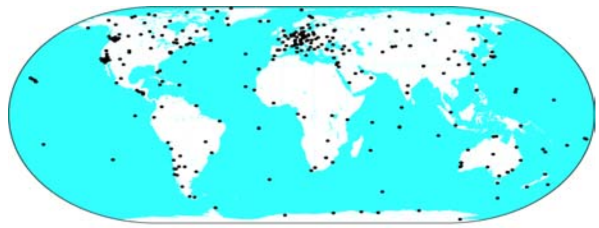
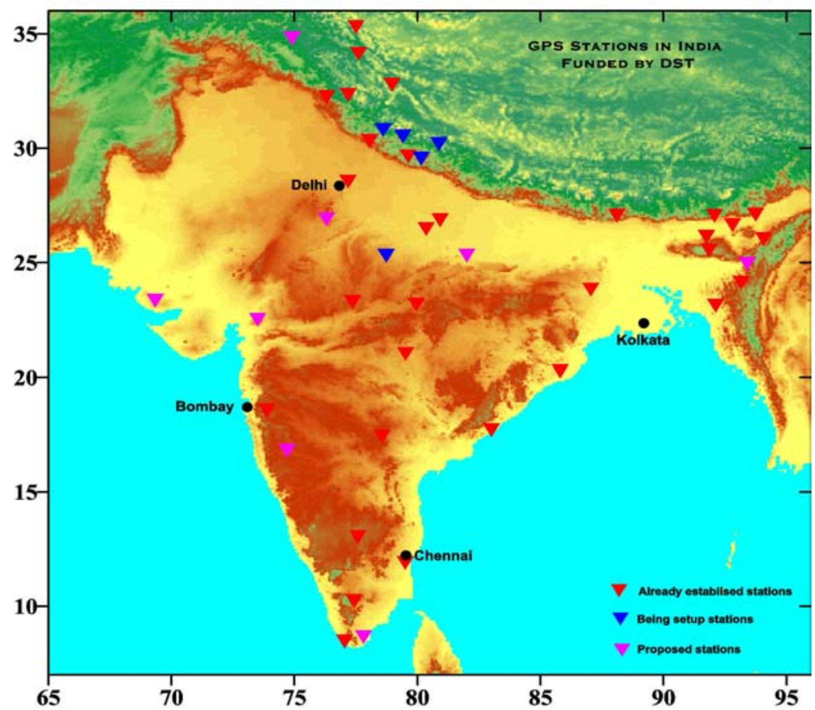
NATIONAL PROGRAMME
on
GLOBAL POSITIONING SYSTEM (GPS)
for
EARTHQUAKE HAZARD ASSESSMENT





SEISMOLOGY DIVISION
DEPARTMENT OF SCIENCE AND TECHNOLOGY
GOVERNMENT OF INDIA
TECHNOLOGY BHAVAN, NEW MEHRAULI ROAD
NEW DELHI - 110 016
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Cover Page:

1. **International GPS Service (IGS) Global Network of Permanent GPS Stations for Earthquake studies.**
2. **Permanent GPS Stations Established in India through DST-GPS Programme.**

सत्यमेव जयते

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FOREWORD

The Department of Science and Technology (DST) had formulated a comprehensive Programme on the use of Global Positioning System (GPS) Technology for earthquake hazard assessment. The Programme was initiated in 1998. A number of permanent stations and semi-permanent stations at representative locations have been established through out the country. This has become possible due to active participation of a number of institutions such as Survey of India (SOI), Dehradun, National Geophysical Research Institute (NGRI), Hyderabad, Wadia Institute of Himalayan Geology (WIHG), Dehradun, C-MMACS, Bangalore, Indian Institute of Technology (IIT), Kanpur, Indian Institute of Technology (IIT), Mumbai, Indian Institute of Geomagnetism (IIG), Mumbai, RRL, Bhopal, Tezpur University, Manipur University, Mizoram University, Guwahati University, etc. Significant scientific contributions have been made by different scientific groups associated with this Programme. A national GPS Data Centre has also been established at SOI, Dehradun for data integration, collation and dissemination. The Programme is being further strengthened by adding up a few more permanent and semi-permanent stations. The brochure highlights some of the contributions made by different groups and I hope the scientific community will find this publication useful.

(V.S. RAMAMURTHY)

PREFACE

The Department of Science and Technology has launched a National Programme on Global Positioning System (GPS) for geodetic studies and monitoring the crustal deformations due to earthquake occurrence and other geodynamic phenomena, on the recommendations of an Expert Group set up by DST for the purpose. The Group recommended that an extensive GPS control network consisting of permanent stations, semi-permanent stations and field stations should be established. It was also recommended that a consortium approach, involving all the concerned organizations that are active in this field, should be evolved. Already, 30 permanent GPS Stations all over India have been established and initiative is being taken to establish more permanent stations. A number of semi-permanent stations have also been established all over the country with the help of different universities and research organizations. A National GPS Data Centre has been established at Survey of India, Dehradun, where all the data of permanent stations are being stored and analyzed. DST is also continuously supporting training programmes at different places of India in order to train scientists in GPS technology. In addition to the above, DST has supported few projects for studying crustal deformation processes with the help of Synthetic Aperture Radar Interferometry techniques. Different field campaigns are being carried out in Himalayan and Peninsular region in order to study the crustal dynamics of Indian sub-continent. Some of the results obtained in the study are presented in this brochure. In this brochure, various aspects of the GPS Programme have been highlighted, including establishment of permanent GPS stations, data collection, processing and analysis, thrust areas for GPS studies, and the work carried out by different organizations. I hope the information available in this brochure will be useful to the geo-scientific community at large.

Dr. G. D. Gupta
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CONTENTS

NATIONAL GPS PROGRAMME FOR EARTHQUAKE HAZARD ASSESSMENT

1. INTRODUCTION

The Navigation Satellite Timing and Ranging Global Positioning System (NAVSTAR GPS), developed by the U. S. Department of Defense, is a satellite-based navigation and surveying system for determination of precise position and time, using radio signals from the satellites, in real-time or in post-processing mode. GPS is being used all over the world for numerous navigational and positioning applications, including navigation on land, in air and on sea, determining the precise coordinates of important geographical features as an essential input to mapping and Geographical Information System (GIS), along with its use for precise cadastral surveys, vehicle guidance in cities and on highways using GPS-GIS integrated systems, it is used for earthquake and landslide monitoring, etc. In India also, GPS is being used for numerous applications in diverse fields like aircraft and ship navigation, surveying, geodetic control networks, crustal deformation studies, cadastral mapping, creation of GIS databases, time service, etc., by various organizations. One of the most important applications of GPS has been its use for monitoring crustal deformations, for studies related to earthquakes.

About a decade ago, DST formulated and initiated a comprehensive programme for use of GPS technology for earthquake hazard assessment. A number of permanent GPS stations all over India have been established and a few GPS campaign mode studies have been initiated in different parts of the country with the help of different scientific organizations and universities. Recently, efforts are also being made to study the ionospheric tomography and meteorology with the help of GPS. Met packages are being installed at some permanent GPS stations to facilitate the above studies and to optimize the scientific outcome from the programme. A National GPS Data Centre has been established at Survey of India, Dehradun, where data from all the GPS Permanent stations are being stored for scientific use. The above programme is steered through a National GPS Expert Committee, constituted by DST.

2. ACHIEVEMENTS

Since 1998, DST has taken up the implementation of the National GPS Programme for Earthquake Hazard Assessment, as recommended by the GPS Expert Group. An extensive network of permanent, semi-permanent, and field GPS stations is being established by the participating organizations, and a National GPS Data Centre has been established. Specifications of the GPS instrumentation for this purpose have also been formulated. A Committee has been constituted for overseeing the programme. A brief report on these activities is given below.

2.1 ESTABLISHMENT OF PERMANENT GPS STATIONS

Permanent GPS Stations at 30 locations all over the country has been set up under the programme. The detail list of the permanent stations and the Institutions responsible for maintaining these stations is given in **Annexure-I**.

2.2 CAMPAIGN-MODE STUDIES

In order to study the local crustal deformation process in seismically active areas, several campaign mode studies have been taken up by various research groups under this programme. A list of different GPS Campaigns and the institutions responsible is given in **Annexure-II.**

2.3 CONTRIBUTION FROM PARTICIPATING ORGANISATIONS

I. SURVEY OF INDIA (SOI), DEHRADUN

PENINSULAR SHIELD PROJECT

GPS-related activities have been carried out by Survey of India, mainly for densification of the Geodetic Control in various parts of the country since 1991. GPS studies in the context of earthquake monitoring were taken up in 1994, after the 1993 Latur earthquake, and continued in the World Bank assisted DST project in Peninsular India. A detailed planning of fieldwork was carried out, and suitable sites for construction of GPS stations were marked. Old GT stations were selected in the area to strengthen the newly established GPS network. Three permanent GPS stations have also been established at Bhubaneshwar, Trivandrum, and Pune, which are now operational. Constructions of monuments and GPS observations for precise order network at spacing of 50-60 km have been completed in many regions in the country.

GPS OBSERVATIONS IN ANDAMAN AND NICOBAR ISLANDS

Survey of India took up the job to connect the Islands of Andaman and Nicobar Island with mainland and to provide control points in the Islands in 1994, using GPS. A total of 28 stations were selected across the Islands; pillars were made on the selected sites and observations were carried out on these pillars. The entire network was connected to three known GT stations of main land namely Nanmangalam H. S., Radhapuram ‘S’, and Yarda H. S. Computations were done and final co-ordinates in WGS 84 as well as in Everest were computed.

Since one set of observations was not sufficient for calculation of transformation parameters and also for the studies of crustal movement between mainland and Island, minimum two sets of observations were required. The second epoch observation on all the existing old GPS stations in Andaman and Nicobar Islands were carried out during 2003-2004. Tide Gauge Bench Marks along the East coast were also connected to the Islands stations for better monitoring of Mean Sea Level.

All the existing GPS stations were observed. Observations for mainland and TGBM connection were also carried out. Two Ashtech, two Trimble, and one Leica dual frequency GPS receivers were used for observations. All standard precautions were taken during observations, and the durations of observations were kept in accordance with the distances involved.

The processing of data is in progress. The results obtained by the second epoch observations will be useful for determining the transformation parameters, and also to monitor the neo-tectonic movement of the area.

