarters in Bengal, came to Tibet via Bhutan at the end of the 18th century. However, it should be noted that they showed little interest in the poverty-stricken mountainous areas. On the 1733 maps of Jean Baptiste d'Anville, the Himalayas are shown merely as "snow caps", with no heights mentioned.

The first hint that the Himalayas might be the highest mountains in the Old World came from Major James Rennell (Fig. 20), who explored the then newly conquered British colony in the 1770s.

Sir William Jones, a judge in Calcutta, in British India, went further than Rennell and demonstrated why the Himalayas were the highest mountains in the world. He had received information from two explorers who had gone into Tibet, and concluded that the highest peaks were even further distant than anyone had at the time presumed. According to Venables (Venables 2003), Jones measured the angles at the peak of Chomo Lhari (Fig. 3), 70 km from the western conjunction of the borders of India, Bhutan and China. He calculated the distance of the peak from the River Ganges as 393 km, and its estimated height as over 6100 m. This would have meant that the Himalayas soared above the known heights of the Andes peaks. The height of Chomo Lharia is 7313m above sea level, according to the *Atlas of the World 1990*, map 28.

However, this result should be taken with reserve, as the question arises as to the feasibility of measuring heights at all under such conditions. At a distance of 393 km:

- the true horizon lies 12.122 km below the apparent horizon (as can be calculated by formula (4), and as can be seen from column 2 in Table 3)
- the angle of elevation would be below the horizon, i.e. – 0°29'15'' (as can be calculated by formulas (5) to (10) in Fig. 23, and as can be seen from column 4 in Table 3).

At the same time, it must be emphasised that the effect of refraction at the horizon is considerable, and that air vibration close to the horizon is high, in addition to the problem of viewing below the horizon. If we take into account the fact that Jones' views must have been below the horizon, then we can surely conclude that any estimates of height made must have been highly questionable.

Since Jones was unable to prove his theory with exact data, his claim was not accepted by the scientists of the day. Some suspected that the Himalayas were a chain of active volcanoes, and mistakenly identified the

Fig. 20. James Rennell (1742–1839) (URL 26)

Slika 20. James Rennell (1742–1839) (URL 26)

se iz ekscentriciteta može izračunati i spljoštenost elipsoida *f* po formuli:

$$f = 1 - \sqrt{1 - e^2}\,.$$

Koliko su veliki lanci trigonometrijske mreže Indije, vidi se na sl. 18, gdje su prikazani trigonometrijski lanci *Velike izmjere Indije*.

Danas se može reći da je na točnost određivanja Everestova elipsoida sigurno utjecao oblik geoida na području Indije. Na osnovi suvremenih satelitskih određivanja zna se da je u Indijskom oceanu veliko udubljenje geoida ispod referentnog elipsoida WGS'84 i da ono iznosi oko 107 m. Osim toga upravo se s druge strane na sjeveru pružaju velike mase Himalaje s najvišim vrhom na svijetu.

G. Everest učinio je veliko djelo u Indiji, ali je nažalost zdravstveno stradao. Umirovljen je 1843, a zatim se vratio u Englesku. Paradoksalno je da nikada nije došao do Himalaje, a najviši vrh na Zemlji dobio je ime po njemu (Smith 1999).

Nakon umirovljenja G. Everesta na njegovo je mjesto postavljen britanski časnik i geodet Andrew Scott Waugh (1810–1878), koji je nastavio završna mjerenja (URL 11). Naglasimo da je određivanje visina vrhova Himalaje oslonjeno na veliku geodetsku izmjeru Indije i da je na Waughov prijedlog prihvaćeno ime najvišega vrha na Zemlji po njegovu velikom prethodniku G. Everestu.

5. Određivanje visina vrhova Himalaje

U ranom 18. stoljeću Ande su smatrane najvišim planinama na Zemlji, a najvišim vrhom "staroga poznatog svijeta" *Pico de Teide* na otoku Tenerife u Kanarskom otočju u Atlantskom oceanu. Visinska izmjera bila je teška iako je kao ishodišna točka uzeta točka relativno blizu razini mora. Visina vrha Pico de Teide bila je mjerena s pomoću pomorskog astrolaba.

Ne zna se kad je izrađen prvi astrolab, no sigurno je postojao u 7. stoljeću, a Arapi su ga usavršili u 8. i 9. stoljeću. U Europu je unesen u 12. stoljeću iz tada islamske Španjolske (Andaluzije). Odigrao je važnu ulogu za određivanje položaja, posebice geografske širine, brodova na moru ili oceanu, a omogućio je u 15. i 16. stoljeću značajna otkrića pomorskih putova i Amerike. Pri mjerenju astrolab slobodno visi, a alhidadu treba postaviti tako da Sunčeve zrake prolaze kroz njezinu gornju i donju rupicu (sl. 19). Na obodu limba ucrtana je stupanjska podjela, koju su koristili već stari Babilonci. Danas možemo reći da točnost mjerenja kutova astrolabom nije bila dobra i da je iznosila obično 4^o do 5^o. Dakle, to je bio instrument sa sigurno znatno manjom točnosti od teodolita. Tako je visina vrha *Pico de Teide* pogrešno određena za više od 1000 m, a njegova visina kao što je danas poznato iz suvremenih mjerenja iznosi samo 3718 m (The Times Atlas of the World 1990), odnosno 3712 m (Atlas svijeta 1966).

Poslije su mnogi europski stručnjaci pretpostavljali da su Ande najveći planinski masiv i da je najviši vrh na Zemlji Chimborazo u Ekvadoru, kojega je visina 6310 m nad morem bila relativno točno određena (Abromeit 2008).

Jezuitski misionari stigli su u Tibet početkom 18. stoljeća preko Kašmira i zapadnog dijela Himalaje. Predstavnici britanske i istočnoindijske kompanije sa sjedištem u Bengalu došli su u Tibet preko Butana krajem 18. stoljeća. Međutim, oni nisu pokazivali interes za planinska područja jer su ona bila siromašna. Zato je Himalaja na kartama Jean-Baptiste d'Anvillea iz 1733. godine označena samo kao "snježni lanac" bez visina.

Fig. 21. William Jones (1746–1794) (URL 27)

Slika 21. William Jones (1746–1794) (URL 27)

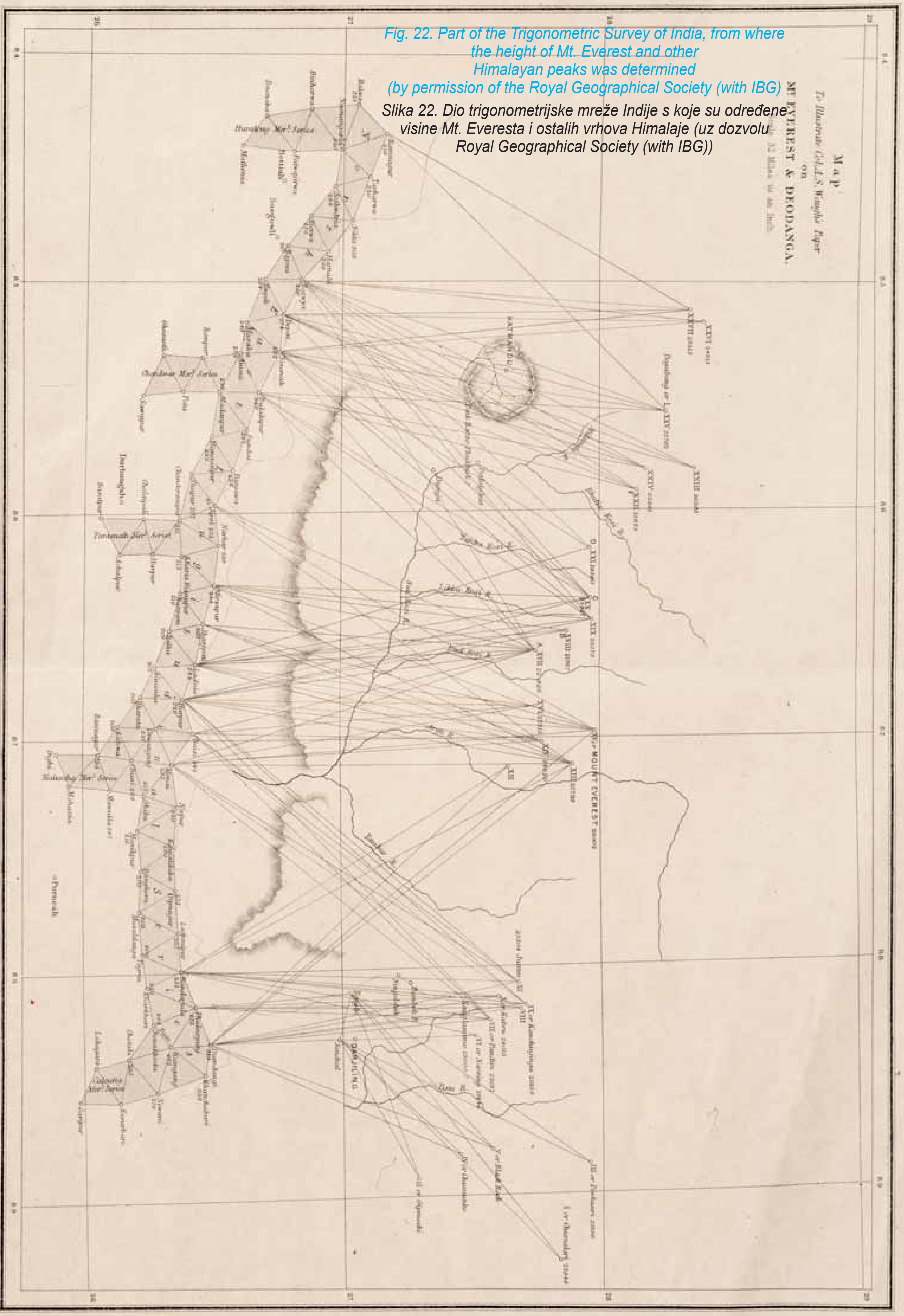


Fig. 22. Part of the Trigonometric Survey of India, from where the height of Mt. Everest and other Himalayan peaks was determined (by permission of the Royal Geographical Society (with IBG)

Slika 22. Dio trigonometrijske mreže Indije s koje su određene visine Mt. Everesta i ostalih vrhova Himalaje (uz dozvolu Royal Geographical Society (with IBG))

Prve naznake da bi Himalaja mogla biti najviša planina *staroga svijeta* potječu od majora Jamesa Rennella (sl. 20), koji je 1770-ih istraživao tada novoosvojenu britansku koloniju.

Sir William Jones, sudac iz Kalkute u britanskoj Indiji, otišao je dalje od Rennella i objasnio zašto je Himalaja najviša planina na svijetu. Naime, imao je informacije od dvaju istraživača koji su ušli u Tibet, te je zaključio da najviši vrhovi leže puno dalje nego što se do tada pretpostavljalo. Prema (Venables 2003), W. Jones je mjerio kutove na vrh *Chomo Lhari* (sl. 3), koji se nalazi 70 km od zapadne tromeđe Indije, Butana i Kine. Izračunao je da je udaljenost toga vrha od Gangesa 393 km i da je njegova približna visina, tj. vrhova Himalaje, viša od 6100 m. To je značilo da se Himalaja uzdiže iznad tada poznatih visina vrhova Anda. Nadmorska visina Chomo Lharija je 7313 m (Atlas of the World 1990, karta 28).

Međutim, taj rezultat treba komentirati i postaviti pitanje je li uopće bilo moguće donositi bilo kakve odluke o visinama. Naime, na udaljenosti 393 km:

- pravi horizont je ispod prividnoga horizonta čak 12,122 km (što se može izračunati po formuli (4), a vidi se i iz stupca 2 u tablici 3),
- elevacijski kut bio bi ispod horizonta, dakle negativan, – $0^{o}29'15''$ (što se može izračunati po formulama (5) – (10) sa slike 23, a vidi se i iz stupca 4 u tablici 3).

Pritom valja naglasiti da je utjecaj refrakcije pri horizontu vrlo velik i da je treperenje zraka blizu horizonta vrlo veliko, a kad je to ispod horizonta, tada se pojavljuju još veći problemi. Ako se uzme u obzir da su Jonesove vizure morale biti ispod horizonta, tada se sigurno može zaključiti da je donošenje bilo kakvih zaključaka o visinama bilo vrlo diskutabilno.

Budući da Jones svoju pretpostavku nije mogao egzaktno dokazati, njegovu tvrdnju nisu prihvatili znanstvenici toga doba. Neki su naslućivali da je Himalaja lanac aktivnih vulkana jer su pogrešno tumačili bjelinu snijega kao dim. Drugi pak nisu vjerovali izvještajima da na Himalaji ima velikih glečera, i to u blizini tropa.

