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Estimation of Very Long Base Lines by GPS Geodesy

For Indian Plate Kinematic Studies

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Bestimmung Langer Basislinien mit GPS für Untersuchungen
zur indischen Plattenkinematik

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ESTIMATION OF VERY LONG BASELINES BY GPS GEODESY FOR INDIAN PLATE KINEMATIC STUDIES

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Under INDO- GERMAN Collaborative Scientific project , between NGRI,CSIR and Geodetic Institute , University of BONN, GPS data for the time span of three years from Sep'95-Sep'98 was acquired. Data was processed and refined data analysis was carried out to study the Indian Plate kinematics. The results obtained are submitted as Ph.D dissertation by Mrs. E.C.Malaimani , Scientist, NGRI , to University of BONN, Germany.

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Kurzfassung

Bestimmung Langer Basislinien mit GPS für Untersuchungen zur indischen Plattenkinematik

von

E.C. Malaimani

Ziel des dieser Arbeit zugrundeliegenden Projektes im Rahmen einer deutsch-indischen Kooperation war die Messung von geodätischen Basislinien mit Hilfe von GPS zwischen dem indischen Subkontinent und den benachbarten Kontinenten zur Untersuchung der plattentektonischen Erdkrustenbewegungen im indo-eurasischen Raum. Die Belange Indiens standen bei diesem Projekt im Vordergrund, da bekanntlich die Kollision des indischen Subkontinentes mit Eurasien, die vor ca. 40 bis 60 Millionen Jahren begann, auch gegenwätig noch zu Erdbeben mit z.T. katastrophalen Folgen führt. Die Ziele der aktuellen geodätischen Meßprogramme sind gerichtet auf die heutigen Bewegungsparameter, um daraus Schlüsse über die aktuellen Spannungen in der Erdkruste, vor allem im Bereich des südlichen Himalaya, ziehen zu können.

Die GPS-Meßkampagnen erstrecken sich über einen Zeitraum von ca. 3 Jahren, wobei in Hyderabad in Durchschnitt an zwei Tagen pro Woche beobachtet wurde. Bei der Station Hyderabad bestand zunächst die Absicht, alle Meßdaten sofort, d.h. quasi on-line, in das IGS Auswertezentrum einfließen zu lassen. Da dies jedoch aufgrund der besonderen technischen Einschränkungen in Hyderabad (kein ftp-link) nicht möglich war, mußte eine Strategie der nachträglichen Einbeziehung der Station in das IGS-Weltnetz entwickelt werden. Diese Strategie besteht in der Beschaffung von Daten der Stationen eines speziell ausgewählten Sub-Netzes und der gemeinsamen Auswertung dieser Stationen im Sub-Netz. Diese Auswertung umfaßt einen Datensatz, der sich über ca. drei Jahre erstrekt und neben Hyderabad 8 weitere IGS-Stationen enthält. Die Auswertung geschah in zwei Etappen, einer ersten mit "manueller" Bearbeitung ausgewählter Datensätze die jeweils einen Tag umfassten und einer zweiten mit weitgehend automatischem Ablauf, bei der alle vorhandenen Epochen bearbeitet wurden.

Die in Kap. 9 (Results and Discussion) vorgestellten Ergebnisse sind in vieler Hinsicht hochinteressant. Zunächst ist an den zeitlichen Änderungen der Basislängen (diese sind am wenigsten von Rotationen der Bezugssysteme betroffen) gut zu erkennen, daß bei Basislängen bis zu etwa 6000km eine relativ gute Wiederholungsgenauigkeit erzielt werden kann und z.T. hochsignifikante Änderungsraten erhalten werden. Die Ergebnisse der Meßreihe von knapp drei Jahren Länge zeigt bereits eine eindeutige Tendenz der Bewegung in nordöstliche Richtung von ca 5 cm/Jahr.

Ein weiteres beachtliches Ergebnis stellt die kleine aber merkliche Verkürzung der Distanz zwischen Hyderabad und Bangalore dar, was auf eine Kompression der indischen Platte in Richtung NNO-SSW hinweist. Diese Information kann große Bedeutung erlangen im Zusammenhang mit den Erdbeben im inneren Bereich der indischen Platte (z.B. Latur).
Bei Basislängen über 6000km verschlechtert sich diese Genauigkeit dramatisch bis zu einem Grade, wo keine signifikante Raten mehr bestimmbar sind (Basislinien Hyderabad-Yaragadee und Hyderabad-Hartebeesthoek). Wesentliche Faktoren sind hier natürlich die geringe simultane Sichtbarkeit der GPS-Satelliten sowie im Falle von Hartebeesthoek, Südafrika die großen Datenausfälle.

Zusammenfassend läßt sich sagen, daß es gelungen ist, mit den drei Jahre umfassenden GPS-Daten der Station Hyderabad die indische Plattenbewegung relativ zur eurasischen Platte nachzuweisen. Gleichzeitig wurden realistische Genauigkeitsschätzungen für die quasi-permanenten GPS-Messungen im globalen IGS-Rahmen bestimmt und die Signifikanz der ermittelten Bewegungsraten nachgewiesen. Damit ist ein Durchbruch zu einer erstmaligen umfassenden Bestimmung der Plattenbewegungsrate des indischen Subkontinents in Relation zu Eurasien gelungen.

SUMMARY

Estimation of Very long Baselines by GPS -Geodesy for
Indian Plate Kinematic Studies.

By
E.C.Malaimani

Under the Indo-German Collaborative, Bilateral Exchange Programme, a Project to study the ongoing Indian plate motion has been initiated between the National Geophysical Research Institute (NGRI, CSIR) and the Geodetic Institute of the University of Bonn, Germany. In this project, a permanent tracking/reference station was established at NGRI, Hyderabad by installing a Turbo Rogue GPS -SNR 8000 Receiver and the corresponding data taking and storing facilities. The GPS measurements in the IGS Global Network are meant to monitor intercontinental and intra plate crustal motion and to determine velocity vectors, eventually to derive information concerning the stresses in the Earth's crust, in particular in the Southern Himalayas.

The GPS-campaigns used in the data analysis cover a time period of approximately 3 years, during which observations were taken at least twice a week. The data transfer had to be carried out off-line by mailing diskettes, which meant that the analysis had to be performed in a post-operative way. The adopted strategy was to retrieve the data from a selected set of IGS-permanent stations on the Eurasian continent as well as in Australia and South Africa.

The refined GPS data processing and analysis by using Bernese software were carried out at the Geodetic Institute. The first data set up to Jan. 1997 was prepared and a Global Network solution was carried out to estimate Very Long baselines between Hyderabad and other IGS selected stations. Subsequently, the processing of 300 epochs was carried out in a semi automatic way using the Bernese Processing Engine (BPE). Special care was taken to eliminate incomplete or otherwise defective data sets before the final run. Two different types of solutions were performed, the first one by an epoch by epoch solution which shows the time evolution of coordinates and baseline lengths, and the second one for simultaneous coordinate and velocity vector estimation. The first solution was helpful to visualize the repeatability of the results for each epoch and to derive realistic error estimates for the site motions.

In chapter 9, (Results and Discussion), we discuss the significance of the most important results achieved so far. Our processing of 3 year's data from Sept. 95 to Sept. 98 by global network solution involves estimation of baselines of 500 km (Hyderabad-Bangalore) to 7000 km (Hyderabad-Yaragadee) lengths. One important result is that the baselines up to 6000km yield quite reliable repeatabilities within 2cm. Thus, the baseline between Hyderabad and Irkutzk (Russia) is shortening at a rate of 5cm/year, with a high level of significance.

The baseline between Hyderabad and Bangalore shows a compression in NNE-SSW direction over the past 3 years, yielding a first constraint for the inner plate stability of the Indian plate of 2mm/yr ± 1mm/yr. This information could gain importance in respect to the inner plate seismicity (cf. recent Latur earthquake). On the other hand, the baselines beyond 6000km suffer from reduced simultaneous visibility and, correspondingly, suffer substantial accuracy losses.

In summary, the most significant result of our analysis is that the baseline vectors from Hyderabad to other stations beyond Himalaya are shortening. This phenomenon is fitting into the basic theory of Indian plate motion. Velocity vectors thus computed for all the stations used in the analysis are comparable with the NUVEL -1A global plate model. This means that a first breakthrough in determining plate motion rates for the Indian Subkontinent has been achieved.

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1. INTRODUCTION

SPACE GEODESY has evolved in the last thirty years into one of the most exciting disciplines of earth sciences. In particular the last 10 years have seen an unprecedented growth in the field with no end in sight. This development is due to the large extent, to the versatility of applications provided by the GPS threshold technology. **Global Positioning System** has already revolutionized almost all conceivable positioning applications on land, in the air, in space, and at sea With the present day fully operational GPS constellation and the availability of affordable receivers, GPS is moving rapidly into the world of space geophysics.

Applications of GPS include centimeter level precise orbit determination (POD) to support ocean altimetry, earth gravity model improvement and other enhancements to global geodesy and geodynamics, high -resolution 2D and 3D ionospheric imaging, radio occultation to recover precise profiles of atmospheric density, pressure, temperature and water vapour distribution. The limitless civilian applications of GPS extend to global time and frequency synchronization, Air craft navigation, surveys (large scale and medium scale) and establishing local reference frame with reference to ITRF.

With various applications like **GPS for Geodynamics,** Space geophysics, oceanography, ionosphere, and atmosphere studies, timing, local and large scale surveys for crustal deformation studies, GPS will be an indispensable tool in the next millennium.

Global models of plate tectonics can be established, based on geological, paleomagnetic, and seismic investigation and derived from accumulated motion rates over longer periods of time. Models of current plate motions have been estimated for almost 20 years using spreading rates at mid ocean ridges, transform faults azimuths and plate boundary earthquake slip vectors (LePichon;1968,Chase ;1972, Minister et.al;1974, Minister and Jordon;1978,DeMets et.al;1970). Early in the development of plate tectonics, it was recognized that plate boundaries in continental areas are substantially wider than those in oceanic plates. (Isachs et.al; 1968, Mckenzie; 1970, Molnar and Tapponier; 1975). It is important to understand the underlying causes for this different behaviour as well as the most appropriate way of describing continental deformation by estimation of very long baseline vectors and their temporal evolution. Global plate models (No Net Rotation NNR NUVEL-1) are available and they explain the large-scale features of plate kinematics models. (Demets.et.al; 1990, Argus and Gordon et.al; 1990, & 1991).

Tectonically active plate motions on the earth's crust are causing catastrophic earthquakes. Accurate measurements of these plate movements-magnitude, rate and direction are very crucial for understanding the crustal dynamics and associated earthquake processes. The seismicity that characterizes the Indian continent is a consequence of complex interaction of Indian and its neighbouring plates and also accumulation of crustal strain within Indian shield. Hence the accurate knowledge of the nature and the extent of the ongoing deformation is very crucial for an understanding of occurrence of earthquakes and associated processes.

Among the existing Space GEODETIC techniques like VLBI, SLR and GPS, GPS has emerged as a threshold technology. GPS has been widely accepted worldwide for GEODYAMICS. It has been particularly useful in measuring / monitoring the more complex deformation pattern across the plate boundaries because of its capabilities to provide millimeter level precision for baselines of several thousand kilometers in length. Among the above mentioned techniques, GPS is proved to be more useful for measuring the displacement/movement of earth features, because of its advantages over other techniques such as economy, high accuracy, portability, global accessibility etc. Establishment of a countrywide network of GPS stations will facilitate assessing the seismic risk zones of the entire country in a systematic way.

Since the Indian plate is active, causing number of earthquakes in the Himalayan region including the very recent earthquake of M=6.8 Richter scale on March 29th 1999 in Chamoli District of Garhwal in the north and intra-plate earthquakes even in the so called stable shield areas of the country, it is very much essential to quantify the rates of strain accumulation in different parts of the country in order to characterize their earthquake potential and for better understanding of the geodynamics process.

With this foregoing assessment, few questions were addressed in this thesis to study further the evidence of ongoing INDIAN plate motion by GPS - GEODESY by estimating very long baselines and velocity vectors.

As a revised programme in SPACE GEODESY, under (CSIR-DLR) INDO - GERMAN collaborative Bilateral Exchange programme, a Turbo Rogue GPS receiver and a Compaq 486PC were gifted to NGRI to establish the IGS permanent tracking station. In June 1995, it was installed and commissioned. It is fully operational since Sep, 1995. continuous operation of the station, data acquisition (1MB /24 hours), offline data transfer in RINEX format in floppies to our GERMAN collaborators , data archiving are on from SEP 95.

In this thesis, while carrying out refined data processing and analysis to estimate the very long baseline vectors and velocity vectors, we discuss the error sources involved, and the influences of them in estimating the accuracy and precision.

Error analysis was carried out to study how the ambiguities are dealt for long base lines. We explain how least square estimation (LSE) is used for parameter estimation and different rms errors dealt with.

Finally the result obtained on the present-day kinematic picture of Indian Plate is presented. By these results, Indian plate kinematics is studied by GPS GEODESY. HYDERABAD COORDINATES in ITRF96 reference frame are estimated.

With just 3 years of data we were able to obtain the rate of movement with only GPS data. The results achieved conform with NUVEL model as far as the plate movement is concerned. Though the Global data centers routinely produce velocity vectors, this analysis is able to show the significant details of how well the actual measurements are fitting with the individual baseline vector evolution.

The work carried out and presented in this thesis is on par with the analysis by many permanent GPS network worldwide. The results obtained have shown the further evidence of ongoing Indian plate motion .

In between the time when the results obtained and the thesis is prepared, an another large earthquake of M=6.8 Richter scale rocked the hilly regions of UtterPradesh (Garhwal Himalayas) and other parts of North INDIA on March 29^{th} 1999. The epicenter of this earthquake is found to be at Chamoli District. It is an indication of the Indian plate motion in NNE direction and crustal strain is getting accumulated in the main thrust fault between Himalayas and INDIA. Hence the results obtained in this thesis are very important and crucial. They provide an immense input to carry out long term GPS measurements and further analysis to estimate crustal strain accumulation in this plate boundary. By GPS – GEODESY, we could study the Indian plate kinematics by estimating very long baselines.

2. GPS - A SPACE GEODETIC TOOL

2.1. SPACE GEODESY

Geodesy is defined as *the science of the measurement and mapping of the earth's surface* by Dr.F.R.Helmert (1880). This definition includes the determination of the earth's external gravity field, as well as the surface of the ocean floor (ref. Torge 1991).

Space geodesy comprises of the observational and computational techniques, which allow the solution of geodetic problems by the use of precise measurements to, from, or between artificial, mostly near earth satellites. Further to Helmert's definition, which is basically still valid, the objectives of satellite geodesy are today mainly considered in a functional way. They also include, because of the increasing observational accuracy, time dependent variations. (Sigl 1984b, NAS 1978)

The basic problems are:

1) Determination of these precise global, regional, and local three - dimensional positions. (e.g. the establishment of geodetic control)

2) Determination of the earth's gravity field and linear functions of this field (e.g. precise geoid).

3) Measurement and modeling of geodynamical phenomenon (e.g. polar motion, earth rotation & crustal deformation).