Figure 1: Part of Andaman Sea where GPS observations were carried out

TRANSFORMATION PARAMETERS

In the DST sponsored project "Determination of Transformation Parameters between Everest Datum and World Geodetic System-1984 (WGS-84 Datum)", Survey of India completed observations at 272 old GT stations till last field season. The data collected has been processed and transformation parameters for all the states have been derived. The observations for northeast state have been completed and processing is in progress. GPS observations for transformation parameters in J & K were not taken up due to insurgency problem.

II. WADIA INSTITUTE OF HIMALAYAN GEOLOGY (WIHG), DEHRADUN

The GPS group at WIHG, with Dr. Parmesh Banerjee as PI, is working on a research project under this programme, with the objective of quantifying the manifestation of India-Asia plate collision process in the N-W Himalayan region and adjoining thickly populated places of Northern India. This would enable to detect zones of higher strain build-up (thus higher earthquake probability) and would provide a unique opportunity to understand India-Himalaya collision-convergence tectonic mechanism in a better way.

DATA ACQUISITION

The project was initiated in May 2003. Permanent GPS stations were installed and being maintained at Delhi (Sept., 2003), Dhanbad (Feb., 2003), Kothi (Oct., 2003), Panamik (Sept., 2003) (Figure 2), Dharamsala, and Dehra Dun (Oct., 1998). Four more permanent GPS stations are being installed at Amritsar, Bhatwari (Uttarkashi), Pithoragarh and Munsiari.

Figure 2: Permanent GPS Station at Panamik, Ladakh, at the Southern foothill of the Karakorum

Repeated GPS measurements were carried out over 50 campaign mode stations that were earlier established in Himachal Pradesh and Garhwal Himalaya. Campaign mode measurements were also carried out in Ladakh to measure movement along Karakorum fault. Repeated measurements were carried out in Central Indian shield region at Delhi, Jhansi, Bhopal, and Nagpur, to investigate earlier found crustal shortening happening between Delhi and Bangalore.

An extensive campaign mode GPS networking was established in Delhi region. More than 40 GPS stations, spread all over Delhi state and surrounding regions, were installed and measured. Repeat measurements of these sites would help to resolve if Delhi-Haridwar ridge is detached from the thick Indo-Gangetic sedimentary basin, and its role in India-Asia convergence process.

DATA PROCESSING AND RESULTS

Entire data starting from the year 1995 were processed at WIHG. An India reference frame was defined so that velocities from Himalayan sites could be properly referenced in order to extract convergence rate and local strain partitioning. Most of the western Himalayan sites were found to have a

significant westward component implying escaping of Himalayan mass because of collision process. A 100 km wide zone, parallel to the Himalayan arc, were identified between the MBT and MCT, where strain is accumulating at a fast rate of nearly 15mm/yr. Inversion of the GPS derived surface deformation data indicated the location of the fault head of the decollement to lie just to the south of the higher Himalaya. This is also the zone of maximum seismic activity. The zone to the south of the fault head up to the MFT is locked with the converging India plate.

Convergence rate of the India-Asia collision process was measured to be about 40mm/yr, out of which 15mm/yr is being consumed within the Himalaya. At least 5mm/yr shortening is taking place within Indian shield. Our recent repeated measurements in Central Indian sites have shown that the South India shield is deforming within itself, as well as having an eastward motion relative to the north Indian counterpart. This motion is being accommodated along the Narmada Son Lineament through strike slip movement.

Under another DST-sponsored project for measuring geoid undulation studies in Ladakh Himalaya, GPS, leveling, and gravity measurements were carried out along Upshi-Karu–Changla-Tangtse-Pangong Tso section. The section crosses across the Ladakh batholith and reaches up to southern splay of the Karakorum fault. The objective was to confirm geoid and gravity anomalies that were earlier found to the north of Khardungla, along Rumtse-Leh-Panamik section. No such strong geoid anomaly could be confirmed from the present section. High error level in the leveling measurements in steeply inclined hills could be one possible reason for that.

SOME IMPORTANT PUBLICATIONS

1. Banerjee Paramesh, Burgmann Roland, (2002). "Convergence across the northwest Himalaya from GPS measurements", Geophysical Research Letters, vol. 29, No. 13, pp. 30.1-30.4.
2. Banerjee Paramesh (2002). "Crustal Shortening and tectonics of the N-W Himalaya from GPS measurements", Proc. Asian GPS Conference, 25-26 Oct., 2002, India International Centre, New Delhi, CSDMS.
3. Banerjee Paramesh (2003). "GPS aided geoid and gravimetric measurements across India-Asia plate boundary in Ladakh, NW Himalaya", Newsletter - Deep Continental Studies in India, No.1, vol. 13, Ed. T. M. Mahadevan, Dept. of Science & Tech., New Delhi.
4. Banerjee Paramesh and Satyaprakash, (2003). "Crustal Configuration in Northwestern Himalaya from Gravity Measurements along Kiratpur-Leh-Panamik transects", J. of Geol. Soc. India, vol. 61, pp. 529-539.
5. Banerjee Paramesh and Satyaprakash, (2003). "Crustal Configuration across the north-western Himalaya as inferred from gravity and GPS aided geoid undulation studies", Journal of the Virtual Explorer (e-journal: www.virtualexplorer.com.au/2003/rajaram/banerjee), vol. 12 Special Issue. A window to Indian Geology.

III. INDIAN INSTITUTE OF TECHNOLOGY BOMBAY (IITB), MUMBAI

The GPS team at Department of Civil Engineering, IIT Bombay, with Prof. Madhav N. Kulkarni as PI, has taken up crustal deformation studies in the Koyna region of Western Maharashtra and Bhuj region of Gujarat, under this programme.

GPS DATA COLLECTION AND PROCESSING

Under the DST-funded projects, two GPS networks have been setup since 2000-2001: a local network in the Koyna region (Figure 3) and a regional network in the Bhuj region (Figure 4). The objective of the local GPS network at Koyna is to understand the deformations induced in the area, in the vicinity of the Koyna dam and in the dam structure due to various factors, including crustal movements. The network consists of 34 GPS stations located in the vicinity of the dam, including 8 stations established for monitoring a fault close to the dam, with connection to a GT station, for reference. Till date, ten sets of observations over this local network have been completed. A regional network (Figure 5) in the Western

Maharashtra and coastal areas of Konkan has also been established in collaboration with IIG Mumbai. This consists of 22 GPS stations, well distributed over the region. GPS Data has been collected at these 22 stations during two field campaigns carried out in April-May 2004 and Sept-Oct 2004. The regional GPS network established in Bhuj area, after the 2001 Bhuj earthquake, comprises 14 stations, covering the earthquake-affected region. This has been observed over three epochs, during 2001, 02 and 03. The data obtained from the entire field campaigns have been processed and analyzed using Bernese 4.2 and GAMIT softwares, and some significant results have been obtained. A permanent GPS station has also been established since 2002, in the campus of IITB, which is being continuously operated, and the data analyzed, to estimate the crustal deformations and strain rates.

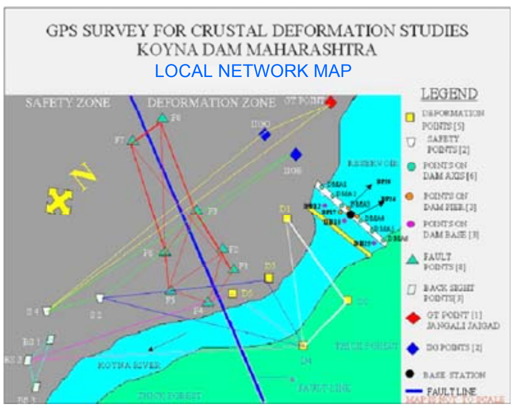


Figure 3: Local GPS Network in Koyna Region

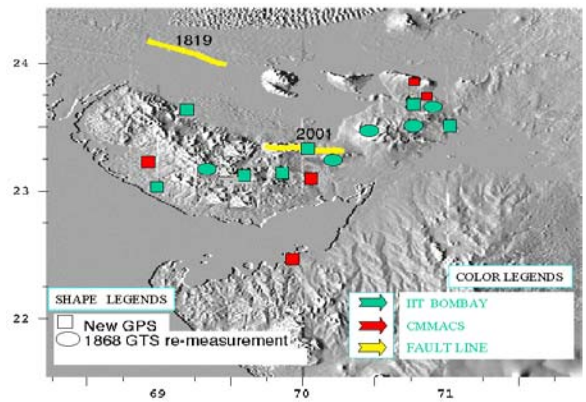


Figure 4: GPS Network in Bhuj Region

Figure 5: Regional GPS Network, with Estimated Strain Rates at Stations

DATA ANALYSIS & PRELIMINARY RESULTS

1. Western Maharashtra Region: From the detailed analysis of the two regional campaigns of 2004, the average strain rate for the Western Maharashtra and Konkan region is estimated to be -1.146×10^{-8} over the year (Figure 5), thus indicating a compression of about 0.1 ppm. An average regional crustal movement of about 45 mm in NNE direction is also estimated. Extended observations over next few years are required to confirm these rates.

From the analysis of the local network data, we also sought to correlate the local deformations of the base station with the water level, in order to understand the pattern of deformation of the dam with respect to change in water level. For this purpose, the standardized water level (z) is computed. The standardized water table is given by the formula:

$$z = \frac{(Waterlevel - MDDL)}{(MWL - MDDL)}$$

where MDDL is minimum drawdown level and MWL is mean water level.

At Koyna, earlier studies done by experts reported that the deflection of the dam increases very gradually for water levels up to 625 meters and increases rapidly for water levels beyond that. Keeping this factor in mind, a polynomial in Δz is fitted to the GPS-estimated local deformations. A polynomial in Δz of third degree fits the data well. As can be seen in Figure 6, this relationship has a correlation of 0.99, which clearly shows that the major part of the deformation of the dam is due to the varying water table. From the detailed analysis, it is also postulated that the high rate of loading and longer duration of retention of high water levels may be causing seepage of water into the fault line, thereby weakening it and progressively lowering the stress needed to trigger an earthquake. These findings require more repeat observations.