Tijekom britanske vladavine u Indiji došli su geodeti (mjernici), koji su na horizontu sjevera Indije otkrivali sve više planinskih vrhova i pokušavali izvesti izmjeru njihovih visina. Tako su 1790. godine iz Bihara, koji se nalazi blizu južne obale Gangesa i blizu većeg naselja Patna (sl. 3), dobili da je izmjerena visina jednog vrha 7925 m. Međutim, poslije je taj rezultat bio poništen.

Nadalje, 1810. godine određena je visina vrha *Dhaulagiri* u središnjem Nepalu, blizu vrha Annapurna, 290 km istočno od zapadne tromeđe Indije, Kine i Nepala (sl. 3), koja je iznosila 7925 m. Danas je iz suvremenih mjerenja poznato da je taj vrh visok 8167 m. Taj rezultat objavljen je u opsežnom znanstvenom članku uz tvrdnju da Himalaja nadvisuje Ande. Međutim, ni ta tvrdnja nije bila priznata u znanstvenoj javnosti.

Prvi geodeti došli su do planina na zapadu Nepala između 1817. i 1820. godine, pa su se počeli skupljati dokazi da su vrhovi Himalaje viši od najvišeg vrha Anda. Tako je izmjerena visina vrha koji domaće stanovništvo naziva *Nanda Devi* (sl. 3), a nalazi se u Indiji 80 km zapadno od zapadne tromeđe Nepala, Indije i Kine. Dobili su da je njegova visina 7816 m, pa je tako taj vrh tijekom tridesetak godina 19. stoljeća bio poznat kao najviši vrh na Zemlji.

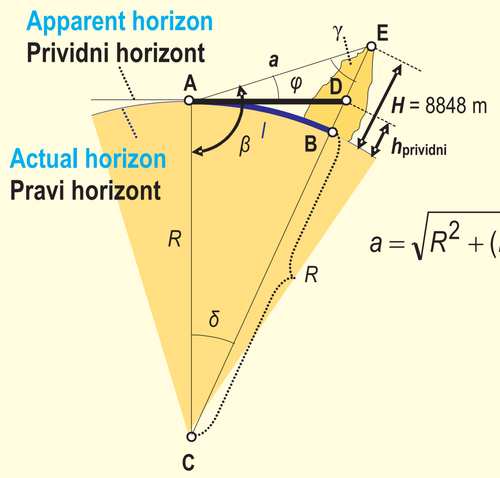
5.1 Prva određivanja visine vrha Mt. Everesta (Chomolungme)

Nasljednik G. Everesta Andrew Scott Waugh došao je s trigonometrijskom mrežom do podnožja Himalaje. Na taj je način imao koordinate trigonometrijskih točaka, a to znači i udaljenosti između tih točaka, i njihove visine u provinciji Darjiling. Ta se indijska provincija nalazi između Nepala, Kine, Butana i Bangladeša.

Table 2. Numbers of trigonometric points, names and distances from Mt. Everest, according to the map in Fig. 22.

Tablica 2. Broj trigonometrijske točke, njezino ime i njezina udaljenost od Mt. Everesta prema karti sa sl. 22

Nr. of trig. point Br. trigonometrijske točke	Name of trig. point Ime trigonometrijske točke	Distance to the Mt. Everest Udaljenost do Mt. Everesta (km)
231	Tirol	194
254	Mirzapur	180
263	Jhanjpati	<u>178</u>
242	Ladnia	178
226	Harpur	182
237	Menia	186
319	Dumdangi	<u>218</u>



$$\delta = \frac{l}{R}\frac{180^{o}}{\pi}$$ (δ is in degrees) (δ je u stupnjevima)..........(5)

$$h_{prividni} \approx \frac{l^{2}}{2R}$$ ....(6)

$$a = \sqrt{R^{2} + (R+H)^{2} - 2 \cdot R \cdot (R+H) \cdot \cos(\delta)}$$ ...... (7)

$$\gamma = \mathrm{asin}\left(\frac{R}{a} \cdot \sin\delta\right)$$ .... (8)

$$\beta = \mathrm{asin}\left(\frac{R+H}{R} \cdot \sin\gamma\right)$$ .... (9)

$$\varphi = \beta - 90^{o}$$ .... (10)

Fig. 23. True and apparent horizon due to the curvature of the Earth and elevation angle φ from which the peak of Mt. Everest is seen. The figure does not take into account the effect of refraction caused by the atmosphere and the formulae by which values are calculated are given in Table 3.

Slika 23. Pravi i prividni horizont zbog Zemljine zakrivljenosti, kao i elevacijski kut φ pod kojim se vidi vrh Mt. Everest. Na slici je zanemaren utjecaj refrakcije izazvan atmosferom i napisane su formule po kojima su izračunane vrijednosti upisane u tablici 3.

snowcaps as smoke. Other could not believe reports of glaciers in the Himalayas, so close to the tropics.

During British rule in India, surveyors noted several mountain ranges on the horizon in northern India and tried to measure their height. In 1790, they calculated the height of one peak, measured from Bihar, near the south bank of the Ganges, and the nearest larger settlement of Patna (Fig. 3) to be 7,925 m. However, this result was later quashed.

In 1810, the height of Dhaulagiri peak, in central Nepal, close to Annapurna, 290 east of the border conjunction of India, China and Nepal, was determined as 7925 m (Fig. 3). Today, contemporary measurements tell us that the true height is 8167 m. The result was published in a comprehensive scientific article, which claimed the Himalayas were higher than the Andes. However, this claim was rejected by the scientific community.

The first surveyors arrived in the mountains of west Nepal between 1817 and 1820, and began collecting data proving that the Himalayan peaks were higher than those of the Andes. The peak which is known by locals today as Nanda Devi (Fig. 3), and which is located in India, 80 km west of the western border conjunction of Nepal, India and China, was measured at 7816 m. As a result, it was accepted for almost thirty years during the 19th century as the highest peak in the world.

5.1. First estimation of the height of Mt. Everest (Chomolungma)

Sir George Everest's successor, Andrew Scott Waugh, reached the foot of the Himalayas with his trigonometric network. Thus, he had established the coordinates of all the trigonometric points, including the distances between them, and the heights of the points in the province of Darjeeling, which is located between Nepal, China, Bhutan and Bangladesh.

Measuring the heights of the Himalayan peaks was no easy task in those days, as the borders of Nepal, China (Tibet) and Bhutan were closed to foreigners. The border of Nepal was closed to foreigners from 1815 to 1945. So Waugh had to estimate the height of the Himlayan peaks from India, from a distance of 200 km (URL 2), and according to some sources, from a distance of over 240 km (URL 1). According to URL 16, the distance was between 170 and 190 km, while according to URL 17, it was over 150 km, and according to URL 11, at least 160 km. However, the most accurate data for Mount Everest are given by Venables in his book *Everest – die Geschichte seiner Erkundung* (2003), in which there is a map showing the trigonometric network of India to a scale of 1:2 000 000, which was used to determine the height of the Himalayan peaks. From this map (Fig. 22) and Table 2, it can be see that the height of Mount Everest was determined from trigonometric points between 178 and 218 km distant from the peak.

Table 3. Dependence of the level of the apparent horizon $h_{apparent}$ and angles δ, γ, β=90°+ φ in triangle ACE on distance l measured along the arc, from the set point to the projection of Mt. Everest at sea level. The effect of refraction caused by the atmosphere is disregarded.

Tablica 3. Ovisnost visine prividnog horizonta $h_{prividni}$ i kutova δ, γ, β=90°+ φ u trokutu ACE o udaljenosti l mjerenoj po luku od stajališne točke do projekcije Mt. Everesta na razinu mora. Pritom je zanemaren utjecaj refrakcije izazvan atmosferom.

Distance to the Mt. Everest **Udaljenost do Mt. Everesta** **l (km)** **(1)**	Height of apparent horizon **Visina prividnog horizonta** **$h_{prividni}$ (m)** **(2)**	Angle on the Mt. Everest **Kut na Mt. Everestu** **γ (° ' ")** **(3)**	Angle of elevation **Elevacijski kut** **φ (° ' ")** **(β=90°+φ)** **(4)**	Angle in center of the Earth **Kut u središtu Zemlje** **δ (° ' ")** **(5)**
150	1 766,03	85° 58' 30"	2° 40' 33"	1° 20' 57"
170	2 268,37	86° 16' 42"	2° 11' 33"	1° 31' 44"
190	2 833,50	86° 29' 56"	1° 47' 32"	1° 42' 32"
200	3 139,61	86° 35' 10"	1° 36' 54"	1° 47' 56"
220	3 798,93	86° 43' 29"	1° 17' 48"	1° 58' 44"
240	4 521,05	86° 49' 31"	1° 00' 58"	2° 09' 31"
393	12 122,75	86° 57' 10"	–0° 29' 15"	3° 32' 05"

Izmjera visina vrhova Himalaje tada nije bila jednostavna zadaća, jer su granice Nepala, Kine (Tibeta) i Butana bile zatvorene za strance. Naime, granice Nepala bile su zatvorene za strance od 1815. do 1945. godine. Zato je A. Waugh sa svojim timom mogao odrediti visine nekih vrhova Himalaje samo iz Indije, iz udaljenosti veće od 200 km (URL 2), a po nekim izvorima više od 240 km (URL 1). Prema (URL 16) ta je udaljenost bila između 170 i 190 km, prema (URL 17) veća od 150 km, a prema (URL 11) najmanje 160 km. Međutim, najtočniji podaci za Mt. Everest dani su u knjizi *Everest die Geschichte seiner Erkundung* (Venables 2003), u kojoj je priložena karta s trigonometrijskom mrežom Indije u mjerilu 1:2 000 000 s koje su određivani vrhovi Himalaje. Iz te karte (sl. 22) i tablice 2 vidi se da je visina Mt. Everesta određena s trigonometrijskih točaka udaljenih od Mt. Everesta između 178 km i 218 km.

Kako bi se dobila predodžba o tim udaljenostima, dana je usporedba pa bi primjerice u Hrvatskoj tome odgovaralo određivanje:

- ❑ visine vrha Učke iz podnožja Sljemena (na udaljenosti 155 km),
- ❑ visine vrha Dinare iz Zagreba (na udaljenosti 210 km),
- ❑ visine vrha Dinare s podnožja Učke (na udaljenosti 218 km).

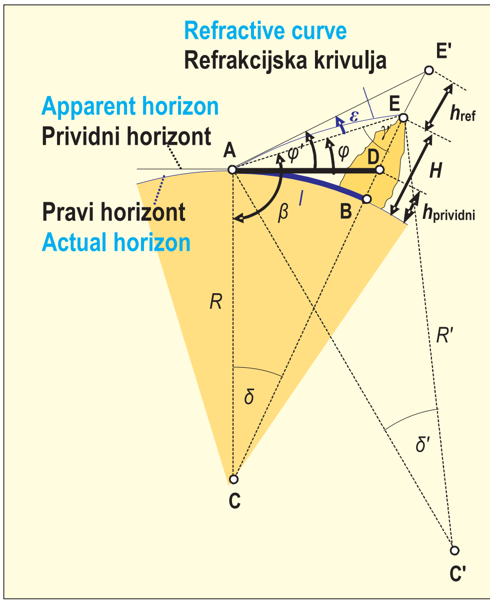
Danas geodeti ne bi određivali visine vrhova planina na tako velikim udaljenostima, čak ni onda kad bi se točke međusobno dogledale.

Očigledno je da se visina vrha Mt. Everesta mogla odrediti samo s pomoću trigonometrijskoga nivelmana. U Hrvatskoj su se po pravilniku za trigonometrijske mreže mogle odrediti visine trigonometrijskih točaka samo na kraćim udaljenostima, od oko 5 do 10 km, tj. u trigonometrijskoj mreži III. i IV. reda, i to vezanjem na repere kojih su visine bile određene geometrijskim nivelmanom. Pritom su trigonometrijskim nivelmanom određivane visine samo na brdovitom terenu, gdje vizure prolaze visoko iznad terena. Zbog utjecaja refrakcije na vertikalne kutove nastojalo ih se izmjeriti u ono doba dana kada je taj utjecaj najmanji i približno konstantan, a to je oko podneva, između 11 i 13 sati. Osim toga bilo ih je obvezno mjeriti obostrano (na poznatoj točki i na određivanoj točki), i to po mogućnosti istodobno (Macarol 1966, str. 520–528).