The use of the artificial satellites in geodesy has some prerequisites: these are basically a comprehensive knowledge of the satellite motion under the influence of all acting forces as well as the description of the positions of the satellites and ground stations in suitable reference frames. Consequently satellite geodesy belongs to the domain of basic sciences. On the other hand, when satellite observations are used for solving various problems, satellite geodesy can be assigned to the field of applied science. Considering the nature of the problems, satellite geodesy belongs equally to geosciences and to engineering sciences.

By virtue of their increasing accuracy and fastness, the methods and results of satellite geodesy are used more and more in other disciplines like GEOPHYSICS, oceanography and navigation.

2.2.THE ROLE OF GPS IN SPACE GEODESY

The NAVSTAR Global Positioning System (GPS) **is an all - weather, space based navigation system developed by the U.S Department of Defence to satisfy the requirements of the military forces to accurately determine their position, velocity, and time in a common reference system, anywhere on or near the earth on a continuous basis.**

Space Geodesy includes four major techniques namely **VLBI, LLR, SLR and GPS.** There are 4 essential features of GPS and other techniques, which can be compared.

1. GPS is a satellite geodetic technique. There are other satellite geodetic techniques, in particular SLR (Satellite Laser Ranging) and, to some extent, LLR (Lunar Laser Ranging). An almost "died-out species" are astrometric observations to artificial satellites.

2.GPS is an interferometric technique. Highest accuracy is achieved using two or more receivers operating simultaneously. VLBI (Very Long Baseline Interferometry) is an interferometric technique, too.

3.GPS is a satellite microwave technique, i.e., signals are transmitted on microwave carriers through the Earth's atmosphere. There are other such techniques like, the French DORIS system, the German PRARE System, and, last but not least, the Russian GLONASS System.

4.Satellite Microwave Systems: The satellites are emitting signals in the microwave band which are received (or retransmitted) by receivers (transponders) on or near the Earth's surface. GPS, DORIS, GLONASS, PRARE are systems available today.

- Only GPS allows for an unlimited number of receivers on and near the Earth surface (up to Low Earth Orbiters).

GPS : Global Positioning System (GPS) is designed so that typically four to eight satellites are visible simultaneously at any time from most locations in the world. The GPS satellites, at an altitude of the 20,000 Km transmit down to the Earth carrier signals at two L- band frequencies (1.227 and 1.575 GHz) which are modulated by a pseudo random noise code. The two frequencies enable the user to remove most of the signal delay originating in the ionosphere. When four satellites are in view, the users have enough information to solve for the station position and clock offset from GPS time. A worldwide network of 30 stations is permanently operated for global applications of interest to IERS, earth rotation and terrestrial reference frame. A global network of 200 stations for IGS for global geodynamical and geophysical applications is permanently operated. Polar motion is determined daily with the precision of +/- 0.2 milli arc seconds. The high frequency variations of universal time are determined daily with the precision +/-60 Micro seconds, the low frequency accuracy being limited by the instability of the orbit orientation due to unmodelled forces acting on the satellites.

A major strength of GPS for IERS is the possibility of fine densification of the terrestrial frame with a precision of +/- 1 cm by connecting regional campaigns to the permanently operated network. The use of GPS as a technique for determining precise orbits in a number of present and future geoscience space missions also opens wide possibilities of interconnecting variety of reference frames. Kindly refer to Annexure I for system concept, principle, various other applications and accuracy.

GPS is the major tool for regional geodetic activity and local deformation studies. GPS is the threshold technology. GPS has been widely accepted worldwide for GEODYAMICS. It has been particularly useful in measuring / monitoring the more complex deformation pattern across the plate boundaries because of its capabilities to provide millimeter level precision for baselines of several thousand kilometers in length. Amongst various space techniques, GPS - GEODESY has proved to be an indispensable tool worldwide for geodynamics and parameters governing seismotectonics and to quantify continental deformation to a precision of a few mm/y . In this thesis, this powerful tool is used to study the ongoing INDIAN PLATE MOTION by estimating very long base line vectors and velocity vectors.

We have reviewed the role of GPS within Space geodesy. It is clear that GPS actually plays an increasingly important role. Thanks to the excellent and rather inexpensive equipment.

Agencies responsible for coordination:

Coordination is vital in Space Geodesy. The following 4 major organizations try to achieve this goal:

* **IERS:** The International Earth Rotation Service is responsible for defining and maintaining the conventional terrestrial and celestial reference frame, and for determining the transformation parameters between them. The IERS uses results from all space geodetic techniques for that purpose.

* **IGS:** (The International GPS Service for geodynamics). The International GPS data from its global network, for producing making available GPS data from its global network, for producing and disseminating high accuracy GPS orbits, Earth rotation parameters, station coordinates, atmospheric information, etc

* **CSTG:** The Commission on International Coordination of space Techniques for Geodesy and Geodynamics is responsible to develop links between groups engaged in space geodesy and geodynamics, coordinate their work, projects implying international cooperation, etc. to review the contributions made by different technique in the past.

Global GPS activities are very well coordinated by IERS, CSTG and the IGS. With a fully operational constellation, improved accurate orbital parameters, developed and enhanced VLSI technology for the hardware, availability of various scientific and commercial software to process the data for innumerable applications, the role of GPS within SPACE GEODESY has reached the pinnacle.

2.3 REFERENCE FRAMES.

Co-ordinate systems:

The basic observation equation in GPS which relates the range **p** with the instantaneous position vector $\mathbf{p}^S$ of a satellite and the position vector $\mathbf{p}^R$ of the observing site

$$|\mathbf{p}| = |\mathbf{p}^S - \mathbf{p}^R|$$

Both the vectors must be expressed in an uniform co-ordinate system. The definition of a three dimensional Cartesian system requires a convention for the orientation of the axes and for the position of the origin.

CONVENTIONAL INERTIAL SYSTEM:

By convention, the $\mathbf{X_3}$ **o** axis is identical to the position of the angular momentum a at a standard epoch denoted by **J 2000.0.** The $\mathbf{X_1}$ axis points to the associated vernal equinox. At pres this equinox is realized kinematically by a set of fundamental stars. Since this system is defined conventionally and the practical realization does not really coincide with the theoretical system, it is called Conventional Inertial Frame.

CONVENTIONAL TERRESTRIAL SYSTEM:

Again by convention, the $\mathbf{X_3}$**-axis** is identical to the mean position of the earth's rotational axis as defined by the **CIO.** The $\mathbf{X_1}$**-axis** is associated with the mean Greenwich meridian. The realization of this system is named Conventional Terrestrial Frame and is defined by a set of terrestrial control stations serving as reference points (ref. Boucher and Altamimi (1989). Most of the reference stations are equipped with GPS, Satellite Laser Ranging (SLR), and Very Long Baseline Interferometry (VLBI) facilities**.**

The mission of the IERS is to provide timely and accurate data on the earth's rotation for current use and long term studies .For this purpose it has established and maintains an international terrestrial reference frame and an international celestial reference frame and it regularly monitors the relative motion of these two frames by analyzing observational data from a variety of techniques including radio interferometry (VLBI), Lunar Laser ranging (LLR) and Satellite geodetic techniques namely SLR and GPS . Kindly refer the web site http://www.hpiers.fr for further details of these reference frames and the maintenance of them.

The IGS has adopted the ITRF as the reference for the orbit computations. The GPS contribution is important for the maintenance and extension of the ITRF as well as for the global consistency of the IERS results through the permanent high resolution monitoring of polar motion.

Since 1987, GPS has used the World Geodetic System **WGS-84** as a reference (ref. Decker (1986). Associated with WGS-84 is a geocentric equipotential ellipsoid of revolution, which is defined by the four parameters listed in the table. However, using the theory of the equipotential ellipsoid, numerical values for other parameters such as the geometric flattening **(f=1/298.2572221)** or the semi minor axis **(b=6356752)** can be derived. Note that the parameter values have been adopted from the Geodetic Reference System 1980 (GRS-80) ellipsoid.

Parameters of the WGS-84 ellipsoid

Parameter and value	Explanation
a= 6378137m	**Semi major axis of ellipsoid**
J2=1082630.10 $^{-9}$	**Zonal coefficient of second degree**
W_E=7292115.10-11 rad.s-1	**Angular velocity of earth**
u=3986005.10^{8} m^{3}.s $^{-2}$	**Earth's gravitational constant**

A vector X in the terrestrial system can be represented by Cartesian coordinates X, Y, Z as well as by ellipsoidal coordinates λ, φ , h. The rectangular coordinates are often called **Earth-Centered-Earth-Fixed** (**ECEF)** coordinates.

3. GOAL - STUDY OF INDIAN PLATE KINEMATICS.

3.1 Current global plate motions :

Theory of plate motions suggests (Le Pichon et.all (1973) that plates are formed along the ocean ridges from uprising material and driven to both sides. In the collision zone of two plates we find the formation of mountain chains, deep sea trenches and islands arcs. One plate may dive beneath the other forming subduction zones. Plate boundaries are usually associated with increased activity. Six major tectonic plates can be identified as the Pacific, American, Eurasian, Indian, African and Antarctic plates and they are in constant motion. The plates move in three primary ways., via 1) they slide past each other 2) they pull apart or 3) they push into each other with one being pushed underneath the other.

The movement of these plates gave rise to large scale features on the earth's surface such as continents, ocean basins, mountain ranges and volcanoes. Earthquake belts coincide with these plate boundaries **(Fig.1)** In addition, about 26 micro plates are known. The overall pattern of motion is fairly complicated, particularly with the increase of seismic activities in all the large number of micro plates. A detailed knowledge of the kinematic behaviour is fundamental to the understanding of the driving mechanisms. Earthquakes are therefore directly related to tectonic motion and crustal deformation.

Global models of plate tectonics can be established, based on geological, paleomagnetic and seismic investigation and derived from accumulated motion rates over longer periods of time. Models of current plate motions have been estimated for almost 20 years using spreading rates at mid ocean ridges, transform faults azimuths and plate boundary earthquake slip vectors (LePichon; 1968,Chase; 1972, Minster et.al; 1974, Minster and Jordon; 1978,DeMets et.al; 1970). Early in the development of plate tectonics, it was recognized that plate boundaries in continental areas are substantially wider than those in oceanic plates. (Isachs et.al; 1968, Mckenzie; 1970, Molnar and Tapponnier; 1975). It is important to understand the underlying causes

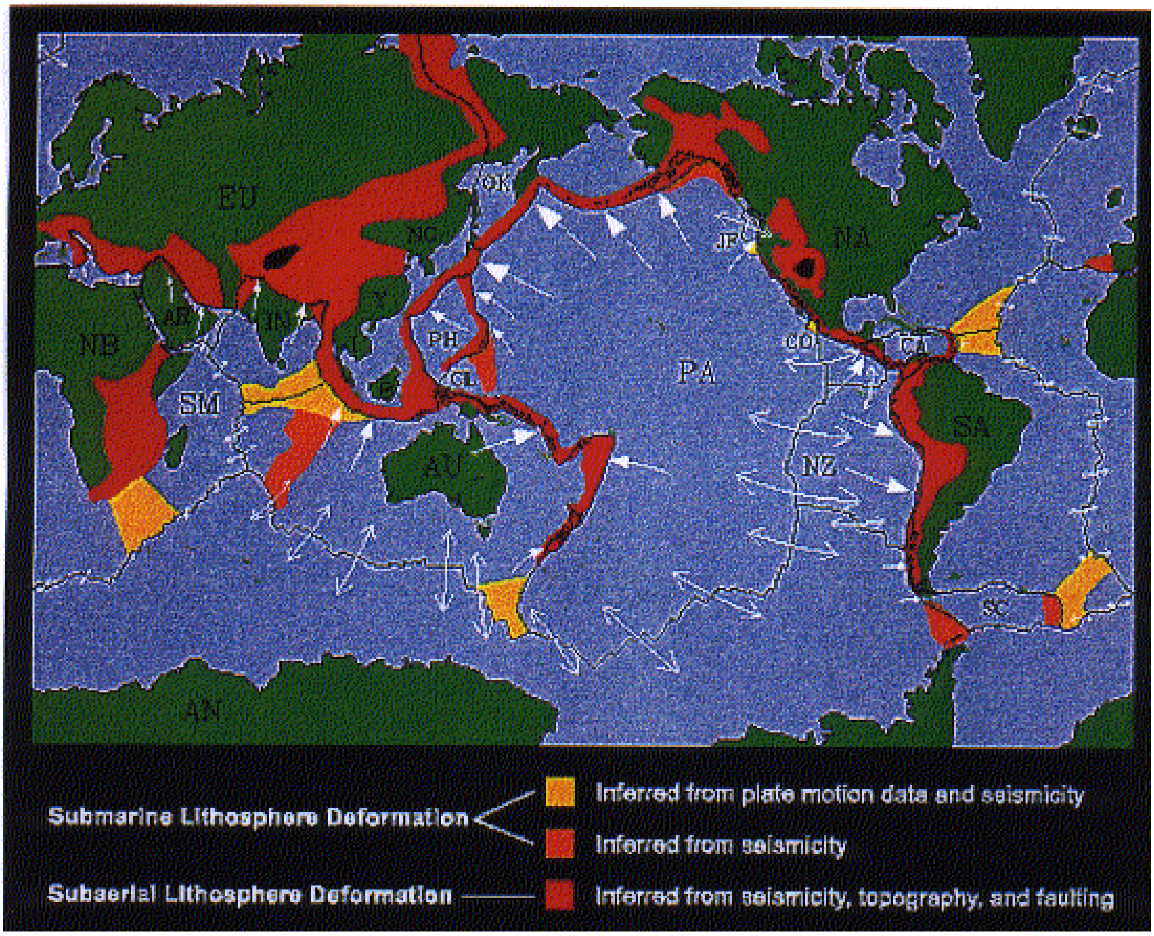


FIG 1. GLOBAL PLATE TECTONICS.

(REF: FROM NEIC)

for this different behaviour as well as the most appropriate way of describing continental deformation by estimation of very long baseline vectors and their temporal evolution. Global plate models (No Net Rotation NNR NUVEL-1) are available and they explain the large scale features of plate kinematic models.(Demets.et.al;1990, Argus and Gordon et.al;1990,& 1991).

3.2 Ongoing INDIAN PLATE MOTION

Tectonically active plate motions on the earth's crust are causing catastrophic earthquakes. Accurate measurements of these plate movements, magnitude, rate and direction are very crucial for understanding the crustal dynamics and associated earthquake process. The seismicity that characterizes the **Indian continent** is a consequence of complex interaction of Indian and its neighbouring plates and also accumulation of crustal strain. Hence the accurate knowledge of the nature and the extent of the ongoing deformation is very crucial for an understanding of occurrences of earthquakes and associated processes.