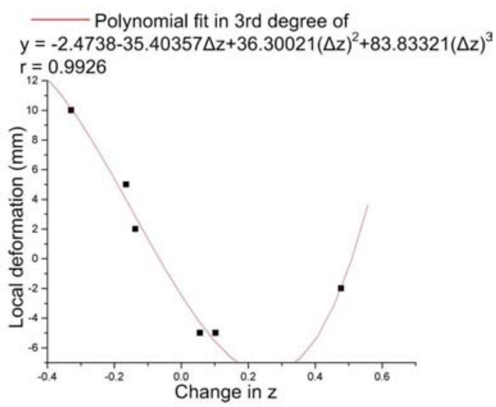


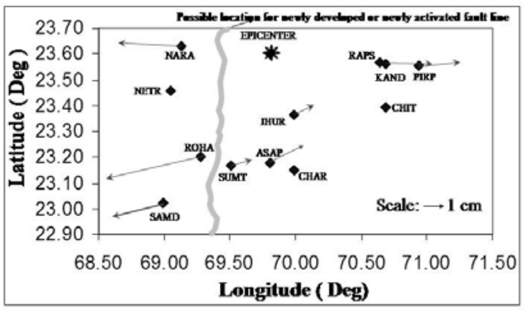
Figure 6: Correlation plot

To understand the process of deformation pattern along the Western Maharashtra region, the strain rates between the campaigns were calculated. The deformation along the stations generates an elastic strain field. These strain rates calculated, thereby represent the amount of strain present between the campaigns and can be used as an indicator of any seismic activity in the area. The strain rates along the station points are estimated using the GPS baseline length data. The strain rates were calculated by using the formula given below:

$$\varepsilon = \frac{\Delta l}{l}$$

Where Δl represents the change in baseline length between two points for two successive campaigns, which represents the deformed baseline length, and l is the original baseline length for the predecessor campaign. The results from this analysis are as given above.

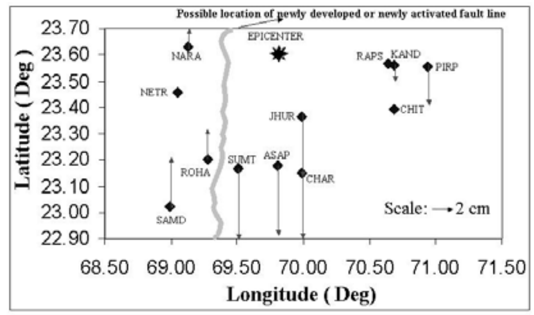
2. Bhuj Region, Gujarat: A network was setup in the Bhuj region of Gujarat, after January 2001 Bhuj earthquake, with the objective of estimating the post-earthquake deformations. A total of 14 GPS stations have been established, out of which five are old Great Trigonometrical (GT) Triangulation stations. Three sets of observations in Feb. 2001, Feb. 2002, and Feb. 2003 have been completed.



Points NETR, CHIT and CHAR are found disturbed horizontally in 2002 and respective anomalies are reflected in deformations values both in terms of magnitude and direction.

Point RAPS was established in 2002, so deformation vector can not be calculated for the 2001-2002 period

Figure 7: Horizontal deformation vectors (N-E) of Bhuj points



Points NETR and CHIT are found disturbed vertically in year 2002 and respective anomalies are reflected in deformations values both in terms of magnitude and direction.

Point RAPS was established in 2002, so deformation vector can not be calculated for the 2001-2002 period

Figure 8: Vertical deformation vectors (Ellipsoidal heights) of Bhuj points

Examining the deformation pattern (Figure 7 and Figure 8) it can be concluded that significant amount of extension is taking place across the fault line. There is a possibility of having a definite geological structure (oblique-slip fault) in Bhuj area and it needs further extensive studies.

3. Permanent GPS Station: A permanent reference GPS station (Figure 9) has also been setup at Civil Engineering Department of IIT Bombay. It is running continuously since January 2002 and the data is being analyzed periodically. The average annual coordinates estimated for the three years have been presented in Table 1. The general horizontal deformation of the station reflected in N-E direction, is due to the Indian plate motion. The horizontal deformation observed is about 2.4 cm in North and about 4.8 cm in East direction over a year, which is in close agreement with the estimated plate motion of about 5.5 cm per year in NNE direction.

Figure 9: Monumentation of IITB permanent reference GPS Station

Table 1: Coordinates of three years of IITB reference station

Year	Northing (m)	Easting (m)	Ellipsoidal Height (m)
2002	2116800.882	280818.883	-3.990
2003	2116800.905	280818.930	-3.987
2004	2116800.930	280818.979	-3.980

GPS TRAINING

Training programmes in GPS-related areas are also being conducted periodically. Three short training programmes were conducted during 2000-2003, with support from DST, and over 200 students were also trained in GPS during vacations. A GPS Laboratory has been established and GPS has been introduced in the B. Tech. and M. Tech. level courses at the Institute, and several student research projects in GPS applications have been completed.

SOME IMPORTANT PUBLICATIONS

1. Kulkarni, M. N., "Earthquake Monitoring & Other GPS Applications", GIM International Journal, The Nether Lands, Oct. 2000, vol. 14, pp 23-25.
2. A. Manake, M. N. Kulkarni, "Study of Deformation of Koyna Dam Using GPS", Survey Review Journal, UK, vol. 36, No. 285, July 2002, pp 497-507.
3. Kulkarni, M. N., D. Rai, P. Pillai, V. S. Tomar, "Establishment of a GPS permanent ref. station at Dept. of Civil Engg., IIT Bombay, India", Acta Geodetica Geophysica, Journal of Hungarian Academy of Sciences, vol. 39 (1), pp. 55-59 (2004).
4. Kulkarni, M. N., S. Likhar, V. S. Tomar, P. Pillai, "Preliminary Results of the GPS Studies for the January 2001 Gujarat Earthquake", Survey Review Journal, International Journal of Surveying, vol. 37, No. 292, April 2004.
5. Kulkarni, M. N., Nisha Radhakrishnan, V. S. Tomar, Deepa Rai, "Monitoring the Structural Deformations of Koyna Dam Using Global Positioning System", Journal of Surveying Engineering, American Society of Civil Engineers (under review: August 2004).

IV. INDIAN INSTITUTE OF GEOMAGNETISM (IIG), MUMBAI

GPS studies for crustal dynamics, glacier and ionospheric studies have been undertaken by IIG Mumbai, with Dr. C. D. Reddy as PI. After the inception of GPS studies during 1995, the Institute has taken up campaign mode GPS studies in many seismic zones of India viz. Western Maharashtra, Bhuj, Chamoli, Northeast and Antarctica regions. The data have been analyzed using GAMIT/GLOBK software. The estimated velocity fields are represented in ITRF2000 (e.g. Figure 10). The velocity distribution is used to estimate the dilatational and shear strain distribution and principal axes of the strains. Some of the significant results are: delineation of extension regime along the western coast of Maharashtra and compressive strain of ~0.1 micro-strain/yr in epicentral region of Bhuj earthquake (Figure 10).

To augment and facilitate the study of crustal dynamics, ionospheric tomography and meteorological studies, ten permanent GPS sites are being setup, funded by DST. The data analysis from these sites can yield strain distribution map for the Indian region that can help earthquake risk evaluation, space weather monitoring, and meteorology.

STUDY OF SCHILMACHER GLACIER VELOCITY

The Schilmacher Glacier in Antarctica is a polar outlet glacier that contributes to the drainage of the East Antarctic Ice Sheet, adjacent to the Schilmacher Oasis and provides a logistically accessible region where the mechanisms of ice sheet dynamics can be studied in detail. With this objective, GPS data have been collected for two campaigns during 2003 and 2004 at 21 sites with about 5 KM inter-site spacing. The total area covered is 50×25 Km and the nearest GPS base station Maitri is at about 15 km from the study region. Monumentation is done by embedding a wooden block of dimension 1×1×1ft in the glacier ice to a depth of 1.5ft (Figure 11).

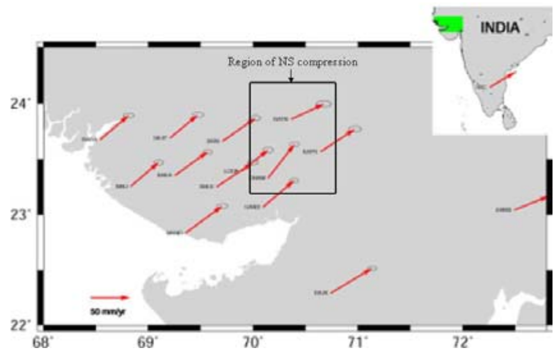


Figure 10: GPS derived velocity vectors in ITRF2000. The study region and velocity of IISC (IGS site) are shown in inset. The region of NS compression of about 0.1 micro-strain/yr is shown in the rectangular block.

Figure 11: Monumentation on the Schilmacher Glacier in Antarctica

The velocity trend of the glacier is found more in the NNE direction and towards the Schirmacher Oasis. The maximum direction of movement is 10.79 m/yr in the Northeast part and minimum found 2.25 m/yr in South Part of the Study area. In general, the maximum velocity is seen at maximum steepness of the glacier and away from the blockage of Schilmacher Oasis. Velocity distribution is influenced by the blockage of the Schilmacher Oasis. Maximum crevasses are found along the region of maximum glacier velocity. The direction of the velocity is outwards w. r. f. high velocity region, i.e. the glacier spreads as it reaches the eastern part of the Schilmacher Oasis.

LOW LATITUDE IONOSPHERIC STUDIES

Recognition of the radio wave signals transmitted from GPS as useful tools for probing the Earth's ionosphere has led to a number of important contributions to the ionospheric studies. In particular, the study of the Total electron content (TEC) in the equatorial ionosphere is important owing to the effects of its variability on communication and navigation systems in the Indian region. As seen in Figure 12, the low latitude is major trouble spot of strong L - band scintillations.

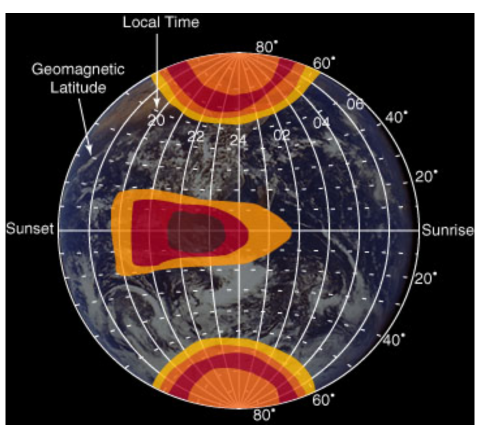


Figure 12: The regions (major trouble spots) and times of strong L - band scintillations

Vertical total electron content (TEC) over a few stations, lying between the dip equator and the crest of the equatorial anomaly, are estimated using dual frequency observations of the L1 and L2 signals

transmitted from GPS satellites. We considered days on which post-sunset scintillations are produced on a BHF radio signal transmitted from a geo-stationary satellite (FLEETSAT) and recorded at the dip equatorial station, Tirunelveli.