Međutim, Waugh i njegov tim nisu mogli mjeriti vertikalne kutove obostrano, jer se tada još ni jedan čovjek nije popeo na Mt. Everest, koji je zaleđen, a i zrak je na vrhu zbog velike visine jako rijedak, tj. s nedovoljno kisika za čovjeka, ali i za ostale oblike života na Zemlji. Zato su vertikalne kutove mogli mjeriti samo s njihovih trigonometrijskih točaka u Indiji i uzeti grubo u račun utjecaj refrakcije izazvan atmosferom (URL 16). Budući da se radilo o velikoj udaljenosti, Waugh i njegov tim morali su imati i vrlo dobro određen Zemljin radijus. Za manje točne radove, tj. za praktične radove na manjem području može se taj dio Zemljine površine zamijeniti dijelom kugline plohe polumjera:

$$R = \sqrt{M \cdot N} \qquad (1)$$

gdje su: M – srednji radijus zakrivljenosti *po meridijanu* i N – srednji radijus zakrivljenosti *po prvom vertikalu* u središtu područja geodetske izmjere.



$$h_{ref} \approx \frac{k \cdot l^2}{2R} \quad \text{.......... (11)}$$

$$\varepsilon \approx \frac{k \cdot l}{2R}\frac{180^o}{\pi} \quad \text{....... (12)}$$

(gdje je ε izražen u stupnjevima)
(where is ε in degrees)

Fig. 24. Effect of refraction caused by the atmosphere on measuring vertical angles

Slika 24. Utjecaj refrakcije na mjerenje vertikalnih kutova, koji je uzrokovan atmosferom

In order to get a better impression of the distances concerned, this would be similar to measuring the following in Croatia:

- the peak of Mt. Učka from the foothills of Sljeme (155 km away)
- the peak of Mt. Dinara from Zagreb (210 km away)
- the peak of Mt. Dinara from the foot of Mt. Učka (218 km away)

Today, no surveyor would dream of determining the height of a peak from such a distance, even if the points were mutually visible.

Clearly, the only way to determine the height of Mt. Everest was by using trigonometric levelling. In Croatia, as a rule, the height of trigonometric points for a trigonometric network can only be determined at shorter distances, between 5 and 10 km, i.e. in the trigonometric networks of the third and fourth orders, by links to bench marks whose heights have been ascertained by geometric levelling. Thus, heights are ascertained by trigonometric levelling only in hilly terrain, where the lines of sight lie high above the land. Due to the effect of refraction on vertical angles, measurements are usually taken at a time of day when such refraction is minimal, close to the constant. This is usually around noon, between 11:00 and 13:00. In addition, surveying should be conducted from both sides (at the known point and the point to be determined), simultaneously if possible (Macarol 1966, pp. 520-528).

However, Waugh and his team were unable to conduct measurements of the vertical angles from both sides, as at that time no-one had ever scaled Mt. Everest, which was not only covered in ice, but was so high that the air at the peak was thin, containing too little oxygen for people, or indeed other creatures, to breathe. So Waugh and his

$$\overline{EE'} = \overline{E''E'''}$$

$$\overline{E''E'''} = 8 \cdot \sin\gamma$$

$$\theta = \text{atan}\left(\frac{8 \cdot \sin\gamma}{a}\right)$$

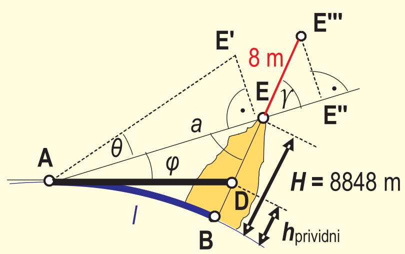


Fig. 25. Angle θ as error in angle of elevation φ due to miscalculation of the height of Mt. Everest by 8 m.

Slika 25. Kut θ kao pogreška u kutu elevacije φ zbog pogrešne visine Mt. Everesta od 8 m.

Nadalje, za manje točne radove može se Zemlja na manjem području zamijeniti kuglom kojoj je polumjer jednak aritmetičkoj sredini triju poluosi. Za Everestov elipsoid (1830) dobije se:

$$R = \frac{a+a+b}{3} = 6370{,}2093 \text{ km}, \qquad (2)$$

gdje su *a* i *b* velika i mala poluos rotacijskog elipsoida Zemlje.

Na velikim udaljenostima na kojima je A. Waugh sa svojim timom određivao visine vrhova Himalaje pravi horizont je ispod prividnoga čak nekoliko kilometara (sl. 23). To se može izračunati prema formulama navedenim u (Macarol 1966, str. 25 i 26):

$$h_{\text{prividni}} = \frac{R}{\cos\left(\frac{l}{R}\right)} - R, \qquad (3)$$

odnosno s pomoću približne formule:

$$h_{\text{prividni}} \approx \frac{l^2}{2R}, \qquad (4)$$

gdje je *l* – udaljenost mjerena po luku od točke A do točke B i *R* – radijus Zemlje (sl. 23). Tako se prema dimenzijama Everestova elipsoida dobije da je za:

- udaljenost *l* = 170 km pravi horizont ispod prividnoga h_{prividni} = 2268,37 m i za
- udaljenost *l* = 220 km pravi horizont ispod prividnoga h_{prividni} = 3798,93 m.

Ostale visine prividnoga horizonta mogu se naći u stupcu 2 tablice 3.

Iz tablice 3 u stupcu (4) vidi se da bi se, kad se zanemari utjecaj atmosfere (refrakcije), Mt. Everest vidio pod vrlo malim elevacijskim kutovima od 2° 40’ do samo 1° 01’. Dakle, sasvim blizu horizonta. Kad bi udaljenost bila čak 393 km od Mt. Everesta, kao što ju je izmjerio W. Jones na Chomo Lhari, tada bi elevacijski kut na Mt. Everest bio čak ispod horizonta, tj. negativan, – 0° 29’.

Svjetlost se ne kreće u atmosferi pravocrtno već po refrakcijskoj krivulji koja se može aproksimirati dijelom kružnice, konkavno okrenute prema dolje k Zemlji (sl. 24). Za slučaj jednostranog određivanja visinskih razlika dobivena je približna formula (Čubranić 1954, str. 559)

$$H = l \cdot \text{tg}(\varphi') + \left(\frac{1-k}{2}\right) \cdot \frac{l^2}{R}$$

gdje je *l* – udaljenost od stajališta do projekcije Mt. Everesta na razinu mora mjerena po luku, *φ’* – elevacijski kut pod kojim se vidi vrh Mt. Everest iz stajališne točke pomaknut zbog refrakcije i *k* – koeficijent refrakcije koji je na osnovi eksperimentalnog određivanja približno jednak 0,13. U formuli je zanemarena visina stajališta. To se može učiniti jer su visine stajališta bile samo oko 60 m iznad mora (URL 15), a osim toga ovdje su učinjena samo približna računanja.

Iz stupca (2) tablice 4 vidi se da kut refrakcije ε, ako je koeficijent refrakcije *k* = 0,13, iznosi između 5’16’’ i 8’23’’. Iz stupca (4) iste tablice vidi se da su Waugh i njegov tim

Table 4. Dependence on distance l: a) of the angle of refraction ε, b) of the effect of refraction on shifting the view of Mt. Everest h_{ref} and c) angle δ, i.e. errors in the angle of elevation, since the height of Mt. Everest was miscalculated by 8 metres.

Tablica 4. Ovisnosti o udaljenosti l: a) kuta refrakcije ε, b) utjecaja refrakcije na pomicanje vizure na Mt. Everest h_{ref} i c) kuta θ, tj. pogreške u kutu elevacije, ako je visina Mt. Everesta pogrešna za 8 m.

Distance to the Mt. Everest Udaljenost od Mt. Everesta *l* (km) (1)	Angle of refraction Kut refrakcije ε (' ") (2)	Shift due to refraction Pomak izazvan refrakcijom h_{ref} (m) (3)	Error in angle of elevation for 8 m Pogreška u kutu elevacije za 8 m kut *θ* (") (4)
150	5' 16"	229,58	10,97"
170	5' 58"	294,89	9,69"
190	6' 40"	368,36	8,67"
200	7' 01"	408,15	8,24"
220	7' 43"	493,86	7,49"
240	8' 23"	587,73	6,86"

Fig. 26. Radhanath Sikdar was the leader of the group charged with the calculations according to which it was claimed for the first time that Mt. Everest was the highest mountain in the world (URL 31)

Slika 26. Radhanath Sikdar bio je vođa grupe za računanje, koja je prvi put utvrdila da je Mt. Everest najviši vrh na Zemlji (URL 31)

team were only able to measure vertical angles using the trigonometric points in India, and make a rough calculation of the effect of refraction caused by the atmosphere (URL 16). Since the distance was so great, Waugh and his team needed a well-defined radius of the Earth. For less precise calculations, i.e. for practical work in smaller areas, part of the Earth's surface can be taken to be the equivalent of a sphere's surface radius:

$$R = \sqrt{M \cdot N} \qquad (1)$$

in which M is the mean radius of curvature *along the meridian* and N is the mean radius of curvature *along the first vertical* in the centre of the area of geodetic measurement.

Furthermore, for less precise calculations, in a small area, the Earth can be replaced by a sphere whose radius is equal to the arithmetic mean of its three semi-axes. For the Everest ellipsoid we get the result:

$$R = \frac{a + a + b}{3} = 6370{,}2093\text{km} \qquad (2)$$

where a and b are the large and small semi-axes of the rotational ellipsoid of the Earth.

At the great distances from which Waugh and his team attempted to determine the heights of the Himalayan peaks, the true horizon is several kilometres below the apparent horizon (Fig. 23). This can be calculated using the formula given by Macarol (Macarol 1966, pp. 25–26)

$$h_{\text{prividni}} = \frac{R}{\cos\left(\frac{l}{R}\right)} - R \qquad (3)$$

or by using the approximate formula

$$h_{\text{prividni}} \approx \frac{l^2}{2R} \qquad (4)$$

where l is the length of measurement along the arc from point A to point B and R is the Earth's radius (Fig 23). Thus, according to the dimensions of the Everest ellipsoid,

- ❑ distance l = 170 km true horizon below apparent $h_{\ apparent}$ = 2268.37 m and
- ❑ distance l = 220 km true horizon below apparent $h_{\ apparent}$ = 3798.93 m

The other levels of the apparent horizon can be found in column 2 of Table 3.

Column 4 of Table 3 shows that, if the effect of atmospheric refraction is disregarded, Mt. Everest can be viewed from extremely small elevation angles, from 2° 40' to as small as 1° 01', i.e. very close to the horizon. At a distance of 393 km from Mt. Everest, which was the position chosen by William Jones on Chomo Lhari, the elevation angle on Mt. Everest would actually have been beneath the horizon, i.e. a negative angle of – 0° 29'.

Light does not travel through the atmosphere in a straight line, but along a refractory curve which can be approximated to a section of a circle, facing Earth concavely (Fig. 24). In the case of determining differences in height from one side only, this approximate formula may be used (Čubranić 1954, p. 559)

$$H = l \cdot \text{tg}(\varphi') + \left(\frac{1-k}{2}\right) \cdot \frac{l^2}{R},$$

where l is the distance from the set point to the projection of Mt. Everest at sea level measured along the arc, φ' is the elevation angle from which the peak of Mt. Everest is viewed from the set point, shifted by refraction, and k is the coefficient of refraction which, based on experimental estimation is usually taken to be close to 0.13. The above formula disregards the heights of the set points. This is possible because the heights of the set points were around 60 m above sea level (URL 15) and here we are dealing with only rough calculations.

Column 2 in Table 4 shows that the angle of refraction ε, taking the coefficient of refraction k to be 0.13, is between 5' 16'' and 8' 23''. Column 4 also shows that Waugh and his team measured the elevation angles on Mt. Everest with a margin of error of between 7'' and 11'', in spite of the great effect of refraction and other problems. In fact, Waugh and his team calculated the height of Mt. Everest at 8840 m, and later, more precise measurements have shown that it is in fact 8848 m, meaning that the margin of error was only 8 metres (Fig 25). A comparison of the values in columns 2 and 4 of Table 4 show that, in the mid 19th century, they were able to calculate the effect of refraction on measuring angles relatively successfully, even though they were unable to measure the angles from both sides, due to the inaccessibility of the mountain.

In addition, we know today that the divergence of the vertical from the normal in an ellipsoid (Fig. 30) in areas izmjerili elevacijske kutove na Mt. Everest unatoč velikom utjecaju refrakcije i ostalih poteškoća s pogreškom od 7'' do 11''. Naime, izračunali su da je visina Mt. Everesta 8840 m, a kasnija točnija mjerenja pokazala su da je ta visina 8848 m, tj. da je razlika bila samo 8 m (sl. 25). Usporedbom vrijednosti iz stupaca (2) i (4) tablice 4 vidi se da su oni sredinom 19. stoljeća relativno dobro izračunali utjecaj refrakcije na mjerenje vertikalnih kutova iako zbog nepristupačnosti Mt. Everesta nisu mogli mjeriti kutove obostrano.

Danas je poznato da i otkloni vertikala od normale na elipsoid (sl. 30) u područjima s tako velikim masama kao što ih ima Himalaja mogu biti veliki, i da utječu na određivanje visina (Čubranić 1954, str. 569–572). U doba prvog određivanja visine Mt. Everesta geodeti nisu uzimali u račun i taj efekt (URL 16).