The Indian plate moves away Fig (2) from the Antarctic, African, Arabian, Australian plates with relative velocities earlier estimated from plate circuit closures Fig (3), but was known to converge with Eurasian plate about 35.4+/-4.1 mm/yr. N and 35.7 +/- 5.8 mm/yr. E. The most dramatic effect of the moving Indian plate on its continental region is manifested at the Himalayan collision boundaries (10^{-7}/yr. strains). However, recoverable elastic strain accumulates elsewhere too within the continental interior, albeit at much slower rates 10^{-8} /year as shown by the occurrences of moderate earthquakes. Longer periods of interseismic quiescence of peninsular earthquakes, perhaps several thousand years, unfortunately mask the weaker seismogenic zones and make it difficult to distinguish active lineaments from the very large number that may in fact have been healed. The southern boundary of the Indian plate is not as sharp as the others and is marked by a wide diffused belt of intensely folded zone in the equatorial Indian ocean which is apparent in incipient plate boundary between India and Australia. These plate boundary fracture zones are the youngest tectonic fracture systems of the Indian plate.

FIG.3. GLOBAL PLATE CIRCUIT
(After C. De Mets et. al. 1990)

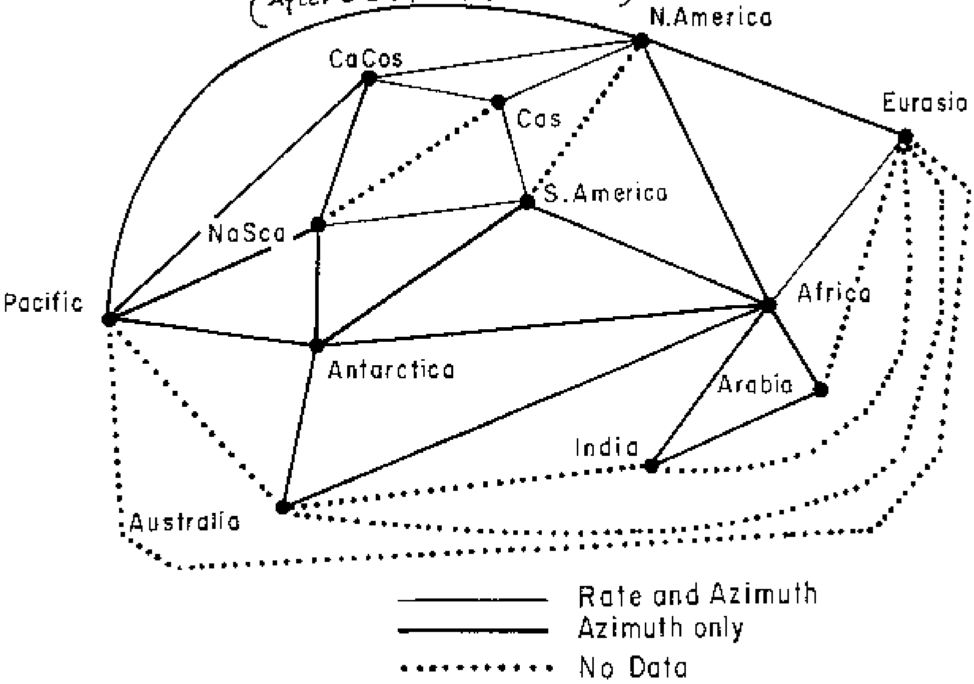
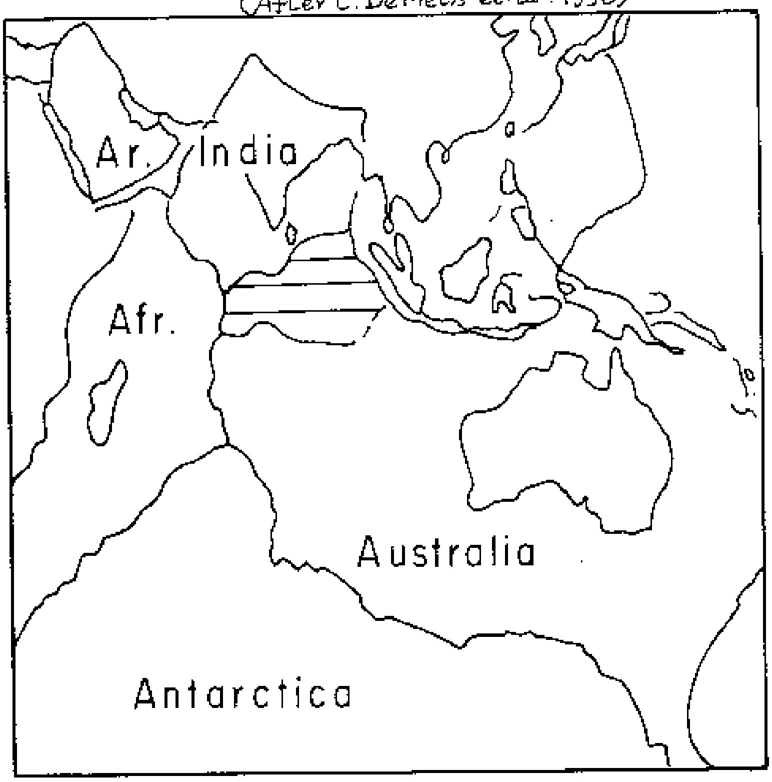


FIG2. Diffused Plate Boundaries Around Indian Plate
(After C. DeMets et. al. 1990)



The Indian plate is able to hold aloft the world's highest mountain range on its northern border only by its persistent northward drive into ASIA. The pervasive north south compression so generated throughout the plate ensures that it is anytime under stress, and provides the basic source for the accumulation of straining energy in its various fracture zones, both old and new. Most of this energy is clearly stored in the rock masses of the detachment faults along which the Himalayas rides over the under thrust Indian plate.

North of the Indo- Asian plate boundary right up to the suture zone between India and Tibet lies the Indian and Nepalese Himalayan terrain itself driven by a number of extensive east-west thrust planes, which today appear to be the major fracture planes accommodating perhaps 40% of the total Indo - Eurasian convergence, and transverse strike slip (transform) faults which segment the Himalayan arc in 7 or larger number of variously offset rupture planes. The main east-west thrust systems are: the trans - Himadri, the main central, the main boundary and the foothill thrusts.

These thrusts are thought by some to represent a southward progression of the fracture zones as persistent convergence steadily raised the northern over thrust planes to appear further south. However, the relative activity of these thrust planes in partitioning and accommodating the INDO - Tibetan convergence of 15-20 mm/yr. remains largely a matter of speculation. A total internally consistent picture of the relative activity of these faults when obtained within a few years will help determine the deformation rate across Indian plate boundary.

3.3 Plate interiors:

The interior of the ancient Indian continental plate although visibly scarred by a very large number of lineaments has generally been considered as a stable land mass- a belief encouraged by and the conceptual understanding of the architecture of shields and platforms of which it is constituted, as also by the relative rarity of the earthquakes. However recent occurrences of number of disastrous earthquakes in its interior clearly point to the existence of not so rigid zones, lying perhaps in between more rigid blocks where recoverable elastic strain leaking from the Indian plate displacement, is accumulating. (Lecture notes by V.K.Gaur).

Studies by (Freymueller et al. 1996) have shown that the velocities of Bangalore and Katmandu (Nepal) are consistent with the hypothesis that the Indian plate moves independently of the Australian plate. They also have confirmed from the geodetic measurements and the amplitude and direction of the India -Eurasia convergence vector which must be partitioned on active structures between India and the stable Eurasian interior (Molnar and Tapponnier, 1975). Minor deformation beneath and south of the lesser Himalaya is insufficient to release more than 1/3 of the convergence rate, and possibly much less. (Bilham et al.1995)

3.4 Crustal deformation by GPS GEODESY.

We have seen in the chapter 2, that among the existing Space GEODETIC techniques, GPS has been widely accepted worldwide for GEODYAMICS. It has been particularly useful in measuring / monitoring the more complex deformation pattern across the plate boundaries because of its capabilities to provide millimeter level precision for baselines of several thousand kilometers in length. GPS based geodetic survey gained momentum and is being used at a number of locations to determine regional level deformation pattern at plate boundaries. One of the largest GPS based experiments carried out is Central And SouthAmerica (CASA) experiment. America, Canada, Central Greece, Germany, Australia and Japan have been involved in monitoring seismic movements for crustal deformation studies, installing dense permanent GPS network.

Since the Indian plate is active, causing number of earthquakes in the Himalayan region in the north and intra-plate earthquakes even in the so called stable shield areas of the country, it is very much essential to quantify the rates of strain accumulation in different parts of the country in order to characterize their earthquake potential and for better understanding of the geodynamics process associated with the Indian plate. GPS based measurements along with geophysical, geological, geodetic data etc., will play a great role in this direction.

Studies have shown, that the normal strain accumulation in the plate boundaries is about 10^{-6} to 10^{-7} yr.$^{-1}$. In the Himalayan region i.e. the Indian plate boundary, about 15-20 mm displacement in a year is observed and accordingly strain accumulation therein is around 10^{-8} to 10^{-10} yr^{-1}. In the intra-plate region, generally, the strain accumulation is around 10^{-8} to 10^{-10} yr^{-1}. In the Indian peninsular region, the displacement is observed to be about 0.1 to 1 mm per year and consequently the strain accumulation is 10^{-7} to 10^{-8} yr^{-1}. In the mobile belts region, normally, the strain accumulation is about 10^{-7} to 10^{-8} yr $^{-1}$. In major parts of the country, the rate of displacement/movement and the accumulated strain is not yet studied/assessed; besides, historical records of earthquakes are also not available. As such, due to the long recurrence time of earthquake in these regions, they appear as though safe, but only till an earthquake of Khillari type strikes. Hence the measurements of displacement and in turn strain accumulation using techniques like VLBI, SLR and GPS are called for, which will greatly help in assessing the seismic risk of different parts of the country.

Among the above mentioned techniques, GPS is proved to be more useful for measuring the displacement/movement of earth features, because of its advantages over other techniques such as economy, high accuracy, portability, global accessibility etc. Establishment of a countrywide network of GPS stations will in fact facilitate assessing seismic risk of the entire country in a systematic way.

Studies have shown, that the accuracy of measurement of displacement achievable using GPS is about 3 mm over a 10 km baseline, which will allow the measurement of strain accumulation to the tune of 10^{-7}. It is observed, that whenever the accumulated strain in any area reaches about 10^{-4}, rupture/failure takes place leading to earthquakes. In an area of dimension of about 50 km, if the strain accumulation were 10^{-7} yr^{-1}, the displacement would be around 5mm. The GPS receivers of present day offer millimeter level precision measurement of displacements, thus enabling detection of strain accumulation of the order of 10^{-7} yr -1. Hence using GPS, it would be possible to demarcate regions/areas, where displacements are taking place/strain is accumulating in a time frame of about 3 years (i.e., when displacements to the tune of about mm takes place).

3.5 The questions addressed in the thesis:

With this foregoing assessment, the following questions were addressed in this thesis to study the further evidence of ongoing INDIAN plate motion by GPS - GEODESY by estimating very long baselines and velocity vectors.

1) What is the recent scenario of the ongoing INDIAN plate motion?

2) How do we compare to plate motion models (NUVEL-1A, DeMets et.al 1990,1994)

3) Determine the inner stability of the Indian plate within plate interiors:

4) Fixing the coordinates of HYDERABAD in an inertial frame of reference so as to constrain GPS measurements within INDIA.

4. GPS MEASUREMENTS.

4.1. International GPS service for Geodynamics (IGS).

The routine IGS started on 1 January 1994. IGS is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS), and it operates in close cooperation with the International Earth Rotation Services (IERS).

The Primary objective of the IGS is to provide a service to support, through GPS data products, geodetic and geophysical research activities. Cognizant of the immense growth in GPS applications the secondary objective of the IGS is to support a broad spectrum of operational activities performed by governmental or selected commercial organizations. The Service also develops the necessary standards/specifications and encourages international adherence to its conventions.

IGS collects archives and distributes GPS observation data sets of sufficient accuracy to satisfy the objectives of a wide range of applications and experimentation. These data sets are used by the IGS to generate the following data products, which are available via anonymous FTP.

* High accuracy GPS satellite ephemerides
* Earth rotation parameters
* Coordinates and velocities of the IGS tracking stations
* GPS satellite and tracking station clock information
* Ionospheric information
* Tropospheric information

The accuracies of these products are sufficient to support current scientific objectives including:

* Realization of global accessibility to and the improvement of the International Terrestrial Reference Frame (ITRF)
* Monitoring deformations of the solid earth
* Monitoring earth rotation
* Monitoring variation in the liquid earth (sea level, ice-sheets, etc.)

* Scientific satellite orbit determinations
* Ionosphere monitoring
* Climatological research, eventually weather prediction.

The IGS accomplishes its mission through the following components: Fig (4)

* Network of tracking stations
* Data centers
* Analysis and Associate Analysis Centers
* Analysis Coordinator
* Central Bureau
* Governing Board.

Networks of Tracking Stations :

IGS Stations (Fig .5) provide continuous tracking using high accuracy receivers and have data transmission facilities allowing for a rapid (at least daily) data transmission to the data centers. The stations have to meet requirements, which are specified in a separate document. The tracking data of IGS stations are regularly and continuously analyzed by at least one IGS Analysis Center or IGS Associate Analysis Center. These analyses must be available to, analyzed and published by the ITRF section of the IERS for at least two consecutive years. During this initial period the IGS Central Bureau can temporarily designate new tracking stations as IGS stations.