It is expected that, over a period of month, days on which equatorial spread F (ESF) irregularities occur, background ionosphere conditions including the distribution of ionospheric plasma are to some extent similar.

Out of these days, we consider specifically days which are magnetically quite, in order to establish a monthly pattern of local time variations of TEC for magnetically quite days. This allows us to identify the effects of prompt penetration of magnetospheric electric fields into the low-latitude ionosphere as well as the effect of a disturbance dynamo on the distribution of plasma in the low-latitude ionosphere. We find that the time interval for which prompt penetration effects are seen decreases as the dip latitude of the station decreases.

Vertical Total Electron content of the stations are estimated using dual frequency observations (both code and phase) of the L1 (1575.42 MHz) and L2 (1227.60 MHz) frequency from GPS. We first considered magnetically quite days on which post sunset scintillations are produced on a VHF radio signal transmitted from a geostationary satellite, FLEETSAT (located at 73^o E), and recorded at the dip equatorial station, Tirunelveli.

VTEC = STEC × sqrt (Fac)

Fac = $(1-\cos^2 E)/(1 + h/R_E)^2$

E = Elevation angle of the signal at the receiver location

RE = Average radius of the Earth

h = Height of the ionospheric pierce point

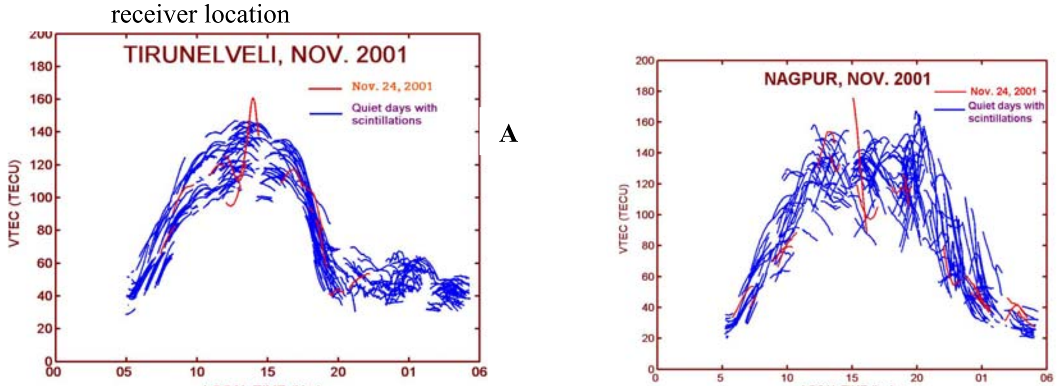


Figure 13: Diurnal VTEC on magnetic quite days (blue) and on disturbed day (red) - (A) at Tirunelveli and (B) at Nagpur

It is found that the day-to-day variation of the TEC in the equatorial region is considerably less compared to that near the anomaly region. When the solar flux is low, it is found that the day-to-day variation in the equatorial anomaly region is relatively greater. The decrease in TEC in the equatorial reign after sunset is found to be steeper when solar flux is high. The effects of the prompt penetration of the magnetospheric field on the TEC have been observed for the magnetically disturbed days - Nov. 24, 2001 and June 16-18, 2003 and that of the disturbance dynamo on Nov. 6, 2001.

SOME IMPORTANT PUBLICATIONS

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2. Reddy C. D., 1996. “Perspective view of Global Positioning System and its application to mining engineering”, Mining Engineering Association of India (Belgaum Chapter), 95-97.

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V. CENTRE FOR MATHEMATICAL MODELLING AND COMPUTER SIMULATION (CMMACS), BANGALORE

GPS group at C-MMACS with Dr. Sridevi Jade as PI has been working on the study of Active tectonics of the Indian Subcontinent, towards understanding the dynamics of continental collision and rheology of lower crust, based on GPS Studies. GPS data from the national network of GPS stations, as well as the data generated through specific campaigns, was used for the above purpose. Following are the major research areas covered:

- Quantification of deformation in North-East India
- Quantification of Intercontinental and Intra-continental deformation zone through experimental determination of strain rate gradients in India
- Estimation of Perceptible water vapor from GPS data
- GPS measurements in the southern peninsular shield of India
- Active tectonics in Shillong Plateau
- Active tectonics of Darjeeling-Sikkim Himalaya

In the last two years, eight additional permanent GPS stations in Northeast India and one in Bhopal (Figure 14), were established in collaboration with local universities, i.e. Aizwal (Pacchhunga University College), Imphal (Manipur University), Guwahati (Guwahati University), Shillong (Central Seismological Observatory), Lumami (Nagaland University), Panthang (G B Pant Institute of Himalayan Environment), Tezpur (Tezpur University), Bomdilla (Indian Institute of Astrophysics and Tezpur University), and Bhopal (Regional Research Laboratory), and handed over to them. Three training programmes also were conducted: *(i) Intensive Course on GPS Theory, Data Processing and Analysis, January-February, 2002; (ii) Workshop on the use of GPS Technology and GPS Data Analysis and Processing, March-April, 2003; (iii) SAARC GPS course for SAARC countries, August–September, 2003.* Campaign style GPS measurements were also carried out in North-East India, Shillong Plateau, Darjeeling-Sikkim Himalayas, Bhuj region, South India and Andaman-Nicobar Islands. Daily repeatabilities in the north, east, up component of one of the permanent network sites is given in Figure 16 to give insight in to the performance of this site as well as the rigorous processing of the GPS data carried out to determine the baseline length changes and the associated deformation and motion. GPS derived motion and deformation using the permanent network and campaign station data is also given in Figure 14. Errors range from ±1 to 6 mm in the estimation of coordinates and velocities of the GPS sites. Some significant findings from the results are as follows:

- GPS derived velocity and deformation rates in the Himalayan arc vary from west to east suggesting the deformation mechanisms in Ladakh, Garhwal, Kumaun and Sikkim Himalayas are different and are to be treated differently.
- GPS derived extension vector between the Himalayan sites and Lhasa is consistent with the east-west extension of southern Tibet.
- Kachchh GPS results give post-seismic deformation consistent with Bhuj rupture zone as GPS measurements were made after the 2001 earthquake.
- GPS measurements in the northeast India seem to indicate that there is strong lateral variation in the convergence rates in northeast Himalayas.
- The measurements in Shillong plateau indicate that there was practically no active deformation within the plateau during 2002-2003.

- Convergence rates in Darjeeling-Sikkim and Himalayas are 10-12mm/yr.
- As an offshoot of the GPS work, Precipitable Water Vapor content (PWV) in the atmosphere has been estimated using the GPS data at IISc, Kodaikanal, and Hanle for the year 2001 and 2002 and the results are given in Figure 15.

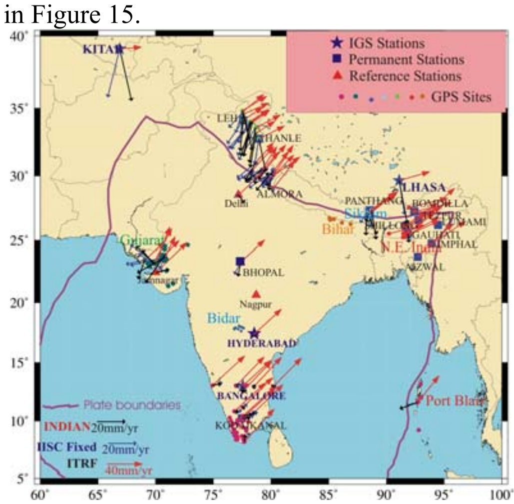


Figure 14: GPS derived motion and deformation

The above 8 north-east stations established (Figure 14) now constitute a significant part of the national network of GPS stations envisaged by the Department of Science and Technology for monitoring the geotectonic activities in the Indian subcontinent. On a regional scale, these stations are expected to generate insightful GPS data to help answer questions related to Indo-Burman Convergence and the tectonic relationship of the Shillong Plateau with the Himalayas. Furthermore, these sites would serve as important reference stations for the Campaign mode GPS surveys in the North-eastern India. Also, the Zenith troposphere delay derived by analyzing the GPS data at these sites and the weather data can be used for the calculation of precipitable water vapor in the atmosphere, to study the monsoon dynamics in the region.

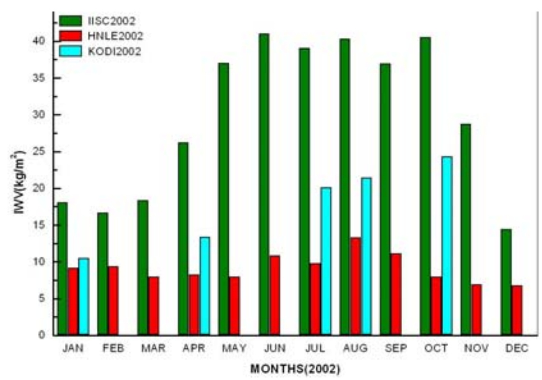


Figure 15: Integrated water vapor from GPS data

There is a need to track these GPS derived rates in the last two years for several more years to ascertain whether these average rates are representative of the transient deformation in the region. Though 10 permanent stations of GPS national network were included in the analysis (Figure 14), we propose to include all the stations of national network to give an overall picture of deformation in the Indian subcontinent and also will help model the dynamics of Indian Subcontinent. Estimation of Precipitable Water vapor content (PWV) in the atmosphere using the GPS data of national network stations will go a long way to design experiments to implement troposphere water vapor tomography. If daily pressure,

temperature, and relative humidity can be measured at some of the national network sites in northeast, then it would help a long way in determining the variation of water vapor content in the atmosphere.