Visine su računane u odnosu na nadmorsku visinu Bengalskog zaljeva, udaljenog oko 600 km od trigonometrijskih točaka s kojih je određivana visina Mt. Everesta. Od poznatih trigonometrijskih točaka s kojima se došlo blizu Himalaje moglo se:

- presjekom naprijed odrediti koordinate položaja vrhova Himalaje, tj. horizontalne udaljenosti do planinskih vrhova s pomoću izmjerenih horizontalnih kutova između susjednih poznatih trigonometrijskih točaka i vrhova, a
- mjereći elevacijske kutove na vrhove mogla se zatim odrediti visinska razlika od stajališne točke do planinskog vrha.

Pritom se nije moralo penjati na vrhove, jer se određivala visina snježno-ledene kape na vrhu. Tako je Waugh najprije odredio visinu planinskog vrha *Kangchenjunge* (sl. 3), koji se nalazi na istočnoj granici Nepala i Indije, 35 km južnije od tromeđe Indije, Nepala i Kine (Tibeta). Dobio je da bi ta visina mogla biti 8590 m te da bi to mogao biti i najviši vrh na Zemlji. Kasnijim mjerenjima ta je visina popravljena na 8586 m. Danas se zna da je to treći po visini vrh na Zemlji. Waugh nije objavio rezultate svojih istraživanja, jer je ispravno pretpostavio da bi vrhunci na granici Nepala i Tibeta mogli biti još viši. Neizmjereni vrh nazvao je *vrh gamma*. Osim toga on je sigurno, kao geodet, bio svjestan da je točnost takvog određivanja visina s vrlo velikih (golemih) udaljenosti ograničena, ali nažalost zbog zabrane da stranci ulaze u Nepal nije mogao prići bliže tim planinskim vrhuncima.

Godine 1847. i 1849. izvedena su nova trigonometrijska mjerenja na vrh koji se tada zvano *vrh b* te se ubrzo došlo do zaključka da je riječ o istom vrhu što ga je zabilježio i Waugh. Mjerenja su pokazala da je taj vrh viši od Kangchenjunge. Waugh je tada preimenovao sve vrhove te još jednom uz pomoć voditelja tima za računanja *Radhanatha Sikdara* provjerio sva računanja i došao do zaključka da je *vrh 15* (kako je tada nazivao nekadašnji *vrh gama*) najviši vrh na Zemlji. On je 1852. godine na osnovi trigonometrijskih mjerenja prvi ustvrdio da je *vrh 15* najviši vrh na svijetu, a 1856. objavio je rezultate svoje ekipe. Taj je vrh poslije nazvan Mount Everest i prema Waughu visok je *8840* m. Ta visina određena je kao sredina iz rezultata određivanja sa šest različitih trigonometrijskih točaka udaljenih 170 do 190 km, kojih je nadmorska visina bila oko 60 m iznad mora (URL 15).

Fig. 27. Prism tripod for measuring distance using an electro-optical distance meter and the antenna of the GPS transmitter Leica System 200, on the summit of Mt. Everest (Photo: EV-K2-CNR Poretti/Leica Geosystems)

Slika 27. Nosač prizmi za mjerenje udaljenosti s pomoću elektrooptičkih daljinomjera i antena GPS-prijamnika Leica GPS 200 system na vrhu Mt. Everest (Foto: EV-K2-CNR Poretti/Leica Geosystems)

5.2 Određivanje visine Mt. Everesta u 1954. godini

Nova mjerenja obavljena su 1954. godine od trigonometrijskih točaka postavljenih znatno bliže Mt. Everestu, također uz pomoć teodolita, trigonometrijskim mjerenjem visina. Zbog toga je, vjerojatno, rezultat točniji od prethodnih. Dobivena je visina *8848* m, a ta je vrijednost izračunana kao aritmetička sredina rezultata dobivenih iz mjerenja na 12 trigonometrijskih točaka udaljenih od 47 do 76 km od Mt. Everesta (URL 15).

Može se reći da je ta visina u literaturi u posljednjih 50 godina bila najčešće prihvaćena. Treba naglasiti da je određivana visina snježno-ledene kape Mt. Everesta jer se nitko nije bio u stanju popeti na vrh i postaviti of such huge mass as the Himalayas must be great, and thus affect height estimation (Čubranić 1954, pp. 569–572). In the early days of estimating the height of Mt. Everest, the surveyors did not take this effect into account (URL 16).

The heights were calculated in relation to the sea level in the Bay of Bengal, 600 km from the trigonometric points used to determine the height of Mt. Everest. Using the known trigonometric points by which the surveying project had reached the region close to the Himalayas, it was possible to:

- establish in advance the coordinates for the positions of the Himalayan peaks, by cross-section, i.e. the horizontal distance to the peaks, by means of measuring the horizontal angles between neighbouring known trigonometric points and the peaks
- establish the difference in height between the set point and a particular peak by measuring the elevation angles at the peaks.

It was not necessary to climb the peaks, since the height of the snow and ice-cap on the peaks had also been determined. Thus, Waugh first determined the height of Kangchenjunga peak (Fig. 3), which is situated on the eastern border of Nepal and India, 35 km south of the border conjunction of India, Nepal and China (Tibet). He estimated its height at 8590 m and suspected it might be the highest peak in the world. Later measurements corrected his result to 8586 m. Today, we know that this peak is the third highest in the world. Waugh did not publish the results of his research, since he presumed, correctly, that the peaks on the border of Nepal and Tibet might be even higher. He called his unmeasured peak Peak Gamma. He also knew, as a surveyor, that the accuracy of any long-distance measurements would be limited, yet he was unfortunately unable to get closer to the mountain peaks, since foreigners were forbidden to enter Nepal.

In 1847 and 1849, new trigonometric measurements were conducted on the peak known as Peak b, and the conclusion was quickly drawn that this was the same peak referred to by Waugh. Measurements showed that it was higher than Kangchenjunga. Waugh then renamed all the peaks, and once again, with the help of the leader of his team of calculators, Radhanath Sikdar, rechecked all the calculations and came to the conclusion that Peak 15 (formerly known as Peak Gamma), was the highest peak in the world. In 1852, he became the first person to establish that Peak 15 was the highest peak in the world, based on trigonometric measurements. Waugh finally published the results of his team's work in 1856, declaring Peak 15 to be the highest in the world. It was this peak which was later renamed Mount Everest, and which Waugh estimated to be *8840* m high. His result was based on the mean derived from the results of measurements taken from six different trigonometric points, at about 60 m above sea level, and at distances of between 170 and 190 km from the mountain.

5.2. Determining the height of Mt. Everest in 1954

Mt. Everest was again subjected to measurement in 1954, from trigonometric points set significantly closer to the mountain, again using theodolites. For this reason, the results were bound to be more accurate. It was established that Mt. Everest was *8848* m high. This value was calculated as the arithmetic mean of results acquired from measurements taken at 12 trigonometric points, at distances of between 46 and 76 km from the mountain (URL 15).

During the past half century, this figure has been most frequently accepted in the literature. However, it should be emphasised that the height included the snow and ice cap on the summit, as so far no-one had been able to reach the summit and set a geodetic marker, let alone carry out measurements there. Before 1954, only two people had ever reached the summit, Sir Edmund Hillary and Sherpa Tenzing Norgay, using oxygen bottles. It was only in 1956 that the next successful ascent was made, by four Swiss, Jürg Marmet, Ernst Schmied, Adolf Reist and Hansrudolf von Gunten.

5.3. Determining the height of the Himalayas from the Chinese side in 1975

The Chinese measured the height of Mt. Everest in 1975 and concluded that it was 8848.13 m. In this case also, the height including the snow and ice cap was measured, rather than the top of the actual rock top (URL 12). On this occasion, the Chinese placed a geodetic structure for a marker on the summit and left a theodolite there. In order to establish the height of the rock top of Mt. Everest, they would have needed to penetrate the thick layer of snow and ice, which was probably too difficult a task in unfavourable weather conditions.

5.4. First GPS measurements in 1991

Dr. Roger Bilham, of the University of Colorado, along with the Nepali Department of Geodetics, made the first GPS measurements in India and the Himalayas. Based on these measurements, they concluded that the Indian Plate was moving in a northeasterly direction towards China (Tibet) at the rate of 5.5 cm per year (URL 17). The movement of the Indian Plate led to collision with the Eurasian Continent, which in turn led to the deformation of the Earth's interior in the region of Asia and India, which is the probably cause of earthquakes in that region.

5.5. International Mount Everest Measurement Campaign in 1992

International cooperation between China, Italy, Nepal and France led to the opportunity of measuring the height of Mt. Everest more accurately, using state-of-the-art technology for geodetic measurement, and relying on the support of the Swiss company, Leica, in terms of providing geodetsku oznaku, a kamoli izvesti ondje neko mjerenje. Naime, prije toga na vrh su se popeli samo Edmund Hillary i Šerpa Tensing Norgay, uz korištenje boca s kisikom. Tek 1956. godine na vrh su se popela još četvorica Švicaraca: Jürg Marmet, Ernst Schmied, Adolf Reist i Hansrudolf von Gunten.

5.3 Određivanje visine Himalaje s kineske strane u 1975. godini

Kinezi su određivali visinu Mt. Everesta 1975. godine i dobili da ona iznosi *8848,13* m. I u tom slučaju vjerojatno je određivana visina vrha snježno-ledene kape, a ne vrha glave stijene (URL 12). Naime, Kinezi su tada postavili na vrh Mt. Everesta geodetski stativ za značku i za teodolit, koji je ondje ostavljen. Da bi odredili i visinu vrha stijene Mt. Everesta, trebali su probiti debeli sloj leda i snijega, što im je sigurno bio pretežak zadatak u tako nepovoljnim klimatskim uvjetima.

5.4 Prva GPS-mjerenja u 1991. godini

Dr. Roger Bilham sa Sveučilišta u Koloradu zajedno s Odjelom za geodeziju iz Nepala izveo je prva GPS-mjerenja u Indiji i na Himalajima. Na temelju tih mjerenja zaključili su da se Indijska ploča pomiče u smjeru sjeveroistoka prema Kini (Tibetu) 5,5 cm godišnje (URL 17). To pomicanje Indijske ploče izaziva sudaranje s Euroazijskim kontinentom što dovodi do deformacija i u Zemljinoj unutrašnjosti na području Azije i Indije, pa su to mogući uzroci potresa.

5.5 Međunarodna kampanja Mt. Everest u 1992. godini

U okviru međunarodne suradnje Kine, Italije, Nepala i Francuske nastojala se što točnije odrediti visina Mt. Everesta primjenom najsuvremenijih tehnologija geodetskih mjerenja uz veliku instrumentalnu podršku švicarske tvrtke Leica. U 1992. godini bila su organizirana simultana geodetska mjerenja s tibetanske i nepalske strane uz sudjelovanje znanstvenika, istraživača i alpinista iz zemalja sudionica. U okviru te međunarodne suradnje izvedena su mjerenja uz pomoć:

- ❑ umjetnih Zemljinih satelita: američkih satelita GPS (Global Position System) i francuskog DORISA-a (Doppler Orbitography and Radiopositioning Integrated by Satellite)
- ❑ elektroničkih daljinomjera i teodolita
- ❑ astronomskih mjerenja.

a) GPS-mjerenja

Dana 28. rujna 1992. blizu vrha Mt. Everesta postavljeni su GPS-antena i GPS-prijamnik Leica GPS 200 system. Preko noći temperatura je bila –30°C. Sutradan 29. rujna druga dvojica alpinista popela su se na vrh, kad je u 10:30 sati bila temperatura –15°C. Oni su aktivirali GPS-prijamnik tako da može registrirati primljene signale s GPS-satelita svake dvije sekunde, a signali su primani 54 minute. Ostala četiri GPS-prijamnika (Leica 200 system) istodobno su primala signale s GPS-satelita:

- ❑ 2 u dolini Khumbu glečera u Nepalu, koji su registrirali primljene signale s GPS-satelita svakih 15 sekundi i
- ❑ 2 na kraju ledenjaka Rongbuk u Tibetu, koji su registrirali podatke svake 2 sekunde.

Očito je da nije bio dobar dogovor između grupa u Tibetu i Nepalu, jer su uzeli različite intervale registriranja primljenih signala s GPS-satelita. To znači da su u zajedničkoj obradi podataka mjerenja mogli koristiti samo interval od tek 30 sekundi, tj. to je najmanji zajednički višekratnik brojeva 2 i 15.