IGS Stations which are analyzed by at least three IGS Analysis centers for the purpose of orbit generation, where at least one of the Analysis Centers is located on a different continent than the station considered, are in addition called IGS Global Stations. Details about data centers, Analysis centers and Central Bureau are available in web site http://igs.igscb.nasa.gov.html/

GPS data products are available from CB via Anonymous FTP. The approximate accuracy of data products is given in Tab no. 1:

Fig.4 ORGANIZATION OF THE INTERNATIONAL GPS SERVICE

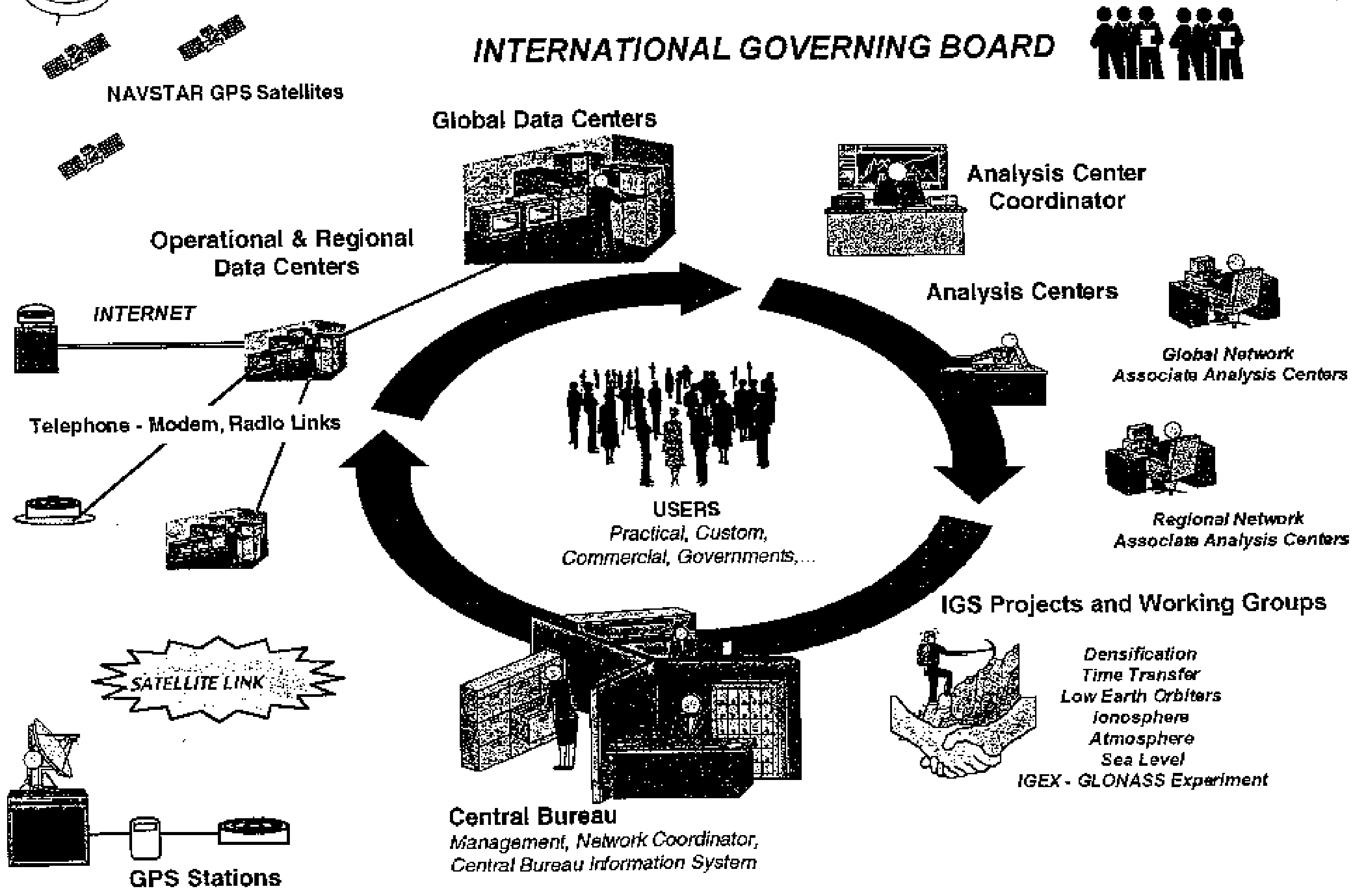


FIG.5. GPS TRACKING NETWORK OF THE INTERNATIONAL GPS SERVICE FOR GEODYNAMICS OPERATIONAL AND PLANNED STATIONS

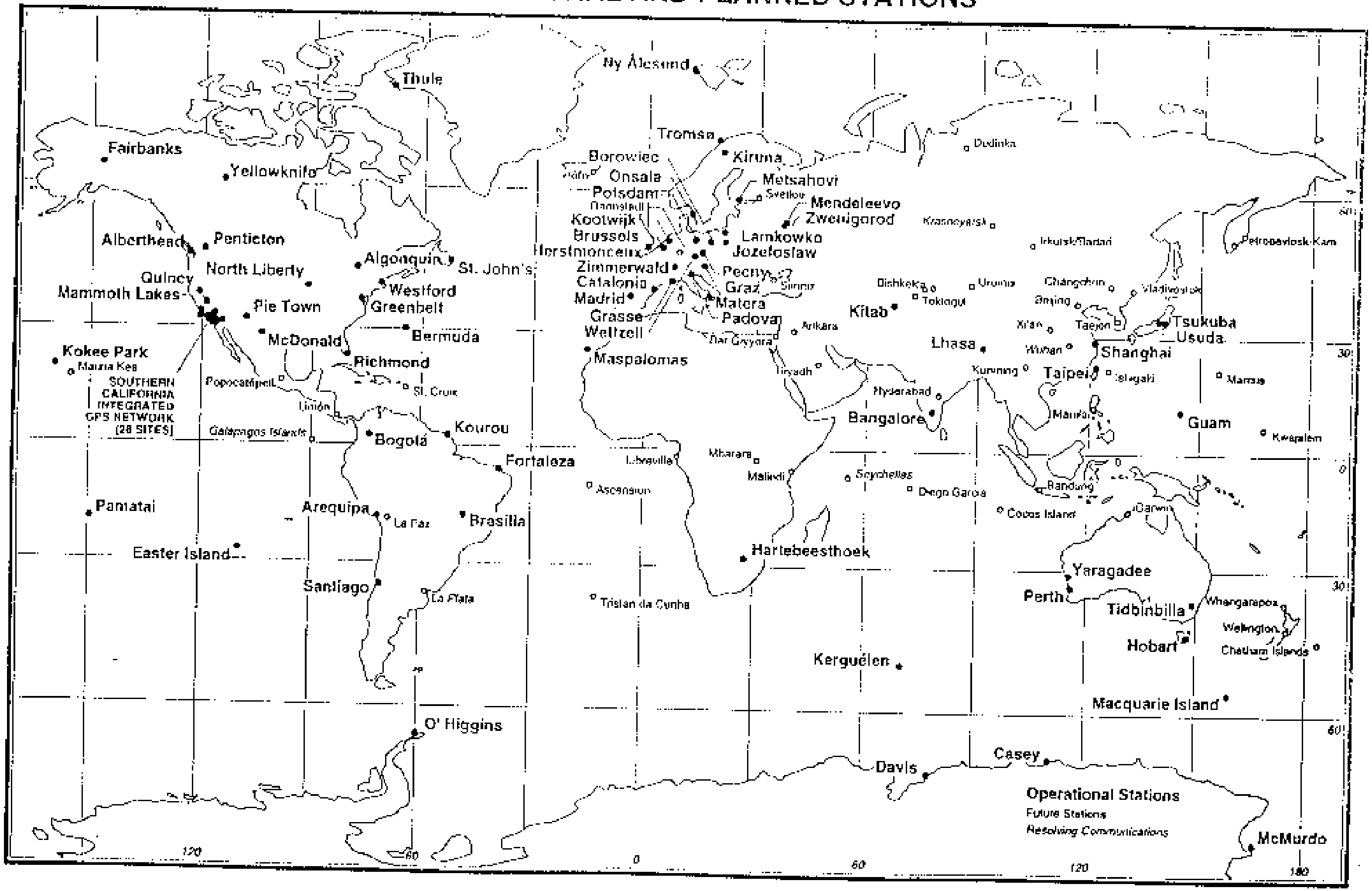


TABLE NO .1

Product	**Availability**	**Accuracy**
1.GPS satellites		
a. Ephemerides		
Predicted	real-time	50cm
Rapid	1-2 days	10cm
Final	10-12 days	5cm
b. Clocks.		
Predicted	real-time	150ns
Rapid	1-2 days	0.5ns
Final	10-12 days	0.3ns
IGS station locations :		
Weekly solutions	4 weeks	3-5 mm
Earth Orientation		
Pole		
Rapid	1-2 days	0.2 mas
Final	10-12 days	0.1 mas
Pole rates:		
Rapid	1-2 days	0.4 mas/ day
Final	10-12 days	0.2 mas / day

UT1-UTC:

Rapid	1-2 days	300 ms
Final	10-12 days	500 ms

Length of Day (LOD)

Rapid	1-2 days	60 ms / day
Final	10-12 days	30 ms / day

The IGS has been in formal operation for nearly four years. The detailed analysis strategies that exploit the qualities of its data and products are continuously getting developed. High quality RINEX tracking data from the global tracking network, predicted and post processed GPS ephemerides that are more than the broadcast orbits by an order of magnitude, and precisely - determined locations of dozens and eventually hundreds or more of sites distributed over the entire globe, all provide benefits to users.

Geodynamics users who use GPS in local regions can include data from one or more nearby IGS stations, fix the site coordinates from such stations to their ITRF values, and fix IGS determined values. By doing so, the user can reduce their network data with maximum accuracy and minimum computational burden. In addition, the results will be in a well - defined global reference frame.

4.2 Data Acquisition & Participation in IGS Global network.

GPS activities at NGRI:

From 1989 onwards, Author has been working on GPS technology and applications. Worked on Time Transfer GPS Receiver TTR-5. Determination of single point positioning and comparison of stability of local clock with the GPS and satellite clock were done. Detailed studies were made on the parameters affecting the positioning accuracy. Data processing and analysis were done to improve the accuracy by acquiring large set of GPS data. Carried out an experiment to find the system's resolvability. The system's capability for determination of position location was established and reported. Details of the work carried during 91-93 are explained in the **MS** thesis of E.C.Malaimani (ref. Malaimani.E.C, 1993)"**Global Positioning System (GPS), its constellation and analysis of their dynamic Geometric performance to determine position accuracy** ".

4.2.1 INDO - GERMAN Collaborative Bilateral Project -Establishment of IGS Permanent GPS tracking / reference station at NGRI.

Under the Indo - German (DLR-CSIR) collaborative Bilateral Exchange programme between **NGRI** and **Geodetic Institute, University of Bonn,** Germany, an IGS permanent tracking/reference station was established (Fig.6) by installing a **Turbo rogue GPS-SNR-8000 Receiver** to study the ongoing **Indian plate motion.** The GPS measurements in the IGS global network are meant to monitor intercontinental and intra plate crustal motion and fixing reference points in an inertial frame of reference for establishing fiducial sites to constrain geodetic GPS measurements in India.

Turbo Rogue GPS SNR- 8000 Receiver System:

Receiver consists of Antenna, Receiver hardware, and a RISC parallel processor for multi channel digital signal processing.

Antenna Assembly:

It is a drooped crossed dipole antenna mounted to a choke ring back plane. This mount helps eliminating the reduction in SNR due to multi path reflections due to low elevation signals. The choke ring acts as an absorber to L- band signals. This single L band Omni directional antenna receives the L1 and L2 signals from all the visible satellites. After the pre selection of L band frequencies through the pre selection filter of 500 MHz BW, centered at 1400MHz before amplification by LNA (125DEG K), the L band RF signal is then sent along a coaxial cable of 200 ft length to the DCA. (Down converter Assembly) in the receiver which is installed in a room in the Extension building.

Receiver:

It is a spread spectrum communication geodetic receiver which tracks up to 8 satellites simultaneously while measuring the group delays (pseudo range) and phase

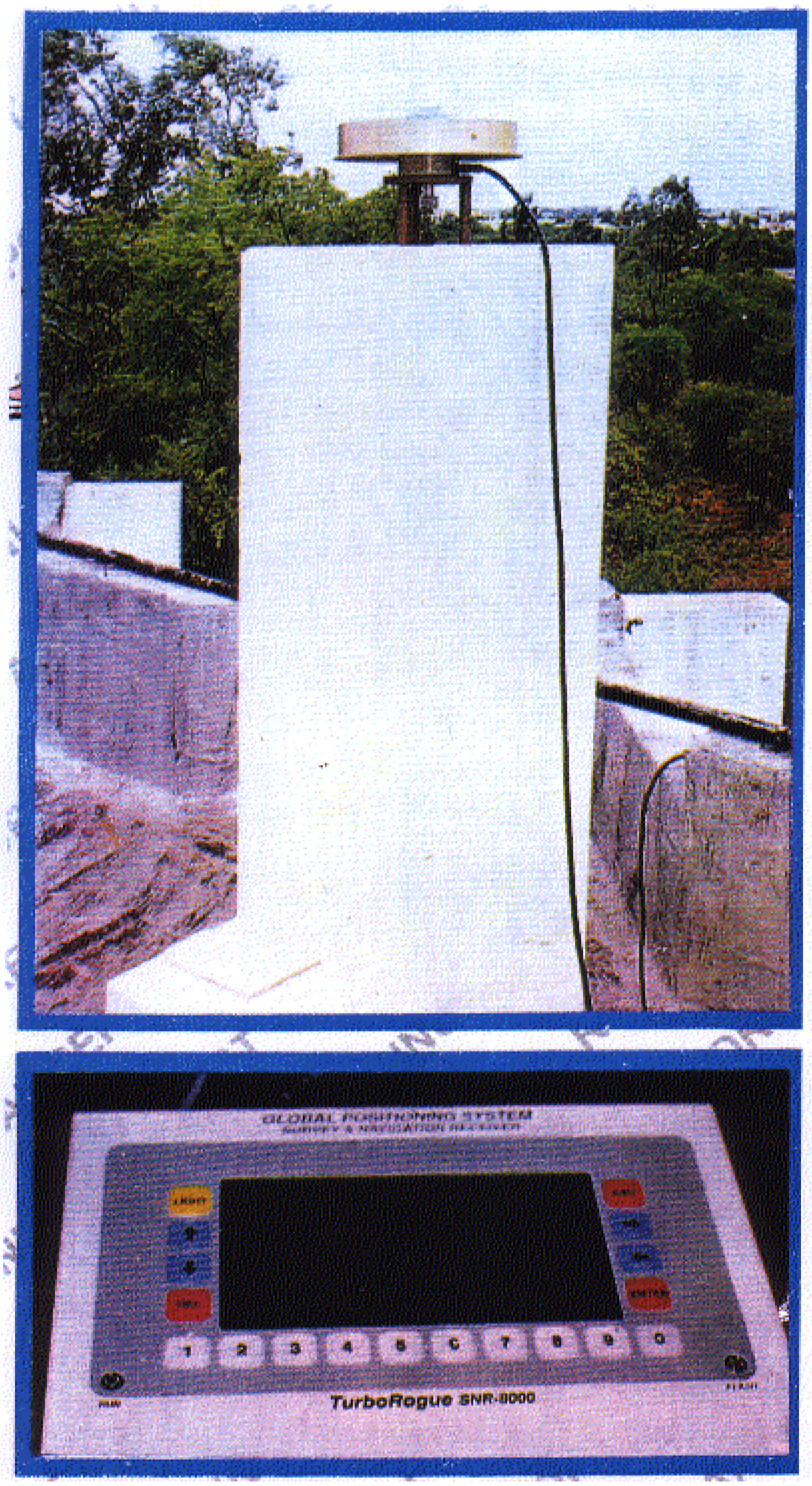


FIG 6. IGS PERMANENT/REF. GPS TRACKING STATION AT N.G.R.I. HYDERABAD, INDIA

delay from L1 C/A, L1-P, and L2-P signals. The system adopts unique signal processing techniques to extract accurate group delays when two or more satellites are differenced. Phase delay measurements provide a high degree of accuracy and precision. It is an 8-channel dual frequency L1 C/A code, L1 P code, L2 P code, and code less (L1phase, and L2 phase) receiver. DCA power divides the L band RF signals into separate L1, L2 paths. RF signals are converted to double side band base signal by mixing with frequencies, which are multiples of single 20.456 MHz sources. Local oscillator and sampling rate are synthesized from an internal quartz oscillator.

A/D converter:

The Signals are 1-bit sampled at just above the Nyquist rate. The sample rate is chosen to be effectively incommensurate with the incoming code transitions (10.23MHz), so discrete sampling errors are reduced to sub centimeter levels after 1 second.

Digital base band processing:

Code signal processing: Parallel signal processing hardware allows the tracking of all satellites by the tracking loop software to extract the L1C/A, L1-P, L2-P, phase and group delays from each satellite as well as GPS ephemeries and almanac information.

The digital hardware removes Doppler generated model C/A and P codes and cross correlates the synthesized code with the received signal. It then sums the resolution between cross correlation products to provide the tracking loop software with the complex correlation sums at a 50 Hz rate.

