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The GPS station at the Pyramid Geodetic Laboratory

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ABSTRACT. A permanent GPS (Global Positioning System) station was installed near the Ev-K^2-CNR Pyramid Laboratory in 2002. This point has been surveyed on several occasions since 1991, and in 1992 it was linked to a beacon of the DORIS (Doppler Orbitography and Radio Integrated on Satellite) for which global solutions are calculated monthly or even weekly. The results obtained from the GPS station in May 2004 outlined a shift of 4.2 cm per year from the point surveyed 12 years earlier, which is in very good agreement with the shift of the DORIS beacon and with the plate tectonics theory. Two weeks of data from the Pyramid GPS recorded in May and September 2005 were processed with reference to the Lhasa IGS station. They pointed out that the earthquake which occurred in Indonesia did not produce any meaningful movement of the Himalayan mountain range.

1. Introduction

In 1991, a few months after the Pyramid Laboratory was inaugurated by Prof. Ardito Desio and by the King of Nepal, a project for geodetic measurements was started in collaboration between the National Bureau of Surveying and Mapping of China, the Royal Nepal Academy for Science and Technology, and the Ev-K2-CNR Committee, at that time headed by Prof. Desio.

The project, approved and financed by the EC commission, involved the survey of 40 GPS (Global Positioning System) points in Nepal and southern Tibet recording each point for 48 hours, and was carried out between May and September 1991.

The project was supposed to repeat the survey of the same points every 3 to 5 years, but was not continued due to lack of funds.

During the first campaign a point was identified and monumented on a big boulder near the Pyramid Laboratory and called for short Point G.

One heavy WM102GPS station recorded on this point for several days and the point was later linked to the beacon of the French Orbitography (Lansman, 1993, personal communication) system called DORIS (Doppler Orbitography and Radiopositioning Integrated on Satellite).

In September 1992, during the first GPS measurement of Mt. Everest, the same point was remeasured for several hours providing a good link with the summit and with the bench mark of the Chinese triangulation system near Base Camp on the Tibetan side of the mountain.

This point was surveyed several times during the following years, generally as a reference station for local campaigns of path mapping or for monitoring the movements of the Khumbu or Changri Nup glaciers.

It was only in 2001 that a project was financed by the Ev-K^2-CNR Committee for the

Fig. 1 - Location of the GPS station near the Pyramid Laboratory.

installation of a permanent GPS station transmitting data continuously to a computer at the Pyramid Laboratory and from there to Italy.

After an initial installation of 2 months in 2002 to check the visibility of satellites, and despite the indication that the location was not "optimal", mainly for security reasons, it was decided to install a Leica 530 GPS System to operate on a permanent basis.

From September 2003 the station recorded at 30" intervals, until it was discontinued in October 2004 for a check-up to investigate some short but unexpected interruptions.

2. World wide connection: the IGS system

The Pyramid Laboratory's permanent GPS station was established with the purpose of entering the IGS network, after a test period for the equipment and the improvement of the data transfer to a server, making them available after a few hours. This has not yet been accomplished and is planned for 2006 and 2007.

3. The DORIS beacon

A beacon of the DORIS System has been operating at the Pyramid Laboratory since1992 and

Fig. 2 - The equipment of the Leica 530 station with choke ring antenna.

monthly coordinates were calculated providing an interesting monitoring of the movements of the Indian tectonic plate to the NE.

The original coordinates calculated in 1993 were:

X = 313666.64	Y = 5633552.701	Z = 2974736.608
φ = 27° 57' 29.368''	λ = 86° 48' 47.372''	h = 4961.9515 m

in the ITRF frame.

From the analysis of the data of the DORIS beacon, the linear regression coefficients of the monthly solutions of the three components showed a drift of

a_φ = 25,9±0,3 mm/year in a north direction;
a_λ = 33,4±0,7 mm/year in an east direction,
a_h = 1,9±0,4 mm/year for the elevation,

After 11.43 years the coordinates are:

X = 313666.4735	Y = 5633552.7026	Z = 2974736.7177
φ = 27° 57' 29.3707''	λ = 86°48' 47.3778''	h = 4961.9960 m

This indicates a shift of 48.27 cm and consequently a rate of 4.23 cm/year.

No meaningful correlation has been possible to fit the elevations that seem to change at a much slower rate.