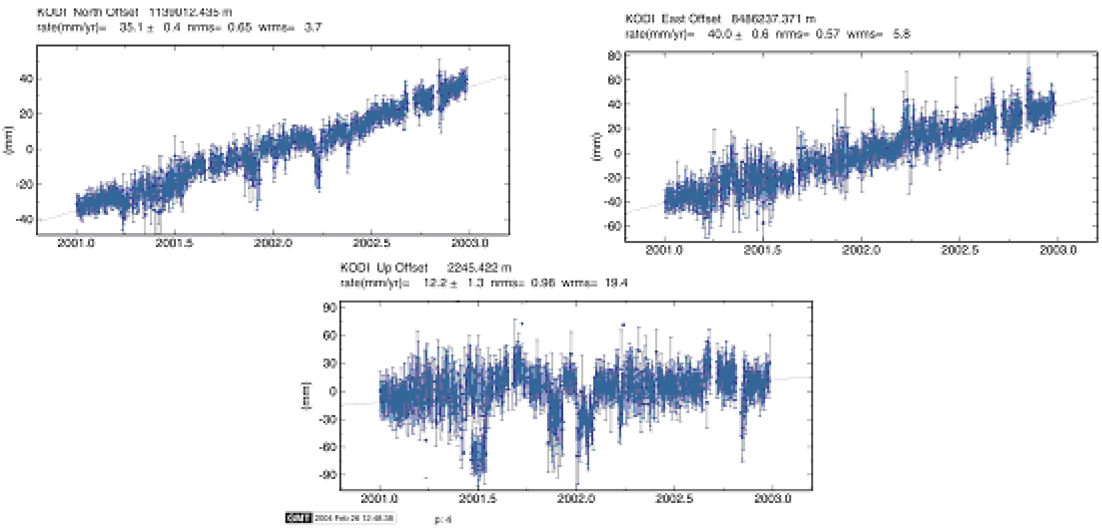


Figure 16: North, East, Up repeatability of Kodaikanal GPS station

SOME IMPORTANT PUBLICATIONS

1. Sridevi Jade, M. S. M. Vijayan, V. K. Gaur, Tushar Prabhu, S. C. Sahu, "Estimates of Precipitable Water Vapor from GPS data in Indian Subcontinent," International Journal of Atmospheric and Solar-Terrestrial Physics, accepted for publication.
2. Sridevi Jade, "Estimates of Plate velocity and Crustal deformation in the Indian Subcontinent using GPS geodesy", Current Science, vol. 86, No. 10, May 2004.
3. Sridevi Jade, M. Mukul, I. A. Parvez, M. B. Ananda, P. D. Kumar, V. K. Gaur, R. Bendick, R. Bilham, F. Blume, K. Wallace, I. A. Abbasi, M. Asif Khan, and S. Ulhadi, 2003, "Pre-seismic, co-seismic and post-seismic displacements associated with the Bhuj 2001 earthquake derived from recent and historic geodetic data", Proceedings of Indian Academy of Sciences (Earth and Planetary Sciences), Bhuj Special edition, September 2003.
4. Sridevi Jade, B. C. Bhat, R. Bendick, V. K. Gaur, P. Molnar, M. B. Ananda and P. Dileep Kumar, "GPS measurement from the Ladakh Himalaya, India: Tsets of Plate-like or continuous deformation in Tibet", Geological Society of America Bulletin, in press.

ACTIVE DEFORMATION AND THE ORIGIN OF THE SHILLONG PLATEAU

The GPS group at CMMACS with Dr. Malay Mukul as PI has been carrying out GPS studies in the Shillong region. The Shillong Plateau has been the subject of extensive study over the past decade or so and its origin and deformation history are still being debated. Traditionally, the Shillong Plateau was considered to be a part of the basement involved Dauki. Thrust sheet that was transported by the Dauki Thrust in a thin-skinned manner. More recently, it has been suggested that the Plateau was formed by thick-skinned "pop-up" tectonics along two reverse faults; the Dauki and the blind Oldham fault. These two scenarios would require that the Shillong Plateau was formed due to compressive tectonics in the region. However, recent Broadband Receiver Function work has indicated that the crust under the Shillong Plateau is arched into a regional antiform, the top of which constitutes the Shillong Plateau. To resolve these questions, C-MMACS has initiated GPS Measurements on the Shillong Plateau in collaboration with Tezpur and Guwahati Universities, Assam and Central Seismological Observatory, Shillong. A permanent station was established at Shillong (Figure 17) inside the CSO compound in the centre of the Shillong Plateau. Another permanent station was established on the northern edge of the Shillong Plateau in the Guwahati University Campus (Figure 17).

Figure 17: Location of points currently occupied in the Shillong Plateau with the uncertainties in their position. The stations marked in white are permanent stations.

Campaign Mode GPS measurements were carried out in November-December 2003 using Trimble 5700 Geodetic GPS Receivers in the Shillong Plateau. Data was collected from 10 stations and processed using GAMIT software at C-MMACS. The GTS sites at Hatimura, Moitsngi, Laidera, Rangsanbo, and Mautherisan were recovered and occupied. The GTS sites at Dinghe, Mun, Mopen and Umter have been destroyed. A GTS site at Mawpani will be occupied in the future because security was not available there due to harvesting season. In addition to this, GPS measurements were carried out in campaign mode at Lal Ganesh-Guwahati, Mun, Tura, Shillong Peak and Mopen. Therefore, 15 sites were examined during this campaign out of which 4 sites were found to be unfit for occupation.

Processed ellipsoidal co-ordinates from the measured sites are given below:

MUN-GPS:	25.41 (±3.1 mm) N;	91.84 (±3.1 mm) E,	1822.94 m (±3.7 mm)
LAIDERA-GTS:	25.50 (±0.8 mm) N;	91.66 (±1.0 mm) E,	1841.15 m (±7.9 mm)
MOPEN-GPS:	25.23 (±0.6 mm) N;	91.43 (±3.4 mm) E,	0741.11 m (±2.1 mm)
LALGAN.-GPS:	26.13 (±0.4 mm) N;	91.74 (±1.1 mm) E,	0088.48 m (±4.4 mm)
SHILPK-GPS:	25.53 (±1.2 mm) N;	91.84 (±3.6 mm) E,	1920.10 m (±24.2 mm)
MOUTH.-GTS:	25.54 (±1.6 mm) N;	91.45 (±1.4 mm) E,	1879.14 m (±7.9 mm)
MOITSIN.-GTS:	25.34 (±3.6 mm) N;	91.58 (±3.5 mm) E,	1723.11 m (±6.5 mm)
RANGSA.-GTS:	25.25 (±2.4 mm) N;	91.71 (±0.5 mm) E,	1309.93 m (±0.6 mm)
HATIMUR.-GTS:	26.17 (±1.5 mm) N;	91.48 (±2.9 mm) E,	0181.33 m (±7.6 mm)
TURA-GPS:	25.52 (±3.5 mm) N;	90.21 (±0.7 mm) E,	0378.07 m (±0.7 mm)

The measurements also included a GTS triangle measured in 1861 during the GTS Survey. The lengths of the triangles as measured during the survey are given below:

BASELINE	**1861**	**2003**
RANGSANBO (XI) - MOSINGI (IX):	16505.7 m	16514.7 m
MOSINGI (IX) – LAIDERA (VIII):	19614.1 m	19620.1 m
MOSINGI (IX) – MAUTHERR. (VII):	25582.4 m	25589.9 m

Future work in the plateau would reveal the nature of deformation there.

SOME IMPORTANT PUBLICATIONS

1. Jade, S., Mukul, M., Parvez, I. A., Ananda, M. B., Kumar, P. D., Gaur, V. K., 2002. "Estimates of Co-seismic Displacement and Post-seismic Deformation using Global Positioning System Geodesy for the Bhuj Earthquake of 26 January", Current Science, 82 (6), 748-752.

2. Paul, J., Burgmann, R., Gaur, V. K., Bilham, R., Larson, K. M., Ananda, M. B., Jade, S., Mukul, M., Anupama, T. S., Satyal, G., Kumar, D., 2001. "The motion and active deformation of India", Geophysical Research Letters, 28 (4), 647-651.
3. J. Freymueller, R. Bilham, R. Burgmann, K. M. Larson, J. Paul, Sridevi Jade and V. K. Gaur. "Global Positioning System Measurements of Indian plate motion and convergence across the Lesser Himalaya", Geophysical Research Letters, vol. 23, No. 22, pp 3107-3110, November 1, 1996.
4. J. Paul, F. Blume, Sridevi Jade, V. Kumar, P. S. Swathi and 6 authors. "Microstrain stability of Peninsular India 1864-1994", Proc. Indian Acad. Sci. (Earth Planet. Sci.), vol. 104, No. 1, March 1995.

VI. TEZPUR UNIVERSITY, TEZPUR, ASSAM

Northeast India is one of the six most seismically active regions in the world. Two great earthquakes have hit Assam within the past 107 years: (M ~ 8.5) of 1897 and (M ~ 8.7) of 1950. Moderate to low level seismic activity is quite frequent and two or three shocks (M ≥ 3) are felt almost daily in some part or the other in the region. Several significant geological lines of weakness (faults) have been mapped on the basis of surface geology. What is not known, however, is (i) Which earthquake groups are related to which faults, i.e., which of the faults are active and, (ii) What is the crustal velocity structure in the region. These basic knowledge inputs are essential for preparing quantitative earthquake hazard [$P(X, \tau, \ddot{u}_{max})$] maps of the region for various values of τ and $\ddot{u}_{max}$. Tezpur University has initiated one DST sponsored project with Dr. A. Kumar as PI to study the kinematics and crustal deformation of NE region with the following objectives:

- Identify active faults in the Meghalaya -Assam - Arunachal region and to determine their shear strain rates by modeling:
  - GPS based annual surface deformation (velocity field) in the area
  - Crustal structure using available broadband seismic data.
  - Identification of fault using magnetic data
- Model precipitable water vapor in the atmosphere at Tezpur and other permanent sites in the region using continuous data at the fixed sites.

ACHIEVEMENTS

Tezpur University has established two permanent GPS stations, one at Tezpur and the other at Bomdila, for acquiring continuous GPS data. These stations are fully operational since June 14, 2003 and January 11, 2004 respectively.

GPS data of 13 campaign mode stations besides two permanent stations have been acquired and processed using GAMIT with both LHASA and IISC constrained to 3mm. Location estimation, baseline length and velocity estimation (ITRF) and velocity vectors of Bomdila and Tawang relative to IISC have been obtained. Preliminary results show that relative to IISC Bangalore, Bomdila is moving with 0.02052688±0.004975 m/yr in west of south and Tawang is moving with 0.020798±0.005118 m/yr in SE direction.

VII. REGIONAL RESEARCH LABORATORY (RRL), BHOPAL

ESTABLISHMENT OF PERMANENT GPS STATION AT RRL, BHOPAL

Under the on-going DST's Seismology Mission, a National data collection facility is created at RRL, Bhopal. This facility provides continuous recording of crustal movement with the help of a GPS mounted on a permanent structure. The required hardware was provided by CMMACS (Bangalore) and the financial supports for day-to-day operations are provided by DST. The collected and archived data is submitted to CMMACS and SOI on regular basis. The site photographs and the salient features are enclosed. This facility became operational with effect from Oct.2003.