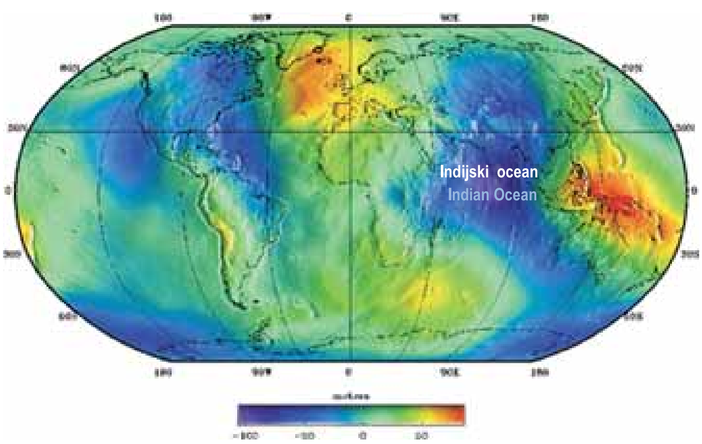
Sigurno je bilo zanimljivo odrediti nadmorsku visinu Mt. Everesta i s pomoću umjetnih Zemljinih satelita, tj. GPS-a. Međutim, budući da se s pomoću GPS-a određuju samo elipsoidne visine, taj zadatak s pomoću najsuvremenije tehnologije geodetskih mjerenja vrlo je složen. Naime, osim elipsoidne visine određene GPS-mjerenjem treba odrediti i geoidnu undulaciju Mt. Everesta, tj. visinu geoida iznad, odnosno ispod referentnog elipsoida, a u tom su području njihove razlike vrlo velike, pa je točnost geoidnih visina manja. Geoidne visine (sl. 28) moguće je odrediti iz poremećaja gibanja umjetnih Zemljinih satelita, ali i opsežnih gravimetrijskih mjerenja na površini Zemlje.

Nadalje, poznato je da je točnost određivanja visina dobivenih GPS-mjerenjem tri puta slabija od horizontalnog određivanja položaja. Osim toga i velika razlika u visinama određivanih točaka utječe na točnost GPS-određivanja. Treba napomenuti da i softver za izjednačenje GPS-mjerenja u 1992. godini nije bio dovoljno kvalitetan.

b) Mjerenje udaljenosti elektroničkim daljinomjerima i kutova teodolitima

Za određivanje visine Mt. Everesta s pomoću elektrooptičkih daljinomjera i teodolita postavljene su tri točke u Tibetu i tri točke u Nepalu. Za svaku skupinu tih točaka izmjereni su svi mogući kutovi i udaljenosti, koji su tako tvorili dvije nezavisne trigonometrijske mreže s Mt. Everestom, kao jednom zajedničkom točkom. Ona je bila udaljena 10–12 km. Na Mt. Everestu nisu izvođena mjerenja, već su na njemu alpinisti, koji su uključili u rad GPS-prijamnik, postavili držač prizmi s GPS-antenom u blizini GPS-prijamnika i orijentirali jedan skup prizmi prema točkama u Nepalu, a drugi skup prema točkama u Tibetu (sl. 27). Svaki skup prizmi sastojao se od tri prizme. Na taj su način elektronički daljinomjeri mogli primati kvalitetno reflektirane svjetlosne impulse s prizmi. Na vrhu Mt. Everesta ostali su dva sata. Za mjerenje su upotrijebljeni Leicini elektronički daljinomjeri i teodoliti:

ME5000, tada najprecizniji daljinomjer na tržištu (0,2 mm + 0,2 ppm), *Leica T3000* i *DI3000* i teodolit *T2*.



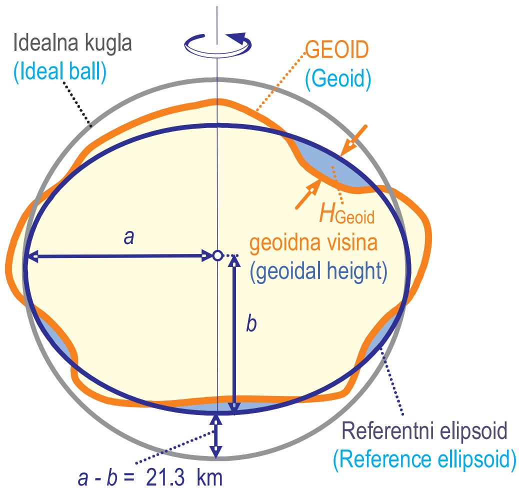


Fig. 29. The ellipsoid height is the height of the point on the terrain above the reference ellipsoid which theoretically most closely touches the entire Earth, and the deviation of the vertical is the angle between the normal on the reference ellipsoid and the direction of the plumb-line.

Slika 28. Geoid EGM 96 jedan je od modela Zemlje, koji odstupa od referentnog elipsoida s najvećom visinom +85,4 m i najvećom dubinom –107,0 m u Indijskom oceanu. Ispod Mt. Everesta geoidna undulacija je negativna i iznosi oko –25 m (URL 33).

instruments. In 1992, simultaneous geodetic surveys were organised from the Tibetan and Nepali sides, involving scientists, researchers and climbers from the participating countries. Within the framework of this international cooperation, measurements were taken with the assistance of:

- artificial satellites: American GPS satellites and the French DORIS satellite (Doppler Orbitography and Radiopositioning Integrated by Satellite)
- electronic distance meters and theodolites
- astronomic measurement

a) GPS measurement

On 28 September 1992, a GPS antenna and GPS Leica System 200 receiver were installed close to the summit of Mt. Everest. Overnight, the temperature reached –30° C. The next day, 29 September, two climbers scaled the summit, where the temperature at 10:30 was –15° C. They activated the GPS receiver so that it registered signals received from the GPS satellite every two seconds, for a period of 54 minutes. Four other GPS receivers (Leica System 200) also received simultaneous signals from the GPS satellite:

- two in the valley of the Khumbu Glacier in Nepal, which registered signals received from the GPS satellite every 15 seconds, and
- two at the end of the Rongbuk glacier in Tibet, which registered data every two seconds.

It seems that the groups in Tibet and Nepal failed to reach complete agreement, since they adopted different intervals for registering signals received from the GPS satellite. This meant that their joint results were only valid for periods of 30 seconds, i.e. the lowest common multiplier of 2 and 15 seconds.

It must have been fascinating to establish the height of Mt. Everest above sea level using artificial satellites, i.e. GPS. However, since GPS can only be used to determine ellipsoid heights, even with the help of the most up-to-date technology for geodetic measurement, the task was extremely complex. Apart from the ellipsoid height determined by GPS measurement, it was necessary to determine the geoidal undulation of Mt. Everest, i.e. the heights of the geoid above or below the reference ellipsoid. In this particular region, the differentials are high, therefore the accuracy of the geoidal heights is compromised. The geoidal heights (Fig. 28) can be calculated from disturbances in the movements of artificial satellites, but also from comprehensive gravimetrical measurements at the Earth's surface.

Furthermore, it is known that the accuracy of determining height through GPS measurement is three times less reliable than horizontal estimation of position. The considerable difference in the heights of specific points affects the accuracy of GPS estimation. It should be mentioned that, in 1992, the software for equalising GPS measurement was not of a high enough quality.

b) Electronic distance measurement and mea surement of angles by theodolites

In order to determine the height of Mt. Everest using electronic distance measurement and theodolites, three

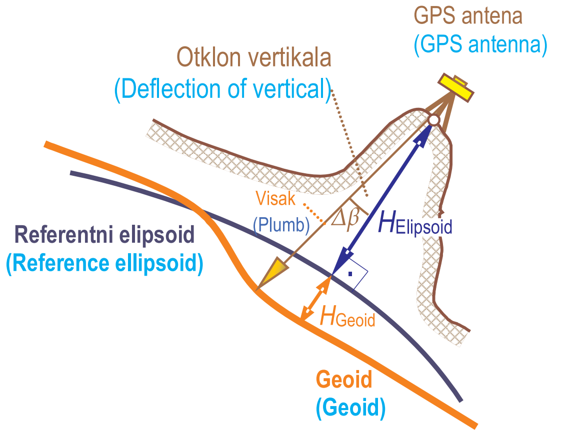


Fig. 29. The ellipsoid height is the height of the point on the terrain above the reference ellipsoid which theoretically most closely touches the entire Earth, and the deviation of the vertical is the angle between the normal on the reference ellipsoid and the direction of the plumb-line

Slika 29. Elipsoidna visina je visina točke terena iznad referentnog elipsoida koji se teorijski najbolje priljubljuje uz čitavu Zemlju, a otklon vertikale je kut između normale na referentni elipsoid i smjera viska

Na nepalskoj geodetskoj mreži na točkama osnovnog trokuta (K, N i L) mjerili su Talijani, a na tibetanskoj na osnovnim točkama (R, III7 i W1) Kinezi (sl. 30).

c) Mjerenje meteoroloških podataka

Za što točnije određivanje utjecaja atmosfere na mjerenje kutova, udaljenosti, ali i za GPS-mjerenja bio je izrađen poseban senzor koji je mjerio temperaturu i tlak zraka na vrhu Mt. Everesta i slao te informacije radioputem prijamniku u dolinu svakih 15 sekundi. Osim toga, za vrijeme mjerenja prema vrhu bio je određivan i vertikalni temperaturni gradijent s pomoću meteoroloških sondažnih balona puštanih iz dvaju mjesta. Na mjestima opažanja zapisivane su izmjerene vrijednosti temperature, vlažnosti i tlaka zraka svakih 15 sekundi.

d) Astronomska mjerenja

Na četirima točkama između Lukla i Kampa baze Everest određene su astronomske koordinate (astronomska širina i dužina) s pomoću teodolita T1600 tvrtke Leica povezanog s jedinicom za točno mjerenje vremena. Kako su izmjerene i geodetske koordinate φ i λ na referentnom elipsoidu WGS '84 s pomoću GPS-prijamnika, bilo je moguće odrediti otklone vertikala od normale na elipsoid WGS '84.

e) Dubina snijega

Dvojica alpinista popela su se na vrh Mt. Everest dan nakon GPS-mjerenja, tj. 30. rujna, kako bi odredili dubinu snijega. Bušenjem snježne kape na nekoliko mjesta u blizini stativa izmjerili su da je dubina snijega 2,55 m.

f) Fotogrametrija

Za usporedbu dobivenih rezultata GPS-mjerenjima i mjerenjima elektrooptičkim daljinomjerima i teodolitima bilo je važno odrediti relativni položaj između GPS-antene i prizmi s centimetarskom točnosti. Njihov međusobni položaj određen je mjernom vrpcom i kompasom, a osim toga snimljen je stereopar za fotogrametrijsku izmjeru.

g) Prethodna mjerenja

Prije kampanje Everest Kinezi su prenijeli nadmorsku visinu od Žutoga mora udaljenog oko 3500 km od Mt. Everesta sa svojom nivelmanskom mrežom do točke R i III7 i odredili geoidne visine (undulacije) izračunane iz gravimetrijskih mjerenja izvedenih sve do visine 7900 m u 1979. godini.

h) Obrada rezultata mjerenja

Svi podaci mjerenja bili su odvojeno obrađeni u Kini i u Italiji, a rezultati određivanja visine Mt. Everesta iz GPS i terestričkih podataka skupljenih mjerenja tijekom kampanje Mt. Everest u 1992. godini objavljeni su 1993. godine (Leica 1993, URL 16):

- elipsoidna visina:8823,51 m (na razini snijega)
- geoidna undulacija: 25,14 m (ispod razine referentnog elipsoida)
- nadmorska visina Mt. Everesta: 8848,65 m (visina snijega)
- dubina snijega: –2,55 m
- nadmorska visina Mt. Everesta: 8846,10 m ± 0,35 m (visina stijene).

5.6 Američka ekspedicija *Tim Everest-Millenium* 1999. godine

Američka ekspedicija *Tim Everest-Millenium*, koju je vodio Bradford Washburn, postavila je jedan GPS-prijamnik Trimble 4000SSi na najvišoj točki stijene na vrhu Mt. Everesta (URL 17) 5. svibnja 1999. Pritom je druga GPS-mjerna točka postavljena na južnom sedlu Mt. Everesta na visini 7930 m. Na tim dvjema točkama GPS-prijamnici radili su simultano, a pokretni GPS-prijamnik nosili su članovi ekspedicije uzduž južnog uspona (sl. 31).

Snježna masa koja pokriva vrh Mt. Everesta bila je isključena iz računanja, jer visina snijega varira u skladu s intenzitetom monsuna. Osim toga, vrh stijene i vrh snijega nisu identične točke (sl. 32). Naime, na vrhu pušu snažni vjetrovi koji zanose snijeg u zavjetrinu. Da bi se odredio položaj vrha stijene donesen je na vrh Mt. Everesta ehosonder.

Fig. 30. Geodetic survey during the 1992Mt. Everest measuring campaign, using Leica instruments (Photo: EV-K2-CNR Poretti/Leica Geosystems)

Slika 30. Geodetska mjerenja za vrijeme kampanje Mt. Everest 1992. godine instrumentima tvrtke Leica (Foto: EV-K2-CNR Poretti/Leica Geosystems)

points were set up in Tibet and three in Nepal. Within each group of points, all the possible angles and distances were measured, thus forming two independent trigonometric networks with one common target – the peak of Mt. Everest. The mountain was 10–12 km away from the points. No measurements were taken on Mt. Everest itself, but climbers were positioned on the summit, and they activated the GPS receiver, set up the prism tripod with the GPS antenna near the GPS receiver and oriented one group of prisms towards the points in Nepal, and the other groups towards the points in Tibet (Fig. 27). Each group consisted of three prisms. In this way, electronic distance meters were able to receive high quality reflected light impulses through the prisms. They remained at the summit of Mt. Everest for two hours. Measurements were taken using Leica electronic distance meters and theodolites:

ME5000, then the most precise distance meter on the market (0.2mm + 0.2ppm), Leica T3000 and DI3000 and theodolite T2.