Codeless (Non code) processing:

Since it is making use of the P2-P1 pseudo range and L1-L2 phase observables which are a measure of the differential ionospheric effects between L1 and L2. This can be used to correct the C/A pseudo range and phase measurements. Here effective L2 phase measurements are full cycle (24cm). This provides a greater margin of noise tolerance for ambiguity resolution thus improving system performance over common squaring technique adopted by the other receivers.

4.2.2 IGS station configuration:

The GPS system was installed in June 1995 and it is continuously operational from **SEPTEMBER 1995**. The monument is a standard disk star drilled on the concrete pillar erected on the roof of the extension building of NGRI, HYDERABAD. Pillar size is 0.5 X 0.5 X 2.0 M (square cross section). The DORNE MARGOLIN T choke ring antenna is located on top of the brass platform. The platform is supported by 3 poles, which are fitted to the base plate embedded on top of the concrete pillar

The Turbo rogue SNR - 8000 is installed in the extension building of NGRI. The antenna is connected to the receiver by a 60m coaxial cable. The GPS receiver in turn is connected to an onsite COMPAQ PC via a serial communication port and responds to the X modem protocols. The receiver continuously tracks those satellites, which fulfill preset criteria such as elevation cutoff (set at 10^{o}). There is no obstruction of the horizon. Measurements are at every 30-sec interval. The raw track data is stored in a flashcard in the receiver.

4.2.3 Data transfer:

The daily track data is downloaded to the onsite PC at 00.00 UTC using MANUAL downloading program .It is downloaded in Turbo binary format. About 1MB of data accrues every day. Data collected in turbo binary format is converted to Rinex format using 'n convert ' program. RINEX formatted Observation files include all observables like C/A code pseudo range, L1 phase L2phase, Pcode pseudo ranges, and cross-correlated outputs. Navigation files include the broadcast ehemerides, which comprises of Satellites XYZ position and time of its transmission.

RINEX Observation and Navigation files are compressed using 'PKZIP' program and sent to our collaborators. Daily data is archived and stored as well in the hard disk. Since July '99 the data is transmitted on-line via FTP to University of Bonn. With this on - line data transfer, the important and essential component of the collaboration is accomplished.

5. DATA PROCESSING.

5.1 Bernese Software version 4.0:

The Bernese GPS Software version 4.0 is a program system covering all the static high accuracy geodetic applications of the GPS. The system has been developed by the Astronomical Institute at the University of BERN, Switzerland for Scientific and professional use. Main parts of the program are:

1) RINEX files into Bernese files.
2) Creating standard orbits and tabular orbits from the Broadcast ephemeris or precise orbits.
3) Processing part: dual frequency code and phase pre-processing(removal of outliers and cycle slips)code single point positioning, parameter estimation
4) Simulation part: generate simulated GPS sessions(code and/or phase observations)
5) Service part: Compare coordinates sets, edit and browse binary data files, baseline repeatabilities, residual display, etc.

Baseline determination and its accuracy: With the available Pcode and codeless track data and the precise orbit information from IGS service, solutions with an accuracy of about **1-2 cm** in horizontal position and **2-3 cm** in height are obtained for baseline lengths up to few thousand Kilometers.

The error db (in mm) of the coordinate estimation for a baseline length b (in Km) is of the order of $db/b = \sqrt{(1/\ 2b)}$ i.e. a few millimeters for baselines below 100KM and a few centimeters for baselines of a few thousands Kilometers.

5.2 DATA PROCESSING OF THE 3 YEAR'S DATA SET:

The refined GPS processing & analysis by using Bernese version 4.0 were carried out at the University of BONN during Sep 1996 through 1998. The first data set for the data up to Jan 1997 was prepared and a Global Network Solution was carried out to estimate very long baselines between HYDERABAD and other IGS select stations which are in and around INDIAN PLATE. The HYDERABAD site coordinates were firmed up in the ITRF 94 reference frame. The processing strategies used and the results obtained till JAN 1997 are reported in the technical report **No. NGRI - 97 SEISM -219 by E.C.Malaimani and J.Campbell.**

Our main aim was to include all the data so far acquired from the HYDERABD IGS permanent station from SEP 95 to JULY 98. We used the BERNESE PROCESSING ENGINE (BPE) to process the enormous amount of data for 3 years from all the IGS select stations.

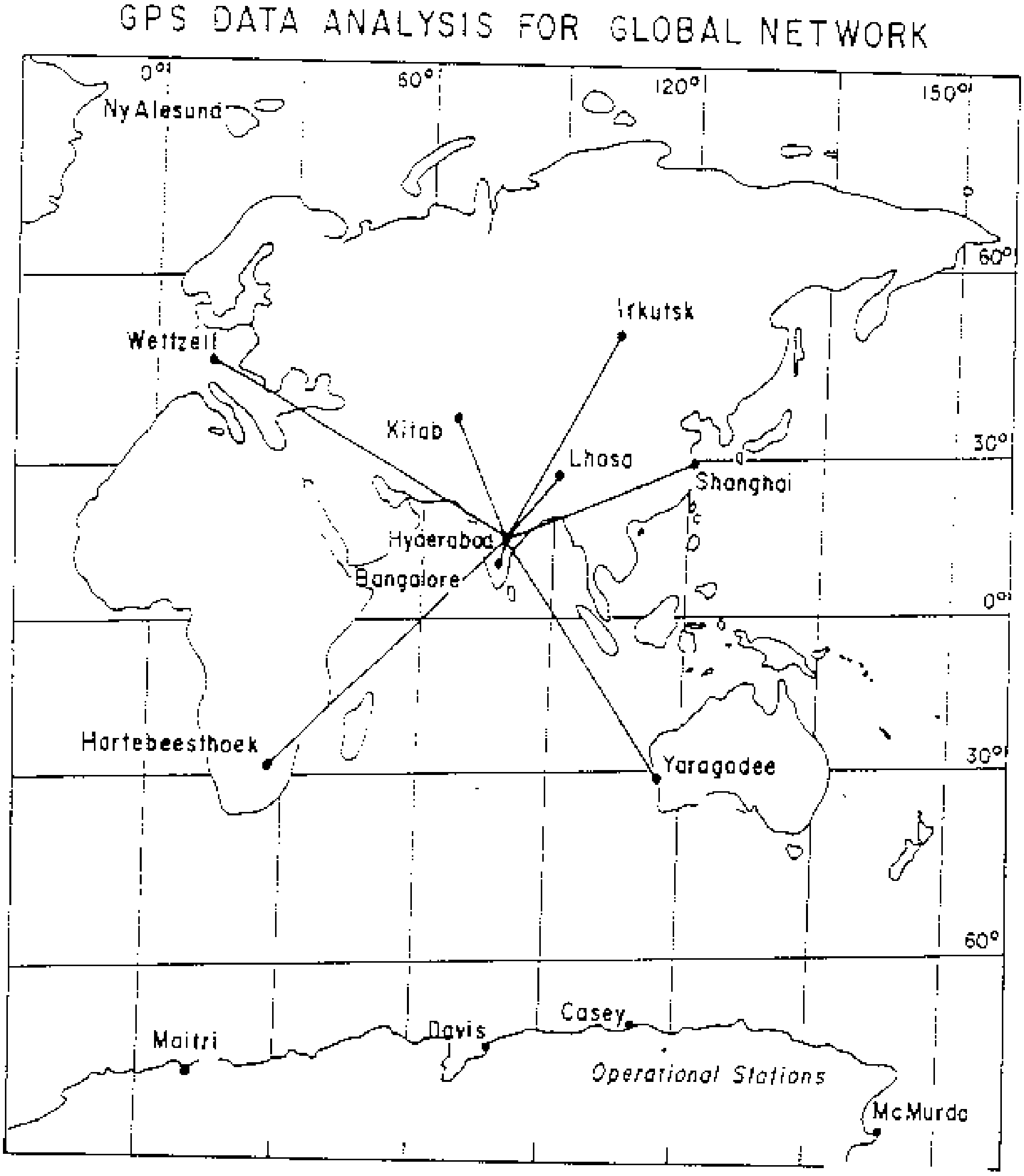
The objective of this analysis is to fix the Hyderabad coordinates in a global inertial frame of reference and estimate the very long baselines. To understand the current motions of Indian plate relative to its neighbouring plates, we selected the IGS GPS stations, which are situated in and around Indian plate for the analysis.

5.3. Data downloading of other select IGS stations:

The first phase involves the selection of stations and downloading the corresponding data. 10 stations were selected for GLOBAL NETWORK ANALYSIS. Hyderabad and Bangalore in Indian plate, Lhasa, Kitab, Shanghai and Irukutz in Eurasian plate, Wettzell in Europe, Hartebeesthoek in African plate and Yarragadee in Australian plate. Thus, the IGS select stations, which are in and around Indian plate, were covering all directions. Fig (7) shows the network of IGS select stations. The following are the station details.

Station Hyderabad:

Tectonic plate	INDIAN plate
Country	Hyderabad/ INDIA
IERS DOMES Number	22307M001
Receiver	Turbo-Rogue SNR -8000
Antenna type	Dorne Margolin T



July, 1999

Fig. 7. Global Network of IGS Stations

Responsible Institute	NGRI/Hyderabad, India & Geodetic Institute, Univ. BONN, BONN, GERMANY

Station Hartebeesthoek:

Tectonic plate	African plate
Country	Pretoria/ South Africa
IERS DOMES Number	30302M002
Receiver	Turbo-Rogue SNR -8000
Antenna type	Dorne Margolin T
Responsible Institute	Centre National d'Etudes Spatiales/ Frankreich

Station Yarragadee:

Tectonic plate	Australian plate
Country	Mingenew/ Australia
IERS DOMES Number	50107M004
Receiver	Turbo-Rogue SNR -8000
Antenna type	Dorne Margolin R
Responsible Institute	JPL, Jet Propulsion Laboratory/USA

Station Bangalore:

Tectonic plate	Indian plate
Country	Bangalore / India
IERS DOMES Number	22306M002
Receiver	Turbo-Rogue SNR -8000
Antenna type	Dorne Margolin T
Responsible Institute	Unavco University NAVSTAR Consortium/Colorado / USA

Station Irkutzk :

Tectonic plate	Eurasian plate
Country	Irkutsk/ Russia
IERS DOMES Number	12313M001
Receiver	Turbo-Rogue SNR -8000
Antenna type	Dorne Margolin T
Responsible Institute	Delft University of Technology/ Netherlands

Station Kitab:

Tectonic plate	Eurasian plate
Country	Kitab/ Uzbekistan
IERS DOMES Number	12334M001
Receiver	Turbo-Rogue SNR -8000
Antenna type	Dorne Margolin T
Responsible Institute	GFZ- Geo Forschungszentrum / Germany.

Station Lhasa:

Tectonic plate	Eurasian plate
Country	Lhasa / China
IERS DOMES Number	21613M001
Receiver	Turbo-Rogue SNR -8000
Antenna type	Dorne Margolin T
Responsible Institute	IFAG Institute For Applied Geodesy/ recently Changed to Bundesamt for Kartography and Geodesy.

Station Shanghai:

Tectonic plate	Eurasian plate
Country	Shanghai/ China
IERS DOMES Number	21605M002

Receiver Turbo-Rogue SNR -8000

Antenna type Dorne Margolin T

Responsible Institute JPL, Jet propulsion Laboratory, USA.

<u>Station Wettzell</u>:

Tectonic plate	Eurasian plate
Country	Kortzing/ Germany.
IERS DOMES Number	14201M010
Receiver	Turbo-Rogue SNR -8000
Antenna type	Dorne Margolin T
Responsible Institute	IFAG Institute For Applied Geodesy/ recently Changed to Bundesamt for Kartography and Geodesy.

These stations have contributed data to IGS data centers and data is available from 1995. Though every day data is available, analysis of 1day/week is chosen for the following reasons. 1) There is little gain in analyzing daily rather than weekly solution compared to the sevenfold increase in the effort. 2) Size of the data set is manageable. (Larson et.al.1996).

Bernese uses the code and phase observables. A general description of GPS observables, their linear combinations and data analyses are given in Holman-Wellenhof et.al (1993) and Leick (1995). In Bernese program we use the double differences as basic observables.

This is used to approximate the satellite clocks by a single point positioning before the precise parameter estimation. In main observation equation, both code pseudo range and phase pseudo ranges are used. The weight ratio between code and phase observation is an input variable. We used the following:

s ***(Code):*** *s* ***(phase) = 1:10,000 for precise code and 1: 100,000 for C/A code.***

5.4 BPE - BERNESE PROCESSING ENGINE:

The quantum of data to be processed increases as the no.of Stations and no.of sessions increase. Processing of the daily data calls for a highly automated GPS data processing and for this sake the BPE has been developed by the Bernese group (G.Beutler et.al; 1996)

The BPE is only available for multi tasking systems, for example UNIX and VAX and not for DOS. It has been installed and running at the Geodetic Institute, Univ. BONN for the routine processing of the Global NETWORK solution. We used BPE to process Hyderabad data with other select IGS station data in a highly automated fashion.

The BPE is a suite of programs, shell scripts and control files designed to run and control the Bernese GPS programs in an automated mode. Process control Script (PCS) is at the heart of the BPE. This script is responsible for starting and monitoring all the processes that are run by the BPE. Fig (8) shows the flow chart of the PCS functions.

The following are the advantages of the BPE over regular processing:

1) All the stages for the processing are carried out automatically.

2) The PCS is able to run more than one task at a time on several CPUs, and can even divide a single task across different CPUs.

3) The BPE provides a sturdy framework for writing shell scripts (BATCH programs) that can use many different programs available in the Bernese software. It takes care of setting up environment variables, creating temporary work directories, error handling and logging and interaction with the Bernese menu system.

4). The Fig (9) shows the MAIN PCS (script program).

Data processing was carried out in four phases on a dedicated HP workstation in which Bernese software resides in an automated fashion by BPE. 1day/week data of Hyderabad station data was selected for the time span from Sep ‘95 to Sep ‘98.