Figure 18: A view of the monument

VIII. G. B. PANT INSTITUTE OF HIMALAYAN ENVIRONMENT AND DEVELOPMENT (GBPIHED), ALMORA

INTRODUCTION

G. B. Pant Institute of Himalayan Environment and Development, Kosi Katarmal, Almora is a primer Institution working for the sustainable development of Himalayan region. Under the Land and Water Resource Management Core Programme of the Institute the GPS related activities and projects are undertaken mainly to quantify the tectonic deformation fields in Kumaun Himalaya and to model the landslides occurring in the region using GPS geodesy. In addition, The Institute is a part of DST's National network of permanent GPS stations and has been archiving and processing the GPS data from the Himalayan region through its two permanent GPS stations at Katarmal (Almora) and Gangtok (Sikkim).

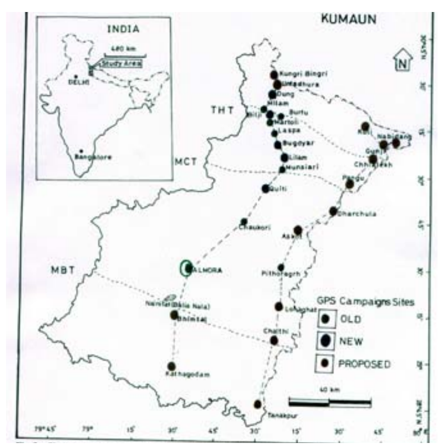


Figure 19: Map of Kumaun and sites along 2 South to North profiles through Almora and Pithoragarh, marked for systematic GPS campaigns to constrain the gradients of strata accumulation along these sites

GPS RESEARCH ACTIVITIES

GPS related research work for Himalaya region is carried out. Currently the DST funded project "Quantification of tectonic deformation field in Kumaun Himalaya - A basic framework for landslide hazard modeling using sub-cm precision GPS surveys" with the following objectives:

1. Study of N-S strain gradient using high-precision GPS survey, to determine the annual strain rate field in Kumaun Himalaya from Dung (north of Milam) to Kathgodam and Malpa to Sukhidhang.
2. To monitor the temporal evolution of some potentially damaging landslides using Kinematics GPS survey.

Processing of GPS data (permanent stations and Campaign stations) is started using GAMIT/ GlobK software for baseline and velocity determination. Landslide monitoring has been initiated on an active landslide using kinematic and rapid static surveys for the first time in the region.

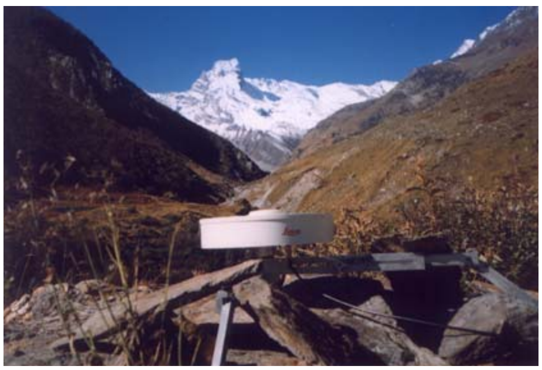


Figure 20: GPS campaign site – Laspa

Figure 21: Permanent GPS station - Gangtok

SOME IMPORTANT PUBLICATIONS

1. Paul, J, Burgmann, R., Gaur, V. K., Bilham, R., Larson, K. M., Ananda, M. B., Jade, S., Mukal, M., Anupama, T. S., Satyal, G., and Kumar, D. (2001). "The motion and active deformation of India", Geophysical Research Letter, vol. 28 (4), pp. 647-650.
2. Satyal, G. S., Kumar, Kireet and Palni, L. M. S. Jade, S., Mukal, Gaur, V. K. (1999) "A continuous reference GPS station at GBPIHED, Katarmal Almora", report submitted to DST.
3. Kumar, K. Satyal, G. S., and Joshi, R. (2001) "Influence of geological features on landslides with particular reference to tectonic deformation rates obtained from GPS surveys in Kumaun Himalaya", status report submitted to DST.

IX. DEPARTMENT OF ENVIRONMENTAL SCIENCE, GUWAHATI UNIVERSITY

The Department of Environmental Science, Guwahati University installed a permanent GPS Station on an exposed granite gneissic rock in the university campus in collaboration with C-MMACS, Bangalore in December 2002 (Figure 22). Since then continuous data acquisition is going on with a Trimble make (*Model No. 4000SSi*) receiver. The data acquisition interval was kept at 30 seconds and the observation period was kept as 24 hours.

ANALYSIS OF DATA AND RESULTS

The data recorded in the permanent station for the year 2003 is analyzed with respect to IGS GPS Station, Bangalore and IGS GPS Station, Lhasa using the GAMIT-GLOBK software. On the basis of the analysis, the crustal velocity at Guwahati is found to be roughly *27.8 mm/yr towards north and 39.8 mm/yr towards east*. The base line length obtained in the analysis is given in Table 2.

Table 2: Baseline Lengths

Baseline	Length (m)	Adjust (m)	Sigma (m)
LHAS-GHTU	392282.3208	0.025	0.001
IISC-GHTU	2060915.3078	0.036	0.003
IISC-LHAS	2299529.1765	-0.008	0.003

A research project entitled "*Study on crustal geodynamics in the Assam foreland basin using GPS*", sponsored by the Department of Science & Technology (ESS Division), New Delhi has been undertaken by the department with Dr. Sarbeswar Kalita as PI and Prof. D. C. Goswami and Dr. M. M. Saikia as Co-PI of the project. The study area comprises mainly the valley region of Assam. The main objective of the project is to monitor the fault activity of the major lineaments/faults that lie across the Assam valley region. Under the project, two Leica GPS receivers (SR 520) have already been procured which are being used as campaign mode stations in different locations across the faults/lineaments in the study region.

Figure 22: Guwahati University Permanent GPS Station

FUTURE PLANS

- To generate a GPS database on the crustal movement/deformation in the Assam foreland region. This might be a good supplement to the National GPS Programme of DST, Govt. of India.
- Application of GPS technology to monitor the crustal movement/deformation of the Assam foreland region to understand its seismotectonic activities and the process of major earthquakes.
- To supplement the current ongoing research in the department on the seismicity of Lower Assam Region under a separate project entitled "Seismic Studies in Lower Assam Region", sponsored by DST, Govt. of India.
- Creation of trained manpower in the university in the application of GPS to geodynamical and seismological studies.

X. MAHARAJA SAYAJIRAO UNIVERSITY (MSU), BARODA

PROJECT TITLE

Active tectonics in the Kachchh, Cambay, and Narmada rift systems using GPS geodesy.

OBJECTIVES

1. To establish a permanent GPS station on the cratonic shoulder of the rift basins to serve as a continuous reference station for GPS geodetic investigations in the region.
2. Annual monitoring of about 60 campaign sites spanning the three rifts and their adjoining cratonic areas.
3. Integration and interpretation of the observed geodetic data to delineate the surface deformation in the region and kinematics of the three rift systems using mathematical modeling.

XI. INDIAN INSTITUTE OF TECHNOLOGY KANPUR (IITK), KANPUR

One permanent GPS station at IITK (Indian Institute of Technology Kanpur) is now operational and other stations at Chitrakut and Jhansi are in the process of deployment. One GPS will be used in campaign mode at Kanpur and also along Agra to Varanasi. GPS equipments and related software are purchased and are in good condition.

A temporary GPS Antenna (Zephyr Geodetic) is set on top of Civil Engineering building, IITK campus using tripod and data are continuously recorded directly in the lab since middle of January 2004. It is configured to record data continuously on a PC at various rates and in multiple formats (DAT, SSF, and RINEX). Trimble Reference Station software has been used for recording at user defined standard intervals. GAMIT is installed on REDHAT LINUX system and also on SUN SOLARIS for data processing.

Campaign mode locations at the interval of 50 km are marked from Kanpur to Varanasi. We have selected locations and took GPS readings. These locations are far away from roads, power lines and trees to avoid electrical/electromagnetic interferences with GPS signals. Repeat measurements at these locations are being made at regular intervals.

GPS data is being collected since January 15, 2004 (day time only). It is available for continuous period from January 27 and in multiple formats and rates as of January 31, 2004. Efforts are being made to carry out geodetic measurements in the Bundelkhand region as well as water vapor, tec, vtec and water vapor studies. Our Permanent Base station at Chitrakut will help in post-processing of data for better positional accuracy, tectonic studies and atmospheric and ionosphere studies. Existing AERONET dataset is currently used to derive water vapor column at IITK. GPS can be used to retrieve water vapour daily, whereas AERONET is largely dependent on the availability of sun and climate. Such data will be useful in meteorological and climate modeling and atmospheric correction of satellite data.

XII. NATIONAL REMOTE SENSING AGENCY (NRSA), HYDERABAD

GROUND SURVEYS BY GLOBAL POSITIONING SYSTEM

The control surveys for the photogrammetry and mapping jobs in NRSA were carried out using Theodolites and EDMs since 1980. In 1994, 2 Trimble 4000SSE Dual Frequency GPS Receivers for Ground Control Surveys were procured. These GPS receivers are extensively used for dense Ground control surveys for photogrammetric control extension and Aerial Mapping project. During the year 1995, 2 Trimble 4000SSE Dual Frequency GPS receivers for Airborne Kinematic GPS applications were procured. With the help of airborne kinematic GPS, the photo principle centre coordinates will be derived precisely. This has tremendously reduced the ground control survey for photogrammetric control extension and further mapping with aerial photogrammetry method. During the year 1998, the Ground Control Point Library (GCPL) generation for entire India using the GPS based field measurements for the CARTOSAT-I satellite was envisaged.