4. The GPS point

The coordinates of the GPS point were originally determined by classical surveying at the moment of the installation of the DORIS beacon (W. Lansman 1992, personal communication):

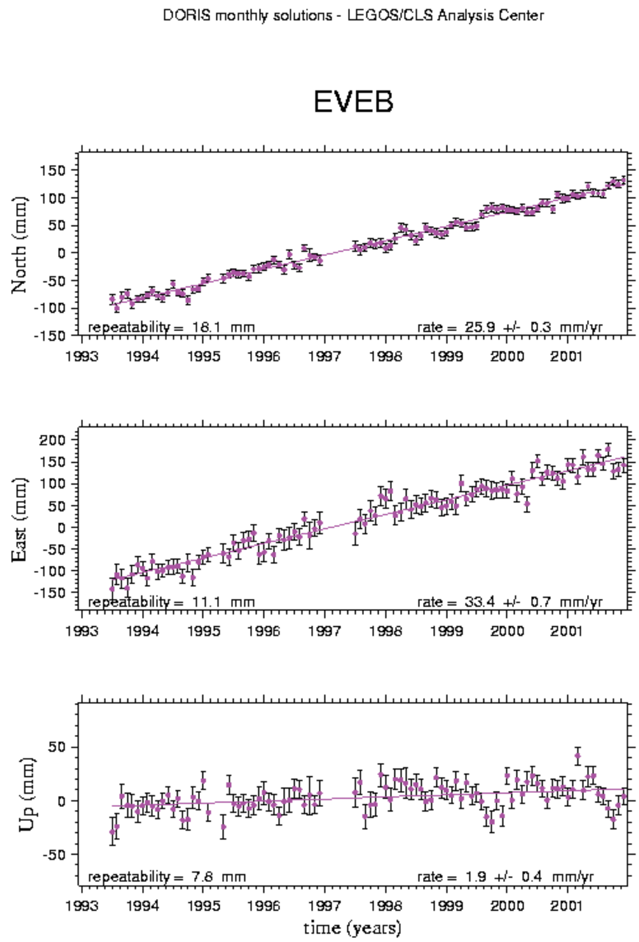

Fig. 3 - The shift of the DORIS station to the NE.

φ= 27° 57' 33.263" λ = 86° 48' 47.110" h = 4993.413.

In 2001 a permanent IGS station was established in Lhasa. The recorded data are presented in the IGS website and can be downloaded in CRINEX format. These data were downloaded and processed on a triangle, Lhasa- Everest Base Camp-Pyramid Laboratory keeping Lhasa as a fixed point. The coordinates in Table 1 resulted from the processing.

Table 1 - The base GPS triangle.

	Latitude	Longitude	Ellips. Height
Lhasa	29°39'26.42568'' N	91°06'14.36431'' E	3624.6580 m
Everest BC	28°08'09.81229'' N	86°51'06.20291'' E	5125.1883 m
Point G (Pyramid)	27°57'33.27097'' N	86°48'47.12458'' E	4993.4201 m

Fig. 4 - The trigonometric point at Everest North Base Camp.

The same results were obtained keeping the coordinates of the Pyramid Laboratory fixed. The weak point of this triangle is at Base Camp that recorded only for a few hours (Fig. 4).

The differences in the coordinates between the values of 1992 for point G are dLat = 0.0081" and dLon = 0.0148" and dh = 0.0085 m that on a time interval of 11.67 years give a shift of 4.15 cm/year.

These coordinates have been used for the processing of the data concerning the elevation of Mt. Everest and in particular to solve the triangle with the master station near the summit and for the kinematic survey of the radar profiles performed on the summit for the measurement of the depth of the snow.

5. The triangle with the summit Master Station

During the survey on the summit in May 2004, three GPS stations were active for several hours: the already mentioned one on the Base Camp trigonometric point at the confluence of the Rongbuck and Fast Rongbuck glaciers, and the master station (M) on the highest outcropping rock near the summit. The processing provided the coordinates of point M: given in Table 2.

Table 2 - The triangle with the summit Master GPS.

GPS Station	Latitude	Longitude	Ellips. Height
Base Camp	28° 08' 09.812''N	86° 51' 06.203''E	5125.190
C. Intermediate	28° 06' 17.471''N	86° 52' 16.734''E	5285.856
Summit Master	27° 59' 16.500''N	86° 55' 30.587''E	8811.281

The coordinates of the points along the profiles on the summit were determined as a kinematic survey. The Leica MX421L provides code and phase data every second. This was the sampling rate even if the radar operated at 10 Hz, and the coordinates of the GPS point and a value of the depth of the snow were recorded every second.

The signals of the radar antenna propagate in a cone with an axis perpendicular to the surface of the antenna and consequently the depth of the snow must be considered in that direction, neglecting possible lateral oscillations.

The computerised model reconstruction of the summit was made with a cubic spline method and also with a more general three dimensional best-fit 4th degree polynomial approximation.

From the sampling of the polynomial functions on a regular network with 10 cm sides, two contour maps were drawn, one for the snow and one for the rock surface, pointing out the highest points of the mountain (Poretti *et al.,* 2005).

From a numerical point of view we can identify the elevations of the two summits reported in Table 3.

Table 3 - The elevations of the summit points.