The Italians surveyed from the Nepali geodetic network at the points of the base triangle (KNL), while on the Tibetan side, the Chinese surveyed from the base points (R, III7 and WI) (Fig. 30).

c) Measuring meteorological data

In order to determine as accurately as possible the effect of the atmosphere on the measurement of angles and distance, even using GPS, a special sensor was built to measure the temperature and air pressure at the summit of Mt. Everest. This information was sent via radio to a receiver in the valley every 15 seconds. In addition, while measurement was being conducted towards the summit, the vertical temperature gradient was provided by sounding balloons launched from two positions. Temperature, humidity and pressure were recorded every 15 seconds.

d) Astronomical measurement

Astronomical coordinates (astronomical latitude and longitude) were determined for four points between Lukla and Everest Base Camp, using a Leica T1600 theodolite connected to a time digitizing unit. Since the geodetic coordinates φ and λ had been measured on the reference ellipsoid WGS'84 using a GPS receiver, it was possible to determine the deviation of the vertical from the normal on ellipsoid WGS'84.

e) Depth of snow

Two climbers reached the summit of Mt. Everest the day after the GPS measurements had been conducted, i.e. on 30 September, with the task of determining the depth of the snow. They pierced the snow cap in several places near the tripod and measured the snow depth as 2.55 metres.

f) Photogrammetry

In order to compare the results obtained using GPS measurement and measurement using electro-optic distance meters and theodolites, it was important to determine the relative positions between the prisms and the GPS antenna to within one centimetre. This was done using a tape measure and compass, while photogrammetry was applied by reconstructing the summit of the mountain in 3D from stereo photography.

g) Previous measurements

Before this campaign, in 1979 the Chinese had brought a levelling network from the Yellow Sea to points R and III7 and established the geoidal level (undulation), calculated with gravimetric observations performed up to 7900 metres.

h) Processing the results of measurement

All the surveying data was processed separately in China and Italy, and the results of determining the height of Mt. Everest obtained from GPS and terrestrial data collected during the Mt. Everest Measurement Campaign of 1992 were published in 1993 (Leica 1993, URL 16).

- ❑ Ellipsoid height: 8823.51 m (at snow level)

Dobivena visina Mt. Everesta bila je *8850* m, a snježno-ledena glava bila je za 1 m viša od vrha stijene (URL 15).

Iz dokumenata se ništa ne može saznati o određivanju geoidne visine, ni o tome na koju razinu mora se odnosi ta visina Mt. Everesta, na Bengalski zaljev ili na Žuto more. Naime, kad se određuju visine s pomoću GPS-mjerenja određuju se elipsoidne visine, te se zbog toga moraju na neki način odrediti i geoidne visine za istu tu točku. To je razlog zbog kojega geodeti ne mogu prihvatiti te novoodređene visine vrha Mt. Everesta unatoč tome što je *The National Geographic Society* prihvatilo tu visinu od *8850* m (29,035 feet) kao novu službeno priznatu visinu. Takvu odluku trebalo bi preispitati i s tim u skladu postaviti nove zadatke za određivanje visine Mt. Everesta.

Fig. 31. Approach to Mt. Everest at the time of the 1999 Everest Millennium Team Expedition (URL 21)

Slika 31. Pristup Mt. Everestu za vrijeme ekspedicije Tim Everest-Millenium 1999. godine (URL 21)

5.7 Kineska ekspedicija u 2005. godini

Kineska ekspedicija uspela se na vrh Mt. Everesta 22. svibnja 2005. Nakon nekoliko mjeseci mjerenja i kompliciranog računanja, 9. listopada 2005. Kineski državni ured za geodeziju i kartografiju objavio je da je *visina stijene Mt. Everesta 8844,43 ± 0,21* m (URL 12).

To je visina najviše točke stijene. Ako se uzme u obzir da je pritom izmjerena visina snijega i leda 3,5 m, dobije se da je *visina snijega Mt. Everesta 8847,93* m.

Dakle, to je u skladu s rezultatom 8848 m iz 1954. godine, kada je mjerena nadmorska visina vrha snijega.

U budućnosti će se nastojati što točnije odrediti visina vrha Mt. Everesta, jer je to važno i zbog znanstvenog određivanja godišnjega pomicanja Zemljinih ploča u horizontalnom i vertikalnom smislu. To je razumljivo, jer je Mt. Everest najviša točka na Zemlji iznad razine mora i oceana, pa neki tu točku nazivaju trećim Zemljinim polom.

Nepal i Kina dogovorili su se 2010. godine da se *visina Mt. Everesta 8848* m prihvati kao službena visina za najviši vrh na Zemlji.

6. Permanentna stanica GPS-a u podnožju Mt. Everesta

U Nepalu je na boku velikoga glečera Khumbu i s dobrim pogledom na vrhove Mt. Everest, Lhotse i Nuptse smješteno talijansko istraživačko središte u staklenoj piramidi, izgrađenoj 1991. godine. U njoj se nalaze laboratoriji za medicinska istraživanja i istraživanja okoliša (sl. 33), a u njezinoj neposrednoj blizini postavljena je permanentna stanica GPS-a u kojoj je 2003. godine smješten *Leica GPS System 530* (sl. 34). On prima radiosignale s GPS-satelita preko hemisferne antene, i to neprekidno svaki dan od 0 do 24 sata tijekom čitave godine, te ih obrađuje i odašilje točan položaj istraživačima, alpinistima i timovima hitne pomoći u regiji svakih 30 sekundi. Osim toga podaci se izravno odašilju u računalo, koje je smješteno u piramidi, i zatim u Italiju u svrhu praćenja tektonskih promjena na području u blizini Mt. Everesta. Pritom solarne ploče opskrbljuju GPS-stanicu i radioodašiljač električnom energijom tijekom cijele godine (URL 34).

Taj referentni signal koji odašilje permanentna stanica GPS-a omogućava korisnicima odgovarajućih GPS-prijamnika određivanje položaja sa standardnim odstupanjem od samo jedan centimetar. Na taj je način omogućeno istraživačima kretanja ledenjaka, ali i alpinistima i timovima hitne pomoći da odrede svoje položaje s

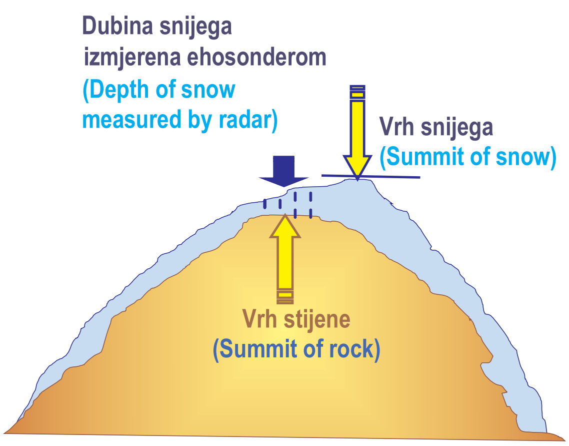


Fig. 32. Discrepancy between the peak of the rock top and the peak of the snowcap

Slika 32. Nepodudaranje vrha stijene i vrha snijega

- ❑ Geoidal undulation: 25.14 m (below the level of the reference ellipsoid)
- ❑ Height of Mt. Everest above sea level: *8848.65* m (including snow and ice cap)
- ❑ Depth of snow: –2.55m
- ❑ Height of Mt. Everest above sea level: *8846.10 ± 0.35* m (height of rock top)

5.6 1999 American Everest Millennium Team Expedition

The American Everest Millennium Team Expedition, led by Bradford Washburn, set up a GPS Trimble 4000SSi receiver at the highest point of the rock top on the summit of Mt. Everest (URL 17) on 5 May 1999. At the same time, a second GPS point was set up on the south saddle of Mt. Everest at a height of 7930 m. The GPS receivers at the two point functioned simultaneously, while a mobile GPS receiver was carried by the members of the expedition up the south ascent (Fig. 31).

The snow mass capping Mt. Everest was excluded from the calculations, since the depth of the snow varied according to the intensity of the monsoon. In addition, the summit of the rock top and the summit of the snowcap are not identical points (Fig. 32). At the summit, fierce winds blow snow into the lee of the mountain. In order to ascertain the position of the rock top, an echo sounder was taken to the summit of the mountain.

The height of Mt. Everest on this occasion was determined as *8850* m, with the snow and ice cap one metre higher than the rock top (URL 15).

From the documentation, nothing can be concluded about the geoidal height, nor the sea level used as a reference point for this height (i.e. the Bay of Bengal, or the Yellow Sea). This is because when GPS measurements are taken, the ellipsoid height is used to ascertain height, so the geoidal height for the same point must be in some way determined. This is the reason why geodetists have not accepted this new figure as the official height of Mt. Everest, even though The National Geographic Society accepted it (*8850* m or 29,035 ft) as the new, accepted, official height. This decision should perhaps be reviewed and a new project to determine the height of Mt. Everest carried out.

5.7. Chinese expedition in 2005

The Chinese expedition scaled the summit of Mt. Everest on 22 May 2005. After several months of taking measurements and making complex calculations, on 9 October 2005 the Chinese State Office of Geodesy and Cartography announced that *the height of the rock top of Mt. Everest was 8844.43 ± 0.21* m (URL 12).

This is the peak of the rock top. If we take into account the fact that during surveying, the depth of the snow and ice was 3.5 m, *the total height of Mt. Everest, including the snow peak, is 8847.93* m.

This is in agreement with the 1954 result, when the height of the peak of the snowcap was measured as 8848 m above sea level.

In the future, more attempts will probably be made to determine more precisely the height of the peak of Mt. Everest, since this is a matter of interest in terms of the scientific determination of the annual movement of the Earth's plates, both horizontally and vertically. It is understandable, since Mt. Everest is the highest point on Earth above sea level, and is even called by some the Earth's third pole.

In 2010, Nepal and China agreed to accept the height of Mt. Everest, officially the highest peak in the world, as *8848* m.

6. Permanent GPS station at the foot of Mt. Everest

On the flank of the huge Khumbu glacier in Nepal, from where there is a good view of the peaks of Mt. Everest, Lhotsa and Nuptsa, an Italian research centre has been set up in a glass pyramid. It was constructed in 1991, and contains a laboratory for medical and environmental research (Fig. 33). Close to the pyramid, a permanent GPS station has been set up, in which a Leica GPS System 530 was installed in 2003 (Fig. 34). It receives radio signals continuously from GPS satellites via a hemispherical antenna, 24 hours a day, 365 days a year, and processes them and sends the exact location to researchers, climbers and rescue teams in the area, every 30 seconds. In addition, the data is sent directly to a computer located in the pyramid, and then to Italy, with the aim of monitoring tectonic changes in the Everest region. At the same time, solar panels supply the GPS station and radio transmitter with electricity throughout the year (URL 34).

This reference signal sent by the permanent GPS station allows users of appropriate GPS receivers to determine their position, with a standard divergence of only one centimetre. In this way, scientists researching the movement of the glaciers, climbers and rescue teams can determine their positions with great accuracy, which can be extremely important in certain cases.

The difference in the coordinates for the position at point G at the foot of Mt. Everest, during a period of 11.67 years, from September 1992 to May 2004, are:

$d\varphi = 0.0081''$, $d\lambda = 0.0148''$ and $dH = 0.0085$ mm

indicating a shift of 4.15 cm per year (URL 36).

Fig. 33. Position of the permanent GPS station in relation to the glass pyramid (Photo: EV-K2-CNR Poretti/Leica Geosystems)

Slika 33. Smještaj permanentne stanice GPS-a u odnosu na staklenu piramidu (Foto: EV-K2-CNR Poretti/Leica Geosystems)

vrlo velikom točnosti, što je osobito važno u nekim posebnim slučajevima.

Razlike koordinata položaja za točku G u podnožju Mt. Everesta, u vremenskom intervalu od 11,67 godina, između rujna 1992. godine i svibnja 2004. iznose:

dφ = 0,0081", dλ = 0,0148'' i dH = 0,0085 mm,

što daje pomake od 4,15 cm/god. (URL 36).

Istraživanja na samome vrhu s pomoću ehosondera pokazala su da je vrh prilično ravan, te je teško utvrditi koja je točka najviša. Naime, to bi mogla biti bilo koja točka na grebenu od oko deset metara dužine.