For the generation of Ground Control Point Library, the Aerial Services and Digital Mapping group of NRSA, with Mr. K. Kalyanraman as General Manager, procured 22 Dual Frequency GPS receivers during 1999 and 8 more in 2000, for GCPs data collection of GCPL project, which strengthened the Ground Surveys facility in NRSA. These systems are being used for carrying out GCP data collection for GCPL project, LSM project, CARTOSAT-II and other aerial and Satellite Mapping Projects. As part of GCPL project, we established Datum in WGS-84 for India – by establishing network of:

1. 26 Primary stations (Zero order stations) with accuracy of better than 5cm
2. 300 first order points with accuracy better than 10cm

THE GROUND CONTROL POINTS LIBRARY PROJECT

The need for the high accuracy GCPs Library came from the high resolution i.e. 2.5m of the CARTOSAT-I. Ground Control Points (GCP) Library for IRS-1A/B and IRS-1C/D projects was developed by Space Applications Center, Ahmedabad in collaboration with Survey of India during 1986 to1993. These databases are being used operationally at NRSA for IRS Data Products related activities, viz. Precision Processing, Swath modeling, Data Quality evaluation, Geocoded products etc., for IRS-1A/B and IRS 1C/D. The IRS-1A/B GCP library has a planimetric accuracy of approximately 25m and is sufficient for processing LISS I and LISS II imagery. The IRS-1C/D GCP library has a planimetric accuracy of approximately 10-15m and is sufficient for processing PAN imagery.

This accuracy level is not sufficient for the planned resolution of 2.5m or better for CARTOSAT. It is suggested to build the GCP library as a program element to cater to the requirements of CARTOSAT. Ground Control Point Library (GCPL) project of CARTOSAT, deals with the generation of approximately 5000 GCPs well distributed over full India. The aim of this activity is to generate high accuracy control point library with the ground coordinates of GCPs of permanent nature and which are well identifiable on the satellite imagery to serve as control points for subsequent processing of CARTOSAT data.

The field GPS data collection for 5000 points at a time is a difficult job. It requires more manpower and instruments to achieve the desired accuracy. Hence the basic Survey principle “WHOLE TO PART” is considered and the survey is planned in three levels:

- 1st Level: “ZERO ORDER”
- 2nd Level: “1st ORDER”
- 3rd Level: “2nd ORDER”, in which the points are GCPs

The 26 zero order points were established by constructing cubic monument of 60 cm side, with a marker brass plate of 10 cm diameter engraved with 0.25 mm size dot, with 1cm diameter circle around it and with a unique number assigned to the point, on the top of DOS centers and State remote sensing centers buildings. The Zero order points are well distributed throughout India. The field GPS data for Zero order points is collected continuously for 72 - 120 hours, in five phases. In each phase, data at 7 zero order points was collected keeping two points common between each phase. These zero order points are established taking IGS Stations around India as Reference stations. The GPS data was processed using Bernese scientific GPS post processing software developed by University of Bern, Switzerland. All the zero order stations data was processed phase wise and networked by combining all the phases’ data. The coordinates of the IGS stations considered were on ITRF97. The accuracy achieved for the final coordinates of these stations is 1-3 cm.

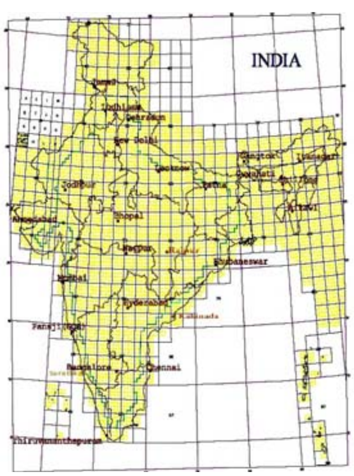


Figure 23: Zero order stations

Figure 24: First order points

The 1st Order points, approximately 300 in number, were selected such that for every 110 km x 110 km grid one 1st order point will be there. These points are also monumented with Brass marker plate. The designed accuracy of these points is better than 10 cm. A minimum of 8 hours GPS data was collected to achieve this designed accuracy. For most of the stations, more than two sessions of 12 hours each GPS data was collected for first order points. The GPS data of all 1st order points was processed using Bernese software, taking Primary points (zero order points) and IGS Reference Stations, wherever required, as reference points and thus, the first order network of more than 300 points was established.

With the zero order and first order points network of stations in WGS-84 datum established, the Ground Control point Library generation with about 4000 out of planned 5000 Ground Control Points consisting of GCP coordinates in WGS-84 datum was taken up. The accuracy requirement for these points is 30 to 50 cm. A stepped pattern was followed in selection of GCPs for swath width of 30 km and length of 500 km. The GCPs selected are mostly road canal crossings, road-road junctions, road-railway line crossing etc. During selection of this type of points, it is also kept in mind that some settlement also exists near the point. Field sketches, field photos, description etc. are collected from the field. GPS survey for GCPs coordinates of entire India was taken over and completed except for Northeast states and Jammu and Kashmir. The results are also very encouraging, with rms values of the GCPs less than 20 cm for 85 percent of NRSA-surveyed GCPs.

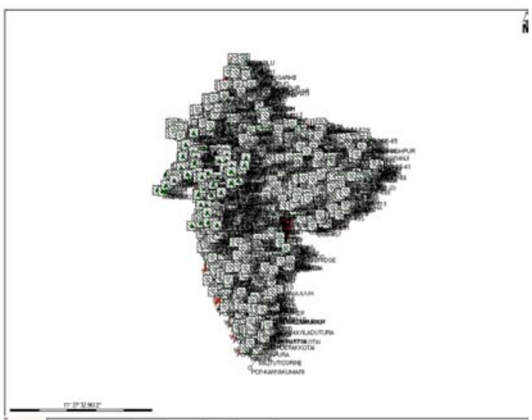


Figure 25: Map obtained from the GCPs collected with GPS data

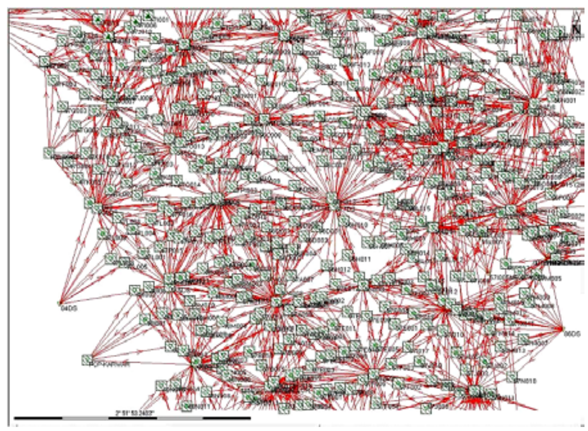


Figure 26: The network of GCPs with Field collected GPS data

XIII. NATIONAL GEOPHYSICAL RESEARCH INSTITUTE (NGRI), HYDERABAD

The GPS Group at the National Geophysical Research Institute, with Dr. V. K. Gahalaut as PI, has taken up GPS measurements in the Indo-Burmese arc region.

OBJECTIVES OF THE PROPOSAL

Campaign mode GPS measurements in the eastern part of the NE India in the region of Indo-Burmese arc are proposed with the following objectives:

1. To assess whether the subduction is still continuing in this region.
2. To understand the geodynamic processes in that region related to the northeastward movement of the Indian plate.

3. Assessment of earthquake hazard in the region by understanding the earthquake occurrence processes in the Indo-Burmese arc.

SUMMARY OF THE PROGRESS

During the two field works, 13 campaign mode GPS sites have been selected in Manipur, Mizoram and southern Assam states of NE India along and across the Indo-Burmese arc (see Figure 27). These stations are established in hard and stable rocky region and are properly marked for reoccupation. The first campaign was carried out during June 2004. All the stations were occupied for three consecutive days. The GPS data will be processed using GAMIT geodetic data processing software. The data from nearby IGS GPS stations, and permanent stations such as Bangalore and Hyderabad and Imphal, Aizawal, Kohima, Shillong and Tejpur, will be included in the processing. The resulting displacement vectors will be analysed and modeled using the available mathematical formulations based on elastic dislocation, or viscoelastic models.

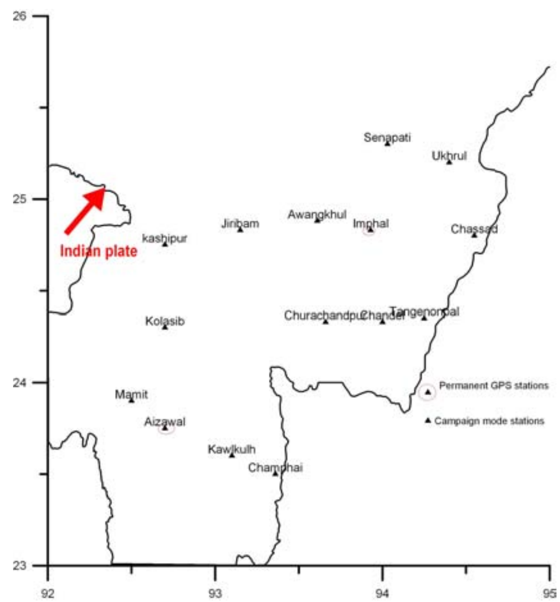


Figure 27: GPS sites selected in Manipur, Mizoram, and southern Assam states of NE India

We have utilized the available results of GEODYSEA and Myanmar GPS campaigns to suggest that the relative plate motion between the Indian plate and Sundland block is shared equally between the Indo-Burmese arc and Sagaing fault through dextral motion.

2.4 INITIATIVE BY OTHER ORGANIZATIONS/INSTITUTIONS

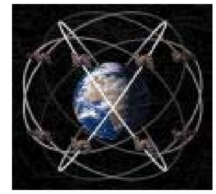
In addition to the above Institutions, several other agencies like National Informatics Centre (NIC), Indian Institute of Remote Sensing (IIRS), Department of Electronics (DOE), etc. have also initiated GPS related work, as a part of their Institutional programme.

2.5 MANPOWER DEVELOPMENT

Considering the future need of suitable manpower in GPS technology, necessary efforts are being made by the Seismology Division of DST for organizing short-term courses, workshops and training programmes. As a result of this, 5 training programmes/short term courses have already been organized at WIHG, Dehradun, IIT Bombay, Itanagar, and CMMACS, Bangalore, in which nearly 100 persons from various universities and research institutes have been trained.

3. THRUST AREAS FOR NATIONAL GPS PROGRAMME

- Determination of strain fields around different tectonic blocks:- i. e. Bhuj, Son-Narmada Lineament, North Western and Eastern part of Himalaya, Khandwa region of Madhya Pradesh, Ongole area of Andhra Pradesh, Great Boundary fault etc.
- Stability of South Indian Peninsula.
- Crustal deformation studies along major shear zones.
- Motion and active deformation of India.
- Geodynamic behavior of Himalaya.
    - Crustal deformation studies along Eastern and Western Ghat regions.
    - Neotectonic movements, study of active faults, landslides etc.
    - Quantitative geomorphology.
    - Ionospheric modeling.
    - Manpower development in GPS technology, SAR Interferometry and ALTM.