	Snow	Rock
Summit GPS	8823.36	8820808
Depth of Snow	3.68	3.04

The approximate coordinates of the summit points have been calculated accordingly.

6. Comparison with the data of the 1992 campaign

In 1992, the first measurement of Mt. Everest was carried out with classical and GPS technologies. On that occasion the GPS receiver was set on the highest point of the snowy crest and the depth of the snow was measured with a probe. The main difference between the 1992 and the 2004 data lies in the geoid-ellipsoid separation and in the depth of the snow. A comparison can be done between the measurements on the snow surface and this is presented in Table 4. One can immediately see that the value of N has been changed by 3.60 m with reference to the new geoid computed in 1996.

Table 4 - Comparison between the results of the 1992 and 2004 surveys with different N values.

	2004	2004	1992
Ellips. Heght	8823.38	8823.38	8823.51
N	-25.14	-28.74	-25.14
Geoidal Height	8848.52	8852.12	8848.65
Depth of snow	3.68	3.68	2.55
	8844.84	8848.44	8846.10

When Mt. Everest was measured in 1992 the main target was the calculation of its height. Only one year later the focus was set on the coordinates of the summit which appeared to have shifted from the original position determined by the observations taken in 1848.

This fact was already noted (Poretti, 1998) as an interesting curiosity because the instruments of that time and the distance of the points from which the observations had been taken, did not permit a fair comparison as there was a probable error of several metres.

This time the error is much smaller, but still quite large due to the distance between Lhasa and Everest Base Camp.

7. The coordinates of the summit

In 1992, the geodetic coordinates of the summit obtained by the Leica GPS 200 System were:

$$\varphi = 27° \ 59' \ 17.079''N \quad \lambda = 86° \ 55' \ 30.776''E \quad h = 8823.51.$$

Comparing the coordinates oobtained from the 2004 survey

$$\varphi = 27° \ 59' \ 16.963'' \quad \lambda = 86° \ 55' \ 30.736'' \quad h = 8823.38$$

with those of 1992, a distance can be calculated of about 2.5 m.

From the elevations surveyed on the summit it seems that being the area rather flat, it is difficult to decide which is the highest point.

8. The earthquake in Indonesia

Another situation in which the GPS station of the Pyramid Laboratory might have been very important was the strong earthquake that occurred in Indonesia on December 26, 2004.

Unfortunately at that time the GPS receiver was having its power supply system checked and no data is available close to the event. Data recorded after the restart of the station in March 2005 were recently processed with reference to the Lhasa IGS station.

Two weeks were taken into account one in May and one in September 2005. They provided the following values for the ellipsoidal coordinates of point G: given in Table 5.

Table 5 - Ellipsoidal coordinates of point G.

Point G Coordinates	Latitude	Longitude	Elevation
May 2004	27° 57' 33.27097'' N	86° 48' 47.12458'' E	4993.4201
May 2005	27° 57' 33.27068'' N	86° 48' 47.12413'' E	4993.4194
September 2005	27° 57' 33.27047'' N	86° 48' 47.12381'' E	4993.4116

Despite the error introduced by the long distance between Lhasa and Point G (460 km) one can exclude that the strong movements claimed in the area of the earthquake might have had any influence in the High Himalayas region, unless Lhasa and Pont G move in the same way. This can also be verified from the most recent weekly solutions of the Doris System (ftp://cddis.gsfc.nasa.gov/pub/doris/products/stcd/ign03wd01/ign03wd01.stcd.eveb.gif).

9. Conclusions

The permanent GPS station (Point G) at the Pyramid Laboratory is extremely useful to the topographers operating in the area and studying the flow of the glaciers, land slides, or locating GIS data. The coordinates of G measured in 1991 were compared with those surveyed by the permanent GPS station in 2003-2004 and with those of the DORIS System showing a drift of 4.2 cm/year in the NNE direction. This value is rather close to the value of 5.2±0.8 cm/year obtained from paleomagnetic data (Windley, 1986).

An important role was played by the Pyramid GPS station during the survey of Mt. Everest carried out in May 2004 within the framework of the "K^2-2004 50 years later" Italian expedition.

During this survey, it was possible to employ a new instrument, a ground penetrating radar coupled with a GPS that allowed the measurement of the depth of the snow covering the summit, outlining the profile of the bedrock and calculating the coordinates of the rocky summit.

The comparison between the coordinates of the summit determined in 1992 and those of the present survey shows a shift of 2.4 m in the NNE direction.

Data collected in May and September 2005 lead to exclude strong movements of the Himalayas connected to the 2004 earthquake in Indonesia. It would however, be interesting to monitor eventual sudden movements following other strong earthquakes that occur along the margins of the Indian plate.

It would be interesting to determine if the remaining 38 points of the Himalayan range surveyed in 1991 have also shifted the same amount and direction.

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