Čitavo istraživanje izvedeno je u sklopu projekta EV-K2-CNR, što ga je odobrila i financirala Europska zajednica, a danas ga vodi prof. Giorgio Poretti iz Trsta. Projekt se izvodi u suradnji s Nepalskom akademijom znanosti i tehnologije, i uz veliku potporu – sponzorstvo tvrtke Leica Geosystems Ltd. Istovjetna istraživanja izvode se i u blizini drugoga najvišeg vrha na svijetu, vrha K2, što se može zaključiti i iz imena projekta.

7. Stanica DORIS

DORIS je skraćenica za francuski satelitski sustav Doppler Orbitography and Radiopositioning Integrated by Satellite, koji se upotrebljava za određivanje satelitskih orbita, npr. satelita TOPEX/Poseidon, kao i za određivanje položaja točaka na Zemlji. On koristi Dopplerov efekt, tj. registrira se pomak frekvencije do kojeg dolazi zbog približavanja i udaljavanja umjetnoga Zemljina satelita. Riječ je o poznatom efektu:

kada se vlak približava nepomičnom opažaču, visina tona zvučnog signala lokomotive sve je viša, dok je pri udaljavanju vlaka visina tona istog zvučnog signala sve niža od frekvencije stvarno odaslanog zvučnog signala piska lokomotive.

Dopplerov efekt upotrijebljen je već kod prvoga satelitskog navigacijskog sustava često nazivanog i TRANSIT, što je detaljno opisano u (Solarić 2008). Glavna razlika između DORIS-a i TRANSIT-a je u tome što se kod DORIS-a pomak frekvencije mjeri na satelitu, a kod TRANSIT-a na točki kojoj se koordinate određuju.

Tako nazvani DORIS-odašiljači (engl. *beacon*) postavljeni su u točkama na Zemljinoj površini i emitiraju radiosignale vrlo stabilne frekvencije. Te radiosignale primaju sateliti s promijenjenom frekvencijom zbog utjecaja Dopplerova efekta izazvanoga kretanjem satelita. Iz tih satelitskih opažanja mogu se odrediti parametri satelitskih orbita, položaji točaka na Zemlji te neki drugi parametri. Glavni odašiljač-prijamnik, koji osigurava komunikaciju sa satelitima, smješten je u Francuskoj u Toulouseu.

Za realizaciju toga satelitskog sustava postavljena je *mreža DORIS-a* (sl. 35) koja se sastoji od oko 60

Fig. 34. Permanent GPS station located on the flank of the huge Khumbu glacier at the foot of Mt. Everest, which receives signals sent by GPS satellite, via a GPS hemispherical antenna (Photo: EV-K2-CNR Poretti/Leica Geosystems)

Slika 34. Permanentna stanica GPS-a smještena na boku velikoga glečera Khumbu u podnožju Mt. Everesta prima signale odaslane s GPS-satelita s pomoću hemisferne antene GPS-a (Foto: EV-K2-CNR Poretti/Leica Geosystems)

Research at the summit using an echo sounder has shown that the summit is fairly flat, thus it is difficult to ascertain the highest point. It could be anywhere on the rock top, which is about 10 metres long.

This entire research was carried out as part of the EV-K2-CNR project, which was approved and financed by the European Community, and is being led at the present time by Prof. Giorgio Poretti of the University of Trieste. The project is being implemented in cooperation with the Nepali Academy of Science and Technology, with the substantial support and sponsorship of Leica Geosystems Ltd. Similar research is being carried out close to the second highest peak in the world, K2, as can be deduced from the project title.

7. DORIS Station

DORIS stands for Doppler Orbitography and Radiopositioning Integrated by Satellite, and is a French system used to determine satellite orbits, for example the TOPEX/Poseidon satellite, and to determine the position of point on Earth. It uses the Doppler effect, i.e. registers shifts in frequency caused by the movement towards and away from it of artificial satellites. This is a well-known effect:

as a train approaches a stationary observer, the level of the signal tone rises, whereas as the train moves further away from the observer, the level of the signal tone decreases in relation to the actual level of the sound emitted by the train's whistle.

The Doppler effect was used in the very first satellite navigation system, known as TRANSIT, and this is described in more detail in Solarić (Solarić 2008). The main difference between DORIS and TRANSIT is that DORIS measures the shift in frequency on the satellite, whereas TRANSIT measures the shift at the point for which coordinates are being determined.

DORIS beacons (transmitters) have been set up at certain points on the Earth's surface and send radio signals of a very stable frequency. These radio signals are picked up by satellites at different frequencies, due to the Doppler effect caused by the movement of the satellites. From the satellite observations, the parameters of the satellites' orbits and the positions of point on Earth can be established, as can other parameters. The main transmitter/receiver, which communicates with the satellites, is in Toulouse, in France.

The DORIS network (Fig. 35), consisting of around 60 DORIS stations, distributed at equal intervals all over the surface of the Earth, serves the satellite system. It ensures correct determination of the satellites' orbits and the positions of the points on earth where the DORIS transmitters are located. DORIS stations require only electrical energy to function, as DORIS transmitters

Fig. 35. DORIS network (URL 38)

Slika 35. Mreža DORIS-a (URL 38)

DORIS-stanica jednoliko raspoređenih po čitavoj Zemljinoj površini. Na taj je način osigurano dobro određivanje parametara orbita satelita, ali i položaja točaka na Zemlji u kojima su smješteni DORIS-odašiljači. Za postavljanje DORIS-stanice potrebna je samo električna energija, jer DORIS-odašiljači samo odašilju radiosignale stabilne frekvencije, a ne primaju bilo kakvu informaciju. Tako je DORIS-odašiljač vrlo jednostavan i ne treba ga posluživati, te ga se može postaviti i u nepristupačne predjele, kao što je područje Mt. Everesta.

Najpoznatiji sateliti opskrbljeni DORIS-opremom jesu TOPEX/Poseidon i Jason. Oni mogu primati radiosignale odaslane iz DORIS-odašiljača sa stanica na Zemlji i tako odrediti njihovu frekvenciju, odnosno pomak frekvencije. Koriste se za opažanje oceanskih površina, a DORIS pridonosi i njihovoj točnosti orbita na oko 2 cm.

Određivanje položaja točaka na Zemlji s pomoću DORIS-a ostvaruje se s nešto manjom točnosti nego GPS-om, ali unatoč tome on pridonosi ITRF-u (International Terrestrial Reference Frame) (URL 37).

DORIS-stanica *Mt. Everest* postavljena je 1992. godine blizu talijanske istraživačke piramide u blizini baznoga logora, a u razdoblju od 11,43 godine pokazan je pomak od 48,27 cm, odnosno pomicanje od 4,23 cm na godinu (URL 36). Za geologe su vrlo interesantna mjesečna rješenja te stanice jer omogućuju i kontinuirano praćenje kretanja sjeveroistočnog dijela Indijske tektonske ploče.

8. Imena najvišega vrha na Zemlji

A. Waugh cijenio je to što je G. Everest učinio za geodetsku izmjeru Indije jer je to bila osnova s koje su određene visine najviših vrhova Himalaje pa je 1865. godine predložio da se u čast njegova slavnog prethodnika najviši vrh na Zemlji nazove Mont Everest. Poslije je to ime promijenjeno u Mount Everest.

Tibetansko ime za taj vrh je Chomolungma ili Qomolangma, što u prijevodu znači Majka Svemira, a na starom sanskrtskom nazivao se Devgiri, što znači Sveto brdo, i Devadurga.

Početkom 1960-ih godina nepalska vlada je zaključila da Mount Everest nije nepalski naziv, ali nije joj bio prihvatljiv ni naziv tibetskih Šerpa Chomolungma. Baburam Acharya (1888–1971) predložio je ime Sagarmatha, što na sanskrtskom znači Glava neba. Kinezi su 2002. godine ustvrdili da bi taj vrh trebalo nazvati Mount

Fig. 36. North and south ascents of Mt. Everest (URL 35)

Slika 36. Sjeverni i južni uspon na Mt. Everest (URL 35)

send only stable frequency radio signals, and do not receive any data. So a DORIS transmitter is quite a simple piece of equipment, which does not need servicing. This means it can be set up in inaccessible places, such as the Everest region.

The best known satellites equipped with DORIS are TOPEX/Poseidon and Jason. They can receive radio signals sent from DORIS transmitters on stations on Earth and determine their frequencies, or shifts in frequency. They are used to observe the surfaces of the oceans, and DORIS contributes to the fact that the accuracy of their orbits is within 2 cm.

Determination of the positions of points on Earth using DORIS is somewhat less accurate than with GPS, but it still makes a contribution to the ITRF (International Terrestrial Reference Frame) (URL 37).

The Mt. Everest DORIS station was set up in 1992, close to the Italian research pyramid near Base Camp, and in the 11.43 years it has been functioning, it has recorded a shift of 48.27 cm, i.e. 4.23 cm per year (URL 36). Geologists find the monthly reports from the Mt. Everest DORIS station very interesting, as they can use them to monitor movements in the northeast section of the Indian Plate on a continuous basis.

8. Name of the World's Highest Peak

Because he knew and valued what Sir George Everest had accomplished in terms of the Great Trigonometric Survey of India, which formed the foundation for determining the heights of the Himalayan peaks, in 1865 A. S. Waugh proposed to honour the memory of his illustrious predecessor by naming the highest peak in the world after him. At first, it was known as Mont Everest, but this was later altered to Mount Everest.

The Tibetan name for the world's highest peak is Chomolungma, or Qomolangma, which means 'Mother of the Universe', and its name in Ancient Sanskrit is Devgiri, which means 'Holy Mountain', or Devadurga.

Fig. 37. Edmund Hillary and Tenzing Norgay at the rest camp at 8300 m, during their ascent of Mt. Everest. They carried loads of 27 kg, including oxygen bottles. Photo: Alfred Gregory, 28. 5. 1953. (by permission of the Royal Geographical Society (with IBG)).

Slika 37. E. P. Hillary i Šerpa T. Norgay na odmorištu na visini 8300 m prigodom uspona na Mt. Everest. Nosili su na vrh 27 kg tereta, među ostalim i boce s kisikom. Foto: Alfred Gregory, 28. 5. 1953. (uz dozvolu Royal Geographical Society (with IBG)).

Qomolangma, jer je pod tim tibetskim imenom prvi put registriran na kineskoj karti prije 280 godina (URL 1).

Prihvaćanje imena Mt. Everest za najviši vrh na Zemlji najveće je priznanje dano jednom geodetu.

9. Osvajanje Mt. Everesta

Mt. Everest postao je vrlo privlačan alpinistima iz svih zemalja svijeta upravo zbog visine i težine uspona. Na Mt. Everest može se uspeti sa sjeverne, tibetske, i južne, nepalske strane (sl. 36). Alpinisti su se obično željeli uspeti na vrh s one strane s koje još nitko prije njih nije to uspio ostvariti, tako da danas ima više putova uspona.

Koliko je poznato, kapetan Francis Younghusband prvi je došao na ideju o usponu na Mount Everest 1893. godine. Međutim, ta se ideja ostvarila tek nakon više od deset godina jer je trebalo najprije istražiti i trasirati najpovoljniji put do vrha. Takvih je pokušaja bilo nekoliko. Najznačajniji planinar toga doba A. M. Kellas, liječnik iz Londona, skupljao je podatke s fotografija koje mu je snimio njegov suradnik s tibetanske strane. S tih snimaka mogle su se procijeniti mogućnosti uspona. Kapetan John Noel je 1913. godine došao na udaljenost 65 km od vrha, ali je zbog I. svjetskog rata svoja istraživanja objavio tek 1919. godine. Osnovan je također i *Odbor za Mount Everest*, a 1921. godine kartirani su pristupi na vrh. Godine 1922. organizirana je prva ekspedicija koja se pokušala uspeti na vrh.

Odbor za Mt. Everest organizirao je od 1921. do 1938. godine 7 ekspedicija, koje su pokušale ''osvojiti'' Mt. Everest. Sve su one bile organizirane sa sjeverne tibetske strane (URL 29). Naime, tada je ulazak u Nepal bio za strance zabranjen.

U pokušaju uspona na vrh 1924. godine nestali su George Leigh Mallory i Andrew Irvine. Američki su planinari

Fig. 38. Reinhold Messner, a climber from South Tyrol, at the summit of Mt. Everest in 1980, with the surveying tripod set up by the Chinese in 1975 visible in the background (by permission of R. Messner).

Slika 38. Reinhold Messner, alpinist iz Južnog Tirola na vrhu Mt. Everesta 1980. godine, a u pozadini se vidi geodetski stativ, koji su postavili Kinezi 1975. godine (uz dozvolu R. Messnera).

In the early 1960s, the Nepali government objected to the fact that Everest was not a Nepali name, but neither could they accept the Tibetan Sherpa name Chomolungma. According to Baburam Acharya (1888–1971), they came up with the name Sagarmatha, which means 'Head of the Sky' in Sanskrit. In 2002, the Chinese announced that the highest peak in the world should be called Mount Qomolangma, as it had first been registered by its Tibetan name on the map of China 280 years previously.