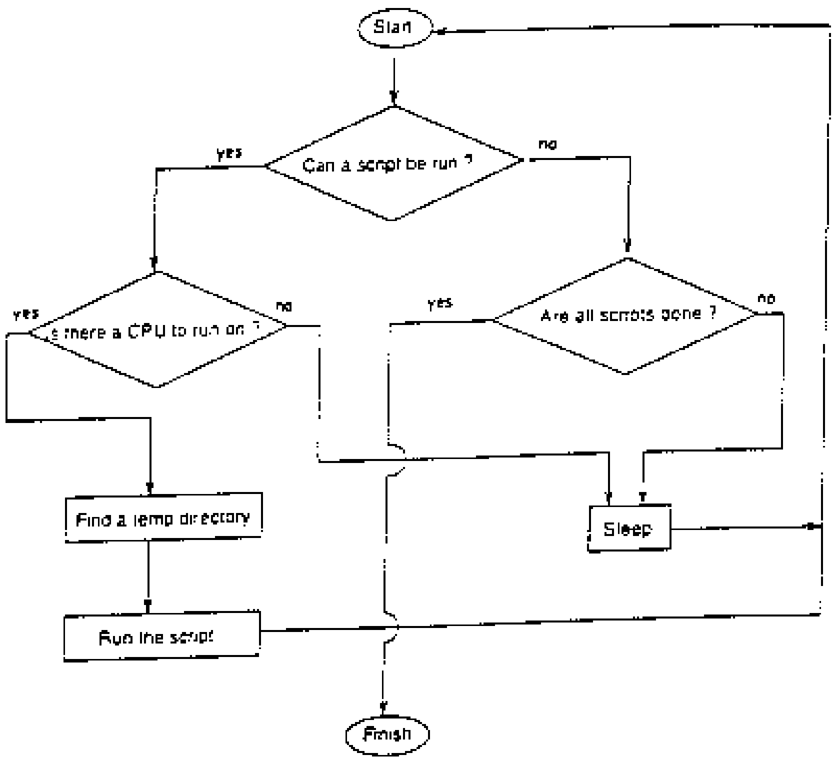


Figure 8. Process Control Script Flow Chart

FIG NO.9. MAIN PCS (Script Program)

India_1

```
# INDIA_1.PCF
#
# NOTICE: Script names that end with '_P' are Parallel Scripts
# and will be started many times. In Front of The Parallel Script
# you will find a preparing single Script, that writes Filenames
# in a file and handles it to the Parallel Script.
#
# Quality Check of Rinex Observation Files (QC_SESS)
# Marking Bad Observation Files (CHECKSUM)
# Transformation of the Rinex Observation Files to Bernese Format
(TRANSO,TRANSO_P)
# Creation of Tabular Orbit (ORBITT)
# Creation of Standard Orbit (ORBITS)
# Estimation of Single Point Positioning (SPCODE,SPCODE_P)
# Calculating Single Differences (S_DIFF)
# Preprocessing (PH_PRE, PH_PRE_P)
# Networksolution (GPS_NET)
PID SCRIPT   OPT_DIR  CAMPAIGN CPU       P WAIT FOR....
3** 8******* 8******* 8******* 8******* 1 3** 3** 3** 3** 3** 3**
3** 3** 3**
001 QC_SESS  INDIA1            any       1
002 CHECKSUM INDIA1            any       1 001
003 FTP_IGS  INDIA1            any       1
004 TRANSO   INDIA1            any       1 002
005 TRANSO_P INDIA1            any       1 004
006 ORBITT   INDIA1            any       1 003
007 ORBITS   INDIA1            any       1 006
008 SPCODE   INDIA2            any       1 005 007
009 SPCODE_P INDIA2            any       1 008
010 S_DIFF   INDIA3            any       1 009
011 PH_PRE   INDIA3            any       1 010
012 PH_PRE_P INDIA3            any       1 011
013 GPS_NET  INDIA4            MIRO      1 012
#
# additional parameters required for PID's
#
PID USER         PASSWORD PARAM1   PARAM2   PARAM3   PARAM4   PARA
M5   PARAM6
3** 12********** 8******* 8******* 8******* 8******* 8******* 8***
**** 8*******
002                       840      12000    60
 "   10
004                       $tmpl
005                       PARALLEL $tmpl
008                       $tmpl
009                       PARALLEL $tmpl
011                       $tmpl
012                       PARALLEL $tmpl
#
# That's it
#
VARIABLE DESCRIPTION                                  DEFAULT
 LENGTH
```

The corresponding days data of the selected stations had to be down loaded from the following IGS data centers via anonymous FTP as a first phase.

1.) **CDDIS** (Crustal Dynamics Data Information System, NASA Goddard Space Flight Center, Greenbelt, USA)

2.) **SOPAC** (Scripps Institute of Oceanography, Permanent Array Center, Santiago, USA)

3.) **IGN** DATA center (Institute Geographique National, PARIS, France)

4.) **IFAG** (Institut fur Applied Geodesy, Frankfurt)

Data includes RINEX observation file, Navigation file, and the corresponding day's IGS precise orbit files. Table no.2 in Appendix provides the data retrieved from various centers through anonymous FTP for our analysis. The second phase involved the pre - processing of the data. Fig (10) shows the flow chart for the entire data processing. For global network analysis the campaign "INDIA" was created. Then the sessions were formulated for simultaneous observations.

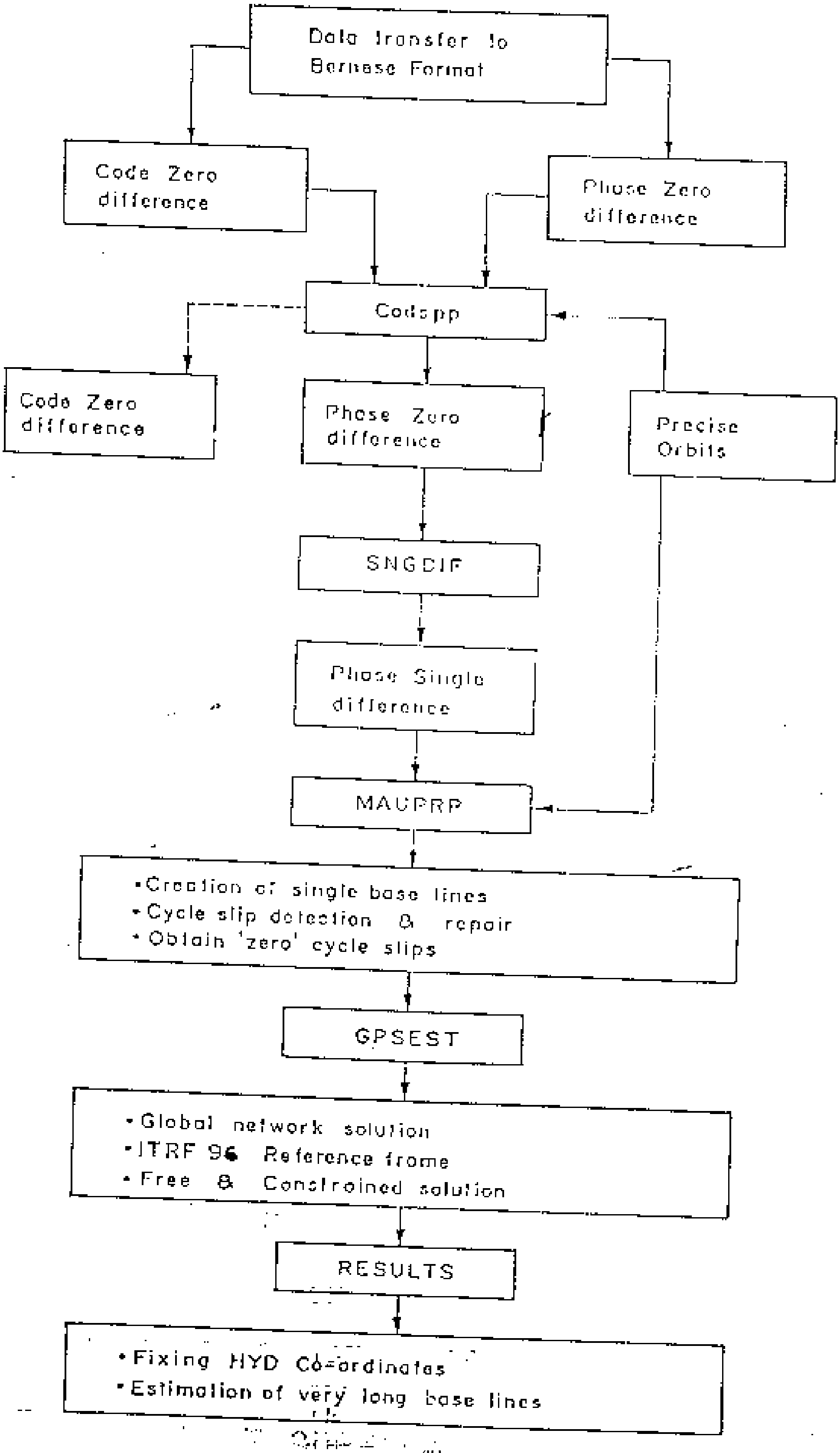
5.4.1 Quality check:

All raw data were passed through **'QC'** quality check program. It checks the data quality of all the sessions of all the stations. It is written by UNAVACO. This module has been implemented in the BPE at the Geodetic Institute, BONN. Quality check is conducted by detection and correction of cycle slips (discontinuities in the phase data). If outliers are found, they are removed. Data, which is marked 'bad', are not taken for processing.

5.4.2: RINEX to Bernese conversion:

After the quality check, all Rinex files (Observation and navigation) are converted to Bernese format.

FIG NO. 10: FLOW CHART OF DATA PROCESSING



5.4.3: Measurement models:

We used the following measurement models in our processing:

1. Preprocessing:

This model uses phase preprocessing in a baseline by baseline mode using triple differences. In most cases cycle slips are fixed looking simultaneously at different linear combinations of L1 and L2. If a cycle slip cannot be fixed reliably, bad data points are removed or new ambiguities are set up. A check of post-fit residuals is performed after 1-day solution. And outliers are removed.

2. Basic observables: Carrier phase, code only used for receiver clock synchronization.

Elevation cut off: 20 ^{o}, sampling rate: 30sec

Weighting: 1.2m for double difference. Ionosphere free LC. All Satellites are given equal weightage.

3. RHC phase rotation correction:

This is carried out by applying phase polarization effects. (Wu. Et.al, 1993)

4. Ground antenna phase center calibration: Elevation dependent phase center corrections are applied to the model **IGS-01.** The corrections are given relative to the Dorne - Margolin T antenna

5. Troposphere - Apriori model: Saastamonian model (Standard atmosphere used) including the map of Saastamonian. Since all the stations did not have meteorological data, to have uniformity in our analysis, we did not include meteorological data. By using Saastamonian model, Zenith delays were estimated for 6 hours intervals for 1day. Mapping function used was 1/ Cos (z), where z = zenith angle.

6.Ionosphere: It was not modeled. We eliminated the ionosphere by forming ionosphere free L3 linear combination of L1 and L2. We used global ionosphere models for ambiguity resolution step

7.Reference frames: We fixed the ITRF96 reference site position and we estimated the long baselines between the reference sites and Hyderabad station. We used the tightly constrained solution and estimated the Hyderabad site co-ordinates.

8. Plate motion: We used ITRF 96 station velocities, which are fixed by 13 core sites, and 290 global network sites. (Boucher, et.al (1998))

9.The other model parameters are Tidal displacements, Earth Orientation parameters, Satellite center of mass correction, relativity corrections and time argument.

Orbit models:

Geopotential	JGM3 model up to degree and order 8
	GM = 398600.4415 km **3/sec**2
	AE = 6378.1363 km
Third body	Sun and Moon as point masses
	Ephemeris: S.Newcomb “Tables of the Sun”
	GMs = 132712500000 km **3/sec**2
	GMmoon = 4902.7809 km **3/sec**2
Solar radiation Pressure	Direct radiation : ROCK 4 and ROCK 42 approximations T10 and T20 For Block I and block II satell.
	Satellite masses used:
	PRN 01 878.2 Kg — PRN 16-19 883.2 Kg
	12 519.8 Kg — PRN 20 887.4 Kg
	14 887.4 Kg — PRN 21 883.9 Kg
	15 885.9 Kg — PRN 23 972.9 Kg
	All other satellites 975.0 Kg
	One scale factor and the Y bias estimated per arc. Earth shadow model includes: cylindric shadow reflection radiation -not included New GPS satellite attitude model - not applied.
Tidal forces	Solid earth tides : frequency independent Love’s Number K2 = 0.300 Ocean tides not applied
Relativity	applied

5.4.4 Orbit Generation:

The IGS precise orbits generated by these orbit models are used in this step. Tabular and standard orbits for each and every session. Estimated quality of the IGS final orbit is about 5cm. (Ref. Bernese Software manual 4.0). This conversion was to transform the precise orbits from the terrestrial into the celestial reference frame.

5.4.5: CODSPP:

The third phase of processing is the estimation of single point positioning using code measurements. Rinex data contains both the code and phase observables. We use the combination of code and phase to improve the accuracy. Initially code observable is processed to eliminate any outlier. Single point positioning was estimated for all stations by making independent run for each and everyday. The apriori co-ordinates from the observation files are used for this estimation. This exercise resulted in computing receiver clock correction as well as single point positioning of a posteriori rms. error value of about 20-30m. This is due to the artificial degradation of satellite clock accuracy known as selective availability which is implemented in all the available satellites (except sv no 14).

5.4.6: Single baseline:

The forth phase is creation of baselines.

From the basic observables, the zero difference and single difference files are created. Both, systematic errors and random noise affect the phase measurements and pseudorange measurements. The error sources may be classified according to Hollman- Wellenhof et, al., 1992 into three groups, namely satellite related errors, propagation medium related errors and receiver related errors.

The differencing techniques as described by (King et al., 1985) or (Wells et al., 1986) allow us to reduce some of the mentioned biases by forming following differences by using the well known notation (given by Rothacher, 1992, Mervert, 1995)

When

P^{i}_{k} = pseudo range

ρ^{i}_{k} = geometric distance between the satellite and the receiver

L^{i}_{k} = phase difference between the satellite and the receiver.

λ_{F} = wave length, then

1) Zero difference: The difference between **i** th satellite and **k** th receiver

2) Single difference: This is formed between pair of receivers by

$$L^{i}_{Fkl} = L^{i}_{Fk} - L^{i}_{Fl} \text{ ----------------------------------(1)}$$

3) Double difference: This is formed between a pair of receivers and between pair of satellites

$$L^{ij}_{Fkl} = L^{i}_{Fkl} - L^{j}_{Fkl} \text{----------------------------(2)}$$

These are the basic observables in our processing. The corresponding equations are:

$$L^{ij}_{1kl} = \rho^{ij}_{kl} - I^{ij}_{kl} + \Delta\rho^{ij}_{kl} + \lambda_1 n^{ij}_{1kl} \text{ --(3)}$$

$$L^{ij}_{2kl} = \rho^{ij}_{kl} - f1^2 / f2^2\, I^{ij}_{kl} + \Delta\rho^{ij}_{kl} + \lambda_2 n^{ij}_{2kl} \text{ -------------------------------------(4)}$$

$$P^{ij}_{1kl} = \rho^{ij}_{kl} + I^{ij}_{kl} + \Delta\rho^{ij}_{kl} \text{-- (5)}$$

$$P^{ij}_{2kl} = \rho^{ij}_{kl} + f1^2 / f2^2\, I^{ij}_{kl} + \Delta\rho^{ij}_{kl} \text{-------------------------------------- (6)}$$

Where I^{ij}_{kl} **…..Ionospheric refraction**

$\Delta\rho^{ij}_{kl}$ **…..Tropospheric refraction**

They are created essentially to eliminate the errors due to common satellites clock errors and receiver clock errors between the stations when individual baselines between HYDERABAD and all OTHER stations are created.