ANNEXURE-I

PERMANENT GPS STATIONS (Institution wise)

ALREADY ESTABLISHED

Sr. No.	Name of Station	Maintained by
1.	Aizwal	Mizoram University, Aizwal
2.	Almora	G. B. Pant Institute, Almora
3.	Bangalore (IGS Station)	Centre for Mathematical Modelling and Computer Simulation (CMMACS), Bangalore
4.	Bhopal	Regional Research Laboratory, Bhopal
5.	Bhubaneshwar	Survey of India
6.	Bomdilla	Tezpur University, Tezpur
7.	Dehradun	Wadia Institute of Himalayan Geology, Dehradun
8.	Delhi	India Meteorological Department
9.	Dhanbad	Indian School of Mines, Dhanbad
10	Dharamshala	Wadia Institute of Himalayan Geology, Dehradun
11.	Gangtok	G. B. Pant Institute, Gangtok
12.	Guwahati	Guwahati University, Guwahati
13.	Hanle	Indian Institute of Astrophysics, Bangalore
14.	Imphal	Manipur University, Imphal
15.	Jabalpur	Survey of India
16.	Kanpur	Indian Institute of Technology Kanpur
17.	Kodaikanal	Indian Institute of Astrophysics, Bangalore
18.	Kothi	Wadia Institute of Himalayan Geology, Dehradun
19.	Leh	Indian Institute of Astrophysics, Bangalore
20.	Lucknow	Geological Survey of India
21.	Mokukchung	Nagaland University, Kohima
22.	Mumbai	Indian Institute of Technology Bombay, Mumbai
23.	Nagpur	Indian Institute of Geomagnetism, Mumbai
24.	Panamik	Wadia Institute of Himalayan Geology, Dehradun
25.	Pondichery	Indian Institute of Geomagnetism, Mumbai
26.	Pune	Survey of India
27.	Shillong	Survey of India
28.	Tezpur	Tezpur University, Tezpur
29.	Trivandrum	Survey of India
30.	Visakhapatnam	Indian Institute of Geomagnetism, Mumbai

PERMANENT GPS STATIONS

BEING SET UP

Sr. No.	Name of Station	Maintained by
1.	Munishiari	Wadia Institute of Himalayan Geology, Dehradun
2.	Bhatwari	Wadia Institute of Himalayan Geology, Dehradun
3.	Pithoragarh	Indian Institute of Astrophysics, Bangalore
4.	Chitrakut	Indian Institute of Technology Kanpur
5.	Jhansi	Indian Institute of Technology Kanpur

PROPOSED TO BE SET UP

Sr. No.	Name of Station	Maintained by
1.	Gulmarg	Indian Institute of Geomagnetism, Mumbai
2.	Jaipur	Indian Institute of Geomagnetism, Mumbai
3.	Allahabad	Indian Institute of Geomagnetism, Mumbai
4.	Silchar	Indian Institute of Geomagnetism, Mumbai
5.	Bhuj	Indian Institute of Geomagnetism, Mumbai
6.	Kolhapur	Indian Institute of Geomagnetism, Mumbai
7.	Tirunelveli	Indian Institute of Geomagnetism, Mumbai
8.	Pavagarh (Gujarat)	M. S. University of Baroda

The tables given above show the status of the permanent GPS stations and the Institutions responsible for maintenance of these GPS stations, established under the National GPS Programme.

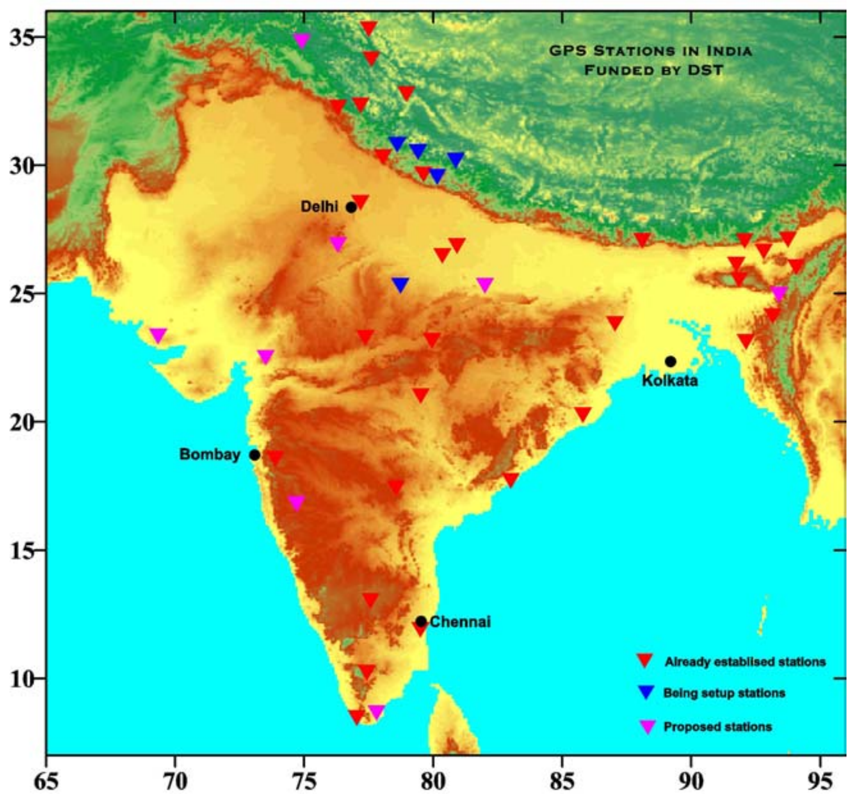


Figure 28: Permanent GPS Stations Network set up under the Programme

ANNEXURE-II

Campaign Mode Studies supported in Project mode

Sr. No.	Region	Institution
1.	North-Western Himalayas	Wadia Institute of Himalayan Geology, Dehradun. (WIHG), CMMACS, Bangalore (CMM)
2.	Shillong Plateau	CMMACS, Bangalore (CMM), Tezpur University,Tezpur (TU), Central Seismic Observatory, Shillong (CSO)
3.	Darjeeling-Sikkim Himalayas	G. B. Pant Institute, Gangtok (GBPIHED), CMMACS, Bangalore (CMM)
4.	Indo-Burmese Arc	Manipur University, Imphal (MU), National Geophysical Research Institute, Hyderabad (NGRI), Aizwal University (AU)
5.	Bhuj region	Indian Institute of Technology Bombay (IITB), Indian Institute of Geomagnetism, Mumbai (IIG), M. S. University, Baroda (MSU)
6.	Western Maharashtra	Indian Institute of Technology Bombay (IITB), Indian Institute of Geomagnetism, Mumbai (IIG), National Geophysical Research Institute, Hyderabad (NGRI)
7.	Meghalaya-Assam-Arunachal Region	Tezpur University, Tezpur (TU), Guwahati University, Guwahati (GU)
8.	Son Narmada Lineament & Central India	Regional Research Laboratory, Bhopal (RRL), Indian Institute of Technology Kanpur (IITK), M. S. University, Baroda (MSU)
9.	Kumaun & Garhwal Himalaya	G. B. Pant Institute, Almora (GBPHIED), CMMACS, Bangalore (CMM)
10.	Southern India	CMMACS, Bangalore (CMM), Cochin University, Cochin (CU)
11.	Palghat gap region	Centre for Earth Science Studies, Trivandrum (CESS)

The table given above shows different GPS campaigns initiated under the National GPS Programme and the Institutions responsible for the campaigns.

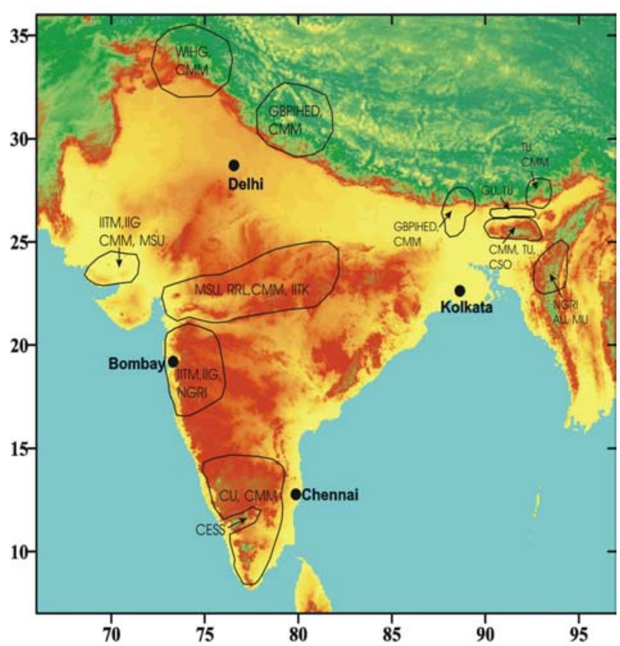


Figure 29: Campaign mode studies carried out under the Programme

Proposals are invited from scientists for studying the crustal deformation process in any part of India with the help of GPS with the following objectives:

- **To establish the rate of movement of the tectonic plates relative to each other.**
- **To establish the strain rates in different tectonic domains of India and to constrain strain partitioning in discrete tectonic domains/block and identify the area of higher strain build up/release.**

The proposals may be submitted to *Head, Seismology Division, DST, as* per the guidelines/format laid down by DST, available at Internet site www.serc-dst.org.

For further information contact:

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New Delhi-110 016.
Tel: 011-6567373 ext 458
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e-mail:-guptagd@alpha.nic.in

Prepared by: ***Prof. Madhav N. Kulkarni & Sagar Deshpande, IIT Bombay, and Shri. M. Mohanty, Scientist, DST, on behalf of the Head, Seismology Division of Department of Science & Technology, Government of India.***
Inputs from participating Institutions up to November 2004 are incorporated and thankfully acknowledged.

Back Cover Page:

GPS Nominal Constellation of 24 Satellites in 6 Orbital Planes.

NATIONAL PROGRAMME
on
GLOBAL POSITIONING SYSTEM (GPS)
for
EARTHQUAKE HAZARD ASSESSMENT

DEPARTMENT OF SCIENCE AND TECHNOLOGY
GOVERNMENT OF INDIA
TECHNOLOGY BHAVAN, NEW MEHRAULI ROAD
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