The acceptance of the name Mt. Everest for the highest peak on the Earth is the highest recognition given to a geodesist.

9. Conquest of Mt. Everest

Mt. Everest became an attraction for climbers from all over the world. Its height and the difficulty of scaling it made it a challenge for extreme sportsmen. Everest can be climbed from the north (Tibetan side) and south (Nepali side) (Fig. 36). Many climbers wanted to reach the summit by virgin routes, so that today, there are many ascent routes.

As far as we know, the first person to think of climbing Mt. Everest was Capt. Francis Younghusband, in 1893. However, he was only able to make the attempt ten years later, since it was first necessary to explore and mark out the best way to reach Mt. Everest. Many such attempts were made. The most prominent climber of this period, A. M. Kellas, a doctor from London, collected data from photographs sent to him by an associate on the Tibetan side. The photographs allowed him to judge the potential for an ascent. In 1913, Capt. John Noel travelled in disguise to a point 65 km from the peak, but the First World War meant that he had to postpone publishing his research until 1919. The Mount Everest Committee was formed, and in 1921, access routes to the mountain were mapped. In 1922, the first expedition succeeded in reaching the upper slopes.

Between 1921 and 1938, the Mount Everest Committee organised seven expeditions with the aim of conquering Mt. Everest. They all started from the north, Tibetan side (URL 29). At the time, foreigners were prohibited from entering Nepal.

In an attempt to reach the summit made in 1924, George Leigh Mallory and Andrew Irvine disappeared, and it was not until 1999 that American climbers found Mallory's body, perfectly preserved in the ice, at a height of 8250 m (URL 13).

The New Zealand climber and researcher, Edmund Percival Hillary (20 July 1919 – 1 January 2008) joined the British expedition in 1951, when he made an attempt on the south ascent with Eric Shipton. He rejoined the British expedition in 1953, under the leadership of John Hunt. With his Sherpa (bearer), Tenzing Norgay (1914–1986), he reached the summit on 29 May 1953 at 11:30, using oxygen bottles (Fig. 37). These two men were the first to conquer Everest, the 'roof of the world'.

Edmund Hillary was knighted for his achievement, while Tenzing Norgay was awarded the highest British civilian medal, the King George Medal. Hillary always emphasised that this was not a personal victory, but an achievement made by the whole expedition.

It is interesting to note that the 1975 Chinese expedition to the summit of Mt. Everest set up a tripod for geodetic surveys (URL 21). However, this tripod was not mentioned later.

Various teams of climbers have forged 15 different routes to the summit of Mt. Everest. Between 1953 and 1969, 21 climbers reached the summit. In the 1970s, there were more than 80, and in the 1980s, almost 200. In the last decade of the 20th century, almost 1000 people have scaled the summit (URL 21).

According to URL 1, by the end of the climbing season in 2004, the total number of those reaching the summit was 2238, of whom 186 died in the attempt.

The first woman to conquer Mt. Everest was Junko Tabei of Japan, from the Tibetan side, on 16 May 1975 (URL 21). Wanda Rutkiewicz of Poland was the first European woman, and the third woman in the world to reach the summit, on 16 October 1978. Reinhold Messner, a climber from South Tyrol in Italy, was the first person to reach the summit without using oxygen, in 1978. He climbed Mt. Everest in 1980 solo, as is documented by shots taken using an Autoknips (Fig. 38), in which the surveying tripod set up by the Chinese in 1975 can clearly be seen.

When the Olympic Games were held in Beijing in 2008, the Olympic flame was carried over Mt. Everest, using the north route, on its way to the stadium.

The Croatian climber Stipe Božić, from Split, scaled Mt. Everest on 15 May 1979, along with the Slovenian Stan Belak and Sherpa Ang Fu. They were the first to reach the summit via the newly conquered western rockface, two days after the Slovenians Jernej Zaplotnik and Andrej Štremfelj. Stipe Božič made a second successful ascent in 1989. Darija and Iris Bostjančić became the first sisters in history to reach the summit together, on 19 May 2009, and two days later, two more Croatian women climbers, Ena Verbek and Milena Šijan, also reached the summit.

Conclusion

Determining the height of the peak of Mt. Everest was a great professional challenge for A. S. Waugh and his team, particularly as they had to do so from a great

1999. godine našli tijelo G. L. Mallorya savršeno uščuvano u ledu na visini od 8250 m (URL 13).

Novozelandski alpinist i istraživač Edmund Percival Hillary (20. 7. 1919 – 1. 1. 2008) priključio se britanskoj ekspediciji 1951. godine, kad je zajedno s Ericom Shiptonom istraživao južni pristup vrhu. On se ponovno priključuje britanskoj ekspediciji 1953. godine, koju je vodio John Hunt. Zajedno sa Šerpom (nosačem) Tenzing Norgayem (1914–1986) uspeo se na vrh 29. svibnja 1953. u 11:30 sati uz uporabu boca s kisikom (sl. 37). Njih su dvojica prvi ljudi koji su se uspeli na Mt. Everest, odnosno *krov svijeta* kako ga neki nazivaju.

E. P. Hillary je za nagradu proglašen vitezom, a T. Norgay je dobio najviše britansko civilno odlikovanje, medalju kralja Georga. Hillary je naglašavao da to nije samo njegov osobni uspjeh nego uspjeh cijele ekspedicije.

Kineska je ekspedicija 1975. godine na vrh Mt. Everest postavila stativ koji je služio za geodetska mjerenja (URL 21). Međutim, poslije taj stativ nije spominjan.

Razni timovi penjača (alpinista) pronašli su 15 različitih trasa do Mt. Everesta. Od 1953. do 1969. godine na taj vrh popeo se 21 alpinist. U 1970-im godinama popelo ih se više od 80, u 1980-im gotovo 200, a u posljednjoj dekadi 20. stoljeća gotovo 1000 (URL 21).

Prema (URL 1) do kraja sezone penjanja 2004. godine uspelo se 2238 planinara (alpinista), a 186 ih je poginulo u pokušaju uspona.

Japanka Junko Tabei prva je žena na svijetu koja je osvojila vrh Mount Everest ostvarivši taj pothvat s tibetske strane 16. 5. 1975. (URL 21). Poljakinja Wanda Rutkiewicz prva je Europljanka i treća žena na svijetu koja je osvojila Mt. Everest 16. 10. 1978. Reinhold Messner, alpinist iz Južnog Tirola (Italija), prvi se popeo bez kisika na Mt. Everest 1978. godine. Osim toga, R. Messner se 1980. godine sam popeo na vrh Mt. Everest, što je dokumentirao snimkom snimljenom autoknipsom (sl. 38) na kojoj se vide on i geodetski stativ koji su postavili Kinezi 1975. godine.

Kinezi su prije održavanja Olimpijskih igara u Pekingu 2008. godine sjevernom rutom prenijeli olimpijsku baklju preko Mt. Everesta.

Iz Hrvatske, splitski alpinist Stipe Božić uspeo se zajedno sa Slovencem Stanom Belakom i Šerpom Ang Fuom na vrh Mt. Everest 15. 5. 1979. Oni su se uspeli na vrh prvi put osvojenim zapadnim grebenom, i to dva dana nakon Slovenaca Jerneja Zaplotnika i Andreja Štremfelja. Stipe Božić je po drugi put osvojio Mt. Everest 1989. godine. Hrvatice Darija i Iris Bostjančić prve su sestre u povijesti koje su istodobno došle na vrh Mount Everest 19. svibnja 2009, a dva dana poslije popele su se također Hrvatice Ena Vrbek i Milena Šijan.

Zaključak

Određivanje visine vrha Mt. Everesta bio je veliki stručni izazov za A. S. Waugha i njegov tim, posebno zato što su ju morali odrediti s velike udaljenosti, čak 178 do 218 km. To geodeti s manjim iskustvom u mjerenju kutova, a osobito oni s većim iskustvom, ne mogu ni zamisliti, jer je utjecaj refrakcije i treperenja atmosfere kod malih elevacijskih kutova vrlo velik. Waugh je sa svojim timom postigao zavidnu točnost određivanja visine Mt. Everesta, posebno ako se to usporedi s rezultatom određivanja visine iz 1954. godine. Naime, razlika u određivanjima visine u 1856. i 1954. godini bila je samo 8 m. Uzrok te razlike nije samo nesigurnost mjerenja vertikalnih kutova, već i pogreška u određivanju udaljenosti do Mt. Everesta, pogreška u procjeni utjecaja refrakcije, utjecaj otklona vertikala i pogreška u Zemljinu radijusu.

Međutim, ni danas nije lako odrediti točnu visinu Mt. Everesta. Naime, u nepovoljnim klimatskim uvjetima nije lako izvesti sva potrebna mjerenja s najvećom preciznosti. Osim toga i primjena suvremenih GPS-mjerenja nije svemoguća, jer se s pomoću njih mogu izmjeriti samo elipsoidne visine, a trebaju se odrediti i geoidne visine. Treba naglasiti da prenošenje visine geometrijskim nivelmanom od vrlo udaljenoga Žutog mora (oko 3500 km) ili od Bengalskoga zaljeva (oko 700 km) do podnožja Mt. Everesta nije lagan zadatak, a tu je i potreba usklađivanja tih dviju nadmorskih visina.

Točno određivanje visine vrha Mt. Everesta sigurno je vrlo važan zadatak za geodete, jer se na taj način može iz ponovljenih mjerenja u nekom dužem vremenskom razdoblju s točnim numeričkim vrijednostima odrediti podizanje i pomicanje u horizontalnom smislu toga najvišeg vrha na Zemlji. To je značajno kako za znanstvena istraživanja, tako i za praktične primjene. Naime, rezultati tih mjerenja omogućuju predviđanja o tome što će se događati s tim dijelom Zemljine kugle i u daljoj budućnosti.

Zahvala

Najljepše zahvaljujemo recenzentima na korisnim primjedbama, kojima su pridonijeli boljoj kvaliteti ovog istraživanja povijesti određivanja visina Mount Everesta.

Zahvaljujemo predstavniku švicarske tvrtke Leica-Geosystem i njihovu predstavniku u Hrvatskoj gospodinu Željku Guliji za kvalitetne slike br. 27, 30, 33 i 34.

Zahvaljujemo Royal Geographical Society (with IBG) i Reinholdu Messneru na suglasnosti da se reproduciraju slike koje su u njihovu vlasništvu.

Također zahvaljujemo Ministarstvu znanosti, prosvjete i športa RH, što je djelomično financiralo ovaj rad, koji je izrađen u okviru projekta Razvoj znanstvenog mjeriteljskog laboratorija za geodetske instrumente br.: 007-000000(1201785)-3539.

distance, between 178 km and 218 km from the mountain. This is something most surveyors cannot imagine, particularly those with less experience in measuring angles, and even those with great experience know that the effects of refraction and air vibrations are enormous when small elevation angles are under consideration. Waugh and his team achieved an enviable degree of accuracy in determining the height of Mt. Everest, particularly in comparison to the result obtained in 1954. The difference between the heights measured in 1856 and 1954 was only eight metres. This difference can be accounted for not only by the uncertainty of measuring vertical angles, but also the distance from Mt. Everest at which measurements were made, the degree of error in estimating the effect of refraction, and the effect of deviation from the vertical and error in the Earth's radius.

However, even today, it is no easy task to determine the exact height of Mt. Everest. Even in the most unfavourable climate conditions, it is difficult to carry out all the necessary measurements precisely. Besides, the application of modern GPS technology is not almighty, because with GPS-equipment it is possible to determine ellipsoidal heigth only, and it is necessary to determine geoidal heights. However, it should also be emphasised that transferring heights by geometric levelling from the distant Yellow Sea (about 3500 km away) or the Bay of Bengal (about 700 km away) to the foot of Mt. Everest is no easy task, which involves the need to align these two sea levels.

Determining the exact height of Mt. Everest is surely an important task for geodetists, since by using repeated measurements over a longer period of time, with precise numerical values, it is possible to determine how much the highest peak in the world is rising and shifting horizontally. This is not only of scientific significance, but has a practical application. The results of such measurements may indicate the possibility of predicting events in this part of the world in the future.

Acknowledgements

We would like to express our thanks to our reviewers for their useful comments, which contributed to the quality of this research into the history of determining the height of Mt. Everest.

We would like to thank the representatives of the Swiss company, Leica Geosytem, and their representative in Croatia, Mr. Željko Gulija, for high-quality figures nos. 27, 30, 33 and 34.

We are grateful to the Royal Geographical Society (with IBG) and Mr Reinhold Messner who gave the permission to reprint their images and photographs.

We are also grateful to the Ministry of Science, Education and Sport of the Republic of Croatia, which subsidised this work, undertaken within the framework of the project *Development of a Scientific Measuring Laboratory for Geodetic Instruments no. 007-000000(1201785)-3559*.

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