Using the double difference equation from two different epochs t_1 and t_2 the *triple differences* are formed. We used the triple differences of the phase measurements in the data preprocessing.

$$\mathbf{L^{ij}_{1kl}(t_2) - L^{ij}_{1kl}(t_1) = r^{ij}_{kl}(t_2) - r^{ij}_{kl}(t_1) - (I^{ij}_{kl}(t_2) - I^{ij}_{kl}(t_1))}\text{------------}(7)$$

$$\mathbf{L^{ij}_{2kl}(t_2) - L^{ij}_{2kl}(t_1) = r^{ij}_{kl}(t_2) - r^{ij}_{kl}(t_1) - f1^2 / f2^2 (I^{ij}_{kl}(t_2) - I^{ij}_{kl}(t_1))}\text{---}8)$$

In these equations we assumed that the unknown ambiguity parameters $n^{ij}_{1kl}, n^{ij}_{2kl}$ remained the same within the time interval $< t_1$ and $t_2 >$ and that therefore the phase ambiguities are eliminated which is the main advantage of triple differences This is very much true if the receivers did not loose lock within this time interval and if no cycle slip occurred. Tropospheric refraction usually does not change rapidly in time and therefore it is considerably reduced on the triple difference level. Whereas the ionospheric refraction may show very rapid variations in time depending on the regions.

5.4.7: Manual and Automatic Pre - processing:

Preprocessing the phase observables was carried out for cycle slip detection and elimination. Normally all the receivers can measure the difference between the phase of the satellite transmitted carrier and the phase of the receiver generated replica of the signal. This measurement yields a value between 0 and 1 cycle (0 and 2 Π). After turning on the receiver an integer counter is initialized. During tracking the counter is incremented by one whenever the fractional phase changes from 2 Π to 0. Thus for every epoch the accumulated phase is the sum of the directly measured fractional phase and the integer count. The initial integer n^i_{fk} of cycles between the satellite ***i** and* receiver ***k** is* unknown and has to be estimated. **THIS INITIAL PHASE AMBIGUITY** remains the same as long as no loss of signal lock occurs. A loss of lock causes a jump in the instantaneous accumulated phase by an integer number of cycles. If there is a difference,

$$n^i_{Fk}(t_2) - n^i_{Fk}(t_1) \neq 0,$$

then we can say a cycle slip has occurred between t1 and t2 . In the Data preprocessing, we have to detect the cycle slips and repair them to become zero. It is carried out in the principle pre-processing program **MAUPRP** (Manual and Automatic Pre-processing). It screens the single difference files and looks for cycle slips too. Since it does not use code measurements, it is code independent. This aspect is very important when processing A/S data since the quality of code measurements is lower during A/S. All the possible sources of cycle slip occurrences, their detection and elimination are explained in detail in the thesis of Mervart, (1995).

5.4.8 GPSEST - Parameter Estimation:

After preprocessing, parameter estimation was carried out. The GPSEST parameter estimation makes use of the LEAST SQUARE ADJUSTMENT / LEAST SQUARE ESTIMATION technique.

The Gauss- Markoff model (GMM) of full rank for the observation equations may be written e.g. (Koch, 1988)

E (y) = X (A); D (y) = σ^2 $\mathbf{P}^{-1}$---------------------------------------(a)

Where

X = n x u matrix of given coefficients with full rank X =u; X is called design matrix,

A = u x 1 vector of unknowns,

y = n x 1 vector of observations,

P = n x n positive definite matrix,

n, u = number of observations, number of unknowns,

E (.) = Operator of expectation,

D (.) = Operator of dispersion,

σ^2 = variance of unit weight (variance factor)

The observation equations are written in this form. When n > u, the equation system X A = y is not consistent.

To make it consistent a residual vector e to the observation vector y we can obtain a consistent but ambiguous system of equations and they are called observation equations.

y + *e* = X A with E (*e*) =*0* and D(*e*) = D(y) = σ^2 $\mathbf{P}^{-1}$--------------- (b)

Equations a and b are formerly identical. E (*e*) =*0* because E (y) = X A and D(e)=D(y) can be written from the law of error propagation.

The necessary condition for least square estimation for the observation equations a & b, is the parameter estimates A should minimize the quadratic form

Ω (A) $= 1/\sigma^2$ ((y - X A)'P (y- X A))--------------------- c

Where

(y - XA)' is the transposed matrix of (y- XA). The introduction of condition Ω A $\rightarrow$ minimum is necessary to lead us from ambiguous observation equations a & b to an unambiguous normal equation system (NEQ) for the determination of A .

The establishment of minimum values for Ω (A) leads to system of u equations d Ω (A) / d A = *0,* and this is called normal equations.

Accordingly the following formulae summarize the Least Square Estimation (LSE) in the Gauss Markoff model

Normal Equations:

$$X' PX \hat{A} = X'Py$$

Estimates:

Of A: $\hat{A} = (X' PX)^{-1} X'Py$

Of the (variance)-covariance matrix: $D(\hat{A}) = \sigma^2 (X' PX)^{-1}$

Of the observations $y = X \hat{A}$

Of the residuals $\hat{e} = y - y$

1. 2.

Of the quadratic form: $\Omega = \hat{e}' P \hat{e} = y' P y - y' PX \hat{A}$

Of the variance of unit weight (variance factor) $\sigma^2 =: \Omega /(n-u)$

Degree of freedom / redundancy:

$$F = n - u\cdot$$

Normal equation matrices: (X' PX), X'P y, (y' P y)

We used these matrices in Parameter program GPSEST.

To estimate the following parameter types, we introduced the constraints in GPSEST.

1.**Coordinates:** absolute constraints (station weights, station fixing, free network constraints.

2.**Velocities:** absolute and relative (concerning sites) constraints.

3.**Troposphere**: absolute and relative (in time) constraints

Co ordinate estimation: In GPSEST, normally, a priori coordinates of a chosen reference station are fixed or at least tightly constrained when processing a baseline or a network. To save the coordinates in NORMAL EQUATION FILES which will be used for ADDNEQ facility later, we have to tightly constrain the coordinates.

6. Refined Data processing and Analysis of the Complete data set by BPE

6.1: Solution strategy for Global Network Solution:

In our processing for **GLOBAL NETWORK SOLUTION** we used the following solution strategy to obtain accurate results.

1. **IGS precise orbits:**

As on today we have precise orbits available which are routinely estimated as one of the data products of IGS as shown in Table No. 1.in chapter 4. Bauersima, 1983; computed the error D_x in a component of a baseline length l as a function of an orbit error of size D_X

$$D_x = \frac{l/d.\ D_X}{25{,}000} \sim l\ (km).\ D_X$$

d is the mean distance between the stations and the satellite system. Using this we can obtain the impact of orbit errors on the estimated station coordinates for different baselines, which is shown in the following table

Tab 3.0

orbit error in ppm	baseline length	baseline error in ppm	baseline error in mm
25 m	1km	1ppm	1mm
25 m	10km	1ppm	10mm
25 m	100km	1ppm	100mm
25 m	1000km	1ppm	1000mm

2.5 m	10km	.1ppm	1mm
2.5 m	100km	.1ppm	10mm
2.5 m	1000km	.1ppm	100mm
.25m	100km	.01ppm	1mm
.25m	1000km	.01ppm	10mm
0.5 m	100km	.002ppm	- mm
0.5 m	1000km	.002ppm	0.5 mm

From this table it is clear that if we use the IGS precise orbits, we can estimate the baselines of thousands of kilometers within a few mm.

2) 1 day / week solution was selected first to obtain the independent solution.
Second, station velocity uncertainities are more sensitive to the time spanned data than additional data points spaced closely together in time. To have a manageable size of a data set for the time span, we used once a week data (Larsen.et.al; 1997)

3) 4 Tropospheric parameters/day were estimated. We used the Saastamonian global model.

4) Ionosphere free linear combination.

5) Elevation mask 20 degree.

6) Ambiguity resolution: Among many options we selected " NO", by which Ambiguities resolved in earlier step are preeliminated before inversion of the normal equation matrix. This option was chosen because baselines of 6000Km and above are very long. Ambiguity resolution parameters will not show a good quality because we loose a lot of data when forming double differences. This is explained in detail in chapter

8.7

7) Reference frames:

For our study we have adopted the ITRF94 ref.frame (Boucher et.al; 1996) to analyze the data from 1995 to 1996. By Jan 1997, ITRF96 reference frame was available to the global users by IERS. It clearly follows the development of previous frames, in particular ITRF94, with improvements both in data quality and estimation strategy. All the reference sites coordinates and velocities were available for ITRF96. It is designed to agree on average with the NNR-A absolute plate motion model. We used ITRF 96 site coordinates and velocities to process the data from 1997 to 1998.

8. The fiducial free strategy:

Our aim was to study the movement of Indian plate by estimating the baseline distances from HYDERABAD to other stations of the IGS network. In order to achieve this we have to select a reference station, which is in the more stable plate, and it is not situated in the adjacent or neighbouring plates. The reference station WETTZELL fits into this category. While computing the Network solution, we fixed WETTZELL and all other stations were loosely constrained in order to obtain the change in the baseline vectors.

6.2 Station coordinates and velocities:

In the global network analysis we need to have good coordinates known in a correct reference frame for one station at least, in order to be able to obtain accurate coordinates for other sites in the same reference frame. Because reference frames have seven degrees of freedom (three translations, three rotations, and a scale factor). It is even preferable to have at least three stations with accurately known a priori coordinates. This however depends on the size of the network, the number of the available sites, and their distance to the network. Normally, the a priori coordinates of the known sites are fixed or at least tightly constrained.

6.3 Fiducial free strategy:

To avoid errors due to incorrect reference frames and their biases while fixing or constraining site coordinates, we have to select at least one site with well established geocentric coordinates to be included in the local and regional network.

It is also possible to generate fiducial free network solution. In the fiducial free network approach only loose (1m-1km) constraints are applied to the reference sites. The coordinates of the reference sites do not have to be known exactly because they are loosely constrained. Therefore practically all available stations may be selected as reference sites. The advantage of this procedure is that the solution will not be distorted due to biases in the a priori coordinates, but the main disadvantage is that the resulting coordinate and other estimated parameters are not in a well-defined reference frame. The results will also show considerable day to day variations because significant translations and rotations will exist between daily coordinate sets. Therefore the results of a fiducial network have to be transformed into an appropriate reference frame using e.g. Helmert transformations. It is of course necessary for this transformation to use known station again. The regular daily transformation may also remove part of the geo dynamical signal contained in the time series. The fiducial free strategy has been mainly used for global networks because of their well-defined station heights and scale of the solution.

6.4: Hyderabad site coordinates:

FOR each and every session, BPE was run for global network solution to obtain the final results of GPSEST parameters. i.e.; **Hyderabad site coordinates , and baseline vectors from Hyderabad to other IGS select stations.** To analyze the results of daily solutions of Hyderabad coordinates further, the following table no. (4) was prepared. (See in APPENDIX)

This table (4) reveals the following:

1. Sigma (s) of single difference observation is an indicator of the posteriori observational rms. error. The values less than 1.5cm represent the good quality of the observation data for that day.

2. Number of Double difference observation and Degrees of freedom depict the strength of the data observed simultaneously.

3. Day to day formal (RMS) errors in

X = max of 0.0077m

Y = max of 0.0092m

Z = max of 0.0096m

4. Day to day formal (RMS) errors

Latitude = max of 0 .0097 sec

Longitude = max of 0 .0012sec

Height = max of 0 .0128m

The individual day rms. errors if they stay within 2 cms , we may conclude that the processing is good. In our solutions it is less than 1cm.

We also computed the weighted RMS and weighted RMS scatter about the mean for the coordinates, which is the indicator of repeatability. Accordingly following are the coordinates for HYDERABAD.

X = 1208445.448 ± 0.0770M

Y = 5966807.378 ± 0.1251M

Z = 1897077.344 ± 0.1070M

To check the reliability of the estimated coordinates a similar analysis was carried out for another station in the same plate (BANGALORE) and TABLE 5 was prepared. (see in APPENDIX) Computations for weighted RMS were carried out.

Table No 5 shows the similar trend of coordinate variation to HYDERABAD.

X = 1337987.339 + 0.0853M

Y = 6070318.413 +0.1537M

Z = 1427877.455 + 0.2517M

This trend as well as the rms. error of 5mm in the estimation of Baseline between Hyderabad and Bangalore shows that they are in a stable region.

6.5: Very long baseline vectors:

INTERNAL CONSISTENCY:

One way to assess the quality of the overall solution is to compare the individual daily solutions. By determining the daily repeatability of the estimated position in terms of baseline length, an indication of internal consistency can be obtained. The reason for using baseline length instead of absolute positions is that it eliminates the effects of possible systematic differences between the daily network solution. This so-called baseline repeatability is defined by the scatter of the estimated daily values about the weighted mean of each individual baseline considered. (see table No.6)

TABLE NO. (6) ESTABLISHED BASELINES FROM HYDERABAD.

TO	DISTANCE m	Scatter about the (m) weighted mean
BANGALORE	497,625.7973	+/- 0.005m
SHANGHAI	4,459,795.2676	+/- 0.02m
LHASA	1,856,738.4828	+/- 0.008m
IRKUTZK	4,381,644.3411	+/- 0.018m
KITAB	2,640,353.5811	+/- 0.011m
WETTZELL	6,481,303.4206	+/- 0.03m
YARRAGADEE	6,208,968.8295	+/- 0.09m
HARTEBEE-STHOEK	6,903,538.00	--------

7. Error sources on the Long Baselines

Studies by Dong and Bock 1989; Blewit, 1989, & Larson (1990.a) have shown that the analysis of GPS measurements collected over a few days show that the scatter in the horizontal component of intersection vector estimates is in millimeters for baselines up to distances of a few hundred kilometers with a proportional error of 10^{-8}. They used the fiducial networks to compute precise satellite orbits. A fiducial network consists of ground stations, which observe satellites that are also being observed, by stations in the crustal deformation experiment. The orbit of the GPS satellite can be estimated with great accuracy when the three dimensional locations of these "fiducial" sites are known to be better than several centimeters. In turn, improved knowledge of the satellite orbit improves the precision and accuracy with which baselines can be estimated.

This is explained in detail in Larson, (JGR 1990 (a)). For Crustal deformation studies, while applying geometrical arguments, the important factors are given in the following equation

$$|dx| / x \approx |dr| / r \approx |df| / f$$

Where x = Baseline length

$|dx|$ = error in baseline length

r = range to the satellite

$|dr|$ = error in the satellite orbit error

f = the distance between two stations in the fiducial network

$|df|$ = error in this distance

- **By the time our data acquisition began, due to the full implementation of GPS satellite constellation, and availability of precise orbits by IGS, errors in estimating the very long baselines of few thousands of kilometers length in global scale are reduced.**

In our analysis we do not improve the orbits of the satellites since the IGS has started to make available very precise satellite orbits. (IGS Annual report 1997& 1998) When no orbit improvement is performed, then we have to make sure that the coordinates, orbits and earth orientation parameters (EOPs) are given in the same reference frame. The EOPs are necessary to transform the IGS precise ephemerides from the earth fixed reference frame to the inertial reference frame. This is used for the numerical integration of the orbits. The consistency between the coordinates, orbits, and EOPS is essential.

The broadcast ephemerides of the GPS Satellites refer to the so-called WGS 84 reference frame. Where as the precise ephemerides of the IGS are given in an International Terrestrial Reference Frame (ITRF, since GPS week 0860 the ITRF94). The main difference between the two systems (WGS84 and ITRF) is that the WGS 84 may only be realized by the users with a quality of about 1 meters geocentric position (because the quality of the broadcast orbits and satellite clocks). The ITRF may be realized with centimeter accuracy if the IGS orbits and ITRF coordinates of the IGS sites are included in the processing. Hence they are consistent at about the 1-meter level. **For both orbit types we may take ITRF coordinates for the reference stations.** When using IGS orbit products, one has to check which one of the ITRF (ITRF92, 94,96) is realized. The precise orbit file header contains this information. In addition to this, we have to make sure that we use the corresponding EOP information.

Since our data analysis is from Sep '95 (GPS week 0819), we used IERS C04 EOP series before the GPS week 0860. After that IGS final orbits are created using a combined IGS pole which is made available together with the orbit. All necessary reference frame information like the ITRF96 coordinates, IERS C04 series and Bulletin A EOP series and the CODE orbits with their corresponding EOP files can be found in the anonymous FTP account at the AIUB.

7.1 Other important errors:

When we are estimating very long base lines, there are many error sources come in. They are summerized in the following equation

$$s^{2} = A^{2} + B^{2} * l^{2}$$

Where σ is the standard deviation, and l is the baseline length.

This equation is formulated by Ruger, (1990) where the measuring equipment has a constant error A and a proportional error B. This follows from the usual law for the combination of independent errors. As we have already explained, the dependence of error on baseline length from GPS is due to many factors. They can be classified as

1) Short term (less than 3 months)

2) Long term (1.1yrs to 3-5 yrs)

3) Short baseline (less than 50 Km)

4) Long baselines (less than 2000Km)

5) Very Long Baselines (more than 2000Km)

Davis et.al (1989) estimated an intrinsic precision and accuracy of the measurement are in mm, over a very short baseline of less than 100m.

The following Table NO (7) is prepared to show how we have reduced the possible errors, which can happen during the estimation of Very long base lines.

TABLE NO. (7)

Errors in estimating Different baselines	**In our solution the remedial measures taken**
1. Davis;et al(1989) expected that the errors in locating the Antenna relative to the Geodetic monument to be Several times than the error in Estimating the short baseline	Now in IGS configuration that was systematically charac - terized/ reduced by the permanent marker.
2. Another source of error that is independent of the baseline is the effect of the multipath.	By making use of the Std. IGS choke ring antenna this is taken care of.

3.Antenna phase center variation	This is reduced/averaged by continuous monitoring for many years.
4.For Global, regional scale long baselines, error sources are:	
a) Troposphere ----------------	was reduced by using Saastamonian model (Explanation follows after this table)
b) Ionosphere-------------------	was minimized by ionosphere free combination
c) Orbit --------- -----------	was reduced by using IGS precise orbit

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7.2 Troposphere Effects and the Estimation of their parameters:

The GPS signals, when propagating from the Satellite antenna to the user antenna are subject to the following propagation effects.

- Propagation delay in ionosphere
- Propagation delay in troposphere
- Multi path propagation at the satellite and in the vicinity of the receiver antenna.

The atmosphere is usually divided into two main shells, the troposphere and the ionosphere.

- The troposphere, also called the neutral atmosphere, is the lower part of the earth's atmosphere which extends from earth's surface to an altitude of about 40Kms.The signal propagation delay depends mainly on the temperature, the pressure and the water vapour content of the atmospheric layers.

When precise orbits of the highest accuracy from IGS are available, the propagation delays of GPS code and phase signals due to the neutral atmosphere (troposphere), probably are the ultimate accuracy limiting factors for

the Geodetic application of GPS.

The troposphere propagation delay is critical for precise position, especially in height component, and baseline determination, since the troposphere is a non-dispersive medium. For GPS frequencies (Seeber2.3, 1995), the tropospheric delay is independent of the frequency. Hence it cannot be determined from dual band measurements. The near surface atmospheric structure has to be adequately modeled. Either mean atmospheric parameters or, measured data on temperature, atmospheric pressure and water vapour content along the signal propagation path must be included in the model.

It is possible to separate (N^{trop})into dry and wet components (Hopfield,1969)

$$N^{trop} = N_d^{trop} + N_w^{trop}$$

where the dry component is due to the dry atmosphere and the wet component is due to the water vapour content in the atmosphere. About 90% of the path delay due to tropospheric refraction stem from the dry component (Janes et. al 1989).

Tropospheric delay depends on the distance traveled by the radio wave through the neutral atmosphere and is therefore also a function of satellite zenith distance (Z). To emphasize this elevation dependence, the tropospheric delay is written as the product of the delay in Zenith direction Δr° and the so-called mapping function **f (z):**

$$\Delta r = f(z)\, \Delta r^{\circ}$$

As suggested by Rothacher, 1992, it is better to use different mapping functions for the dry and wet part of the tropospheric delay.

$$\Delta r = f_d(z)\, \Delta r^{\circ}_d + f_w(z)\, \Delta r^{\circ}_w$$

We used an apriori model for tropospheric refraction, which may be written as

$$f_d(z) = f_w(z) = f(z) = 1/\cos z$$

The apriori model we used is the **Saastamoinen** (Saastamoinen, 1973) which is based on laws associated with an ideal gas.

It is written as the following equation:

$$Dr = \mathbf{0.002277/\cos z\ [p + (12.55/T + 0.005)\ e - \tan^2 z]}$$

where $\Delta\rho$ = tropospheric delay in terms of range bias in meters

p = atmospheric pressure in millibars

e = partial water vapour pressure in millibars

T = temperature in Kelvin.

In our estimation, since we did not have ground meteorological data for any of the stations, we used the values derived from the standard atmosphere. The following are the corresponding values at reference height.

H r (ref.ht) = 0 m

P r =1013.25mb

T r = 18”

H r = 50%

Using only a priori model of the tropospheric delay is not sufficient if highest accuracy is to be achieved. Since error in estimating the long baseline depends upon the tropospheric delay, it is necessary to estimate the troposphere. Therefore we used an a priori model and estimated only the corrections with respect to the a priori model.

In global campaign, it is common to estimate the troposphere parameters for individual stations. As recommended by Rothacher in Bernese manual (1995), we estimated troposphere parameters for all stations.

The total tropospheric delay correction $Dr^{\mathbf{i}}_{\mathbf{k}}$ is given by the following equation.

$$Dr^{\mathbf{i}}_{\mathbf{k}} = Dr_{\mathbf{apr,k}}\ \mathbf{f_{apr}\ (Z^{i}_{k})} \quad + \quad Dr_{\mathbf{k}}\ \mathbf{(t)\ f\ (Z^{i}_{k})}$$

where

$D\rho_{apr,k}$ = is the tropospheric zenith delay according to the a priori model specified. If standard atmosphere is used (no met.files), this is time – invariant (depends on the station height only),

(Z^{i}_{k}) = is the zenith distance (satellite *i*, station k),

f_{apr} = is the mapping function (each a priori model has its mapping function),

$D\rho_{k}(t)$ = is the (time- dependent)troposphere parameter for station *k*, and

$f(Z^{i}_{k})$ = is the mapping function used for the parameter estimation. This mapping function may be different from f_{apr}. We selected **cosz** as our mapping function.

As per the earlier explanation, the troposphere parameter $\Delta\rho_k$ (t) are time dependent. In our processing, a set of parameter $\Delta\rho_k$ (t) was estimated for each site, each parameter is valid within a time interval (t_i to t_{i+1}). To have maximum number of parameters estimated, we used 2hrs. time interval so that we obtain 12 parameters for every 24hrs.session and for all the stations, for example, for the session 206/98 , the number of tropospheric parameters estimated were 96 , thus reducing the absolute troposphere biases caused by errors (unmodeled effects) of tropospheric refraction common to both end points of base line.

This reduction helped minimizing the scale biases of the estimated very long base line lengths.

8. ERROR ANALYSIS in the estimation of Very long baselines.

8.1 Precision:

To calculate the changes in the Baseline vectors, we need to know precision and accuracy of the estimation for our global network analysis. The smallest baseline is about 500 km. and the largest is about 7000km.

Davis et, al; (1989) has shown that the short term precision and accuracy of baselines up to 200km is in sub centimeter level. Hence they referred long term precision to be estimated for the data spanning for 1.1 rears to 3 years. In our study we discuss the longer regional scales that is very long baseline estimation. This requires an empirical investigation of the precision and accuracy of GPS measurements in global network. Way back **in 1969, Bevington** defined the precision being the measure of how exact the estimate is and the accuracy a measure of how close the estimate is to the truth. Later in **(1990,a), Larson** referred, the measure of precision is thus the scatter of results about a mean value and accuracy to be an agreement with some other technique (VLBI).

The evolution of long term, long base line precision, which we have calculated in our estimation, stems out of the following:

To begin with, precision of baseline vectors estimated is characterized by the use of scatter, independently estimated for every session. In our case, it is every GPS day. Short-term precision will be defined by the weighted RMS scatter about the mean of daily estimates, each determined from a single day orbit solution. If we have N independent values y_1, y2...y_n with (formal) standard errors σ1, σ2, σ3, … σn and this scatter is

$$\sigma_{mean} = \sqrt{\frac{N/N-1 \sum ((Y_i - \bar{Y})^2) / \sigma_i^2}{\sum \sigma_i^2}}$$

Where $\bar{y}$ is the weighted mean of the **Yi's.** This quantity is termed as **repeatability.** We avoid this term, because it leads to ambiguity. A high repeatability may be construed as a good result, whereas a large S_{mean} is not desirable. Since short-term precision underestimates the actual plate motion by GPS estimates, we used a similar standard technique adopted by Ma et, al. for long term precision for horizontal measurements and calculated the weighted RMS about the best fitting line.

$$S_{line} = \sqrt{\frac{N/N-2 \sum \frac{(y_i - (a+b\,t_i)^2)}{\sigma_i^2}}{\sum \sigma_i^2}}$$

Where a and b are the intercept and slope of the best fitting line and t_i is the time of the i^{th} measurements. This can be defined as a linear fit and X^2 statistics for S_{line} is

$$X^2 = 1/N-2 \sum \frac{Y_i - (a+b\,t_i)^2}{\sigma_i^2}$$

Since our measure of precision is weighted by our expected error let us describe how these formal errors are calculated.

8.2 Formal errors:

The measurement of standard deviation is calculated by propagating standard deviations of the carrier phase and code pseudo range data through variance and covariance matrix. Our formal errors are then dependent on the data weights we attributed for the carrier phase and code observation

σ(Code): σ (phase) = 1:10,000 for precise code

= 1:100,000 for C/A code

Every single session (day) processing results in estimating RMS Errors for coordinates and baseline. They are the formal errors, which can be called as daily solution.

8.3 Characterization of Errors :

When we are obtaining accurate velocity estimates, variety of error sources with different time scales can corrupt the data. An individual error source also may change with time. Therefore it is convenient to characterize errors as **white (no time dependence) and colored (time correlated).** While the effect of white noise can be greatly reduced through frequent measurements and averaging, this is less useful for time correlated noise, the random walk. Langbein and Johnson, 1997 suggest that the geodetic monument noise can be modeled as a random walk. Other source for time correlated noise includes mismodeled satellite orbits, ref.frame effects, (EOP), atmospheric effects, and antenna phase center variation which may vary with satellite elevation, Azimuth and local environmental factors. They are known as **systematic errors**. Receiver and satellite clocks are modeled as white noise, in other words, each estimate was independent and uncorrelated with the clock bias at previous measurements. Double differencing used in Bernese is essentially for white noise clock modeling.

Mao, et al (1999) have shown that the combination of white noise and flicker noise appears to be the best model for the noise characteristics. They also suggested that the velocity error in coordinate time series may be underestimated by factors 5-11 if a pure white noise model is used and longer time series of continuous measurements are required to accurately assess random walk noise and reduce time correlated noise.

8.4 Very Long Baseline Vs Error:

In our analysis, we are dealing with the long-term precision of continental scale intersection vectors measured with GPS. It is investigated in a systematic fashion by making use of the modified formula given by (Lichten 1990)

$s^2 = A^2 + B^2 * L^2$

Where

σ = Error in estimation

A = orbit independent contribution

B = orbit related errors which grow larger with baseline length.

L = baseline length (in km)

A is estimated as =0.5 cm

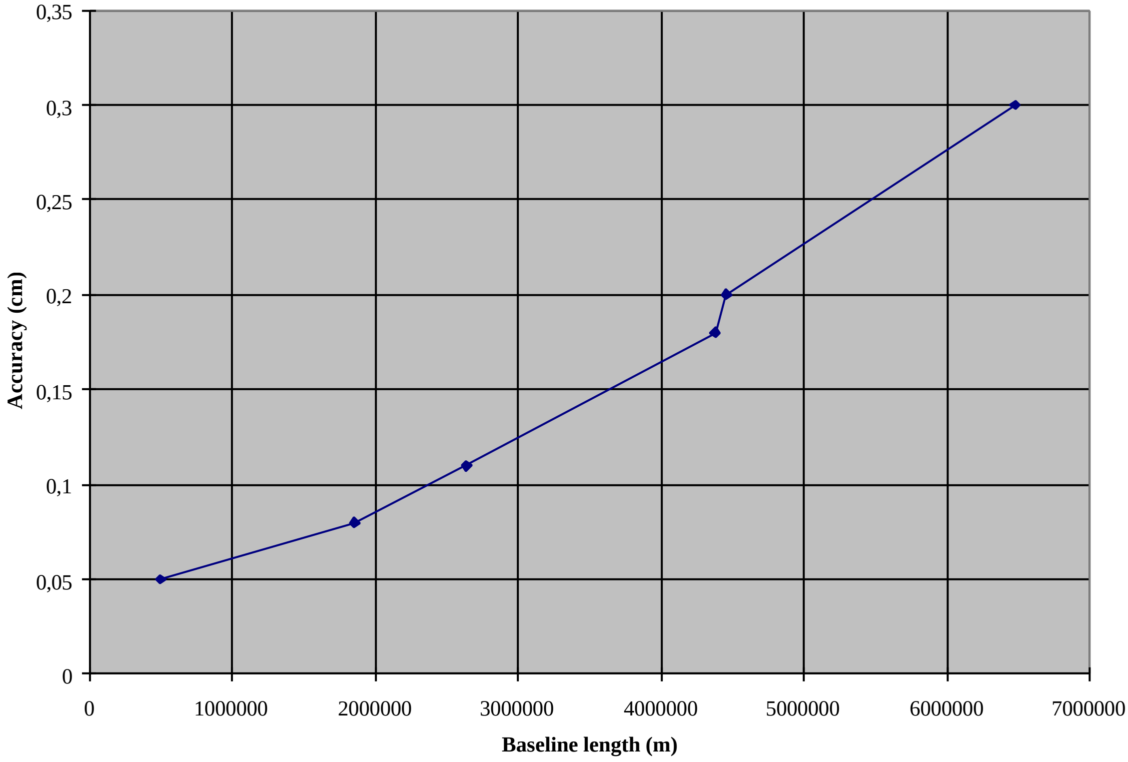
B = 10 $^{-8}$

Seeber (1997) showed these errors of this nature exist up to the estimation of baseline lengths up to 2000km, whereas we could extend these results up to the baselines of 6000km with our improved solution strategy. It is shown in **Fig (10.a)**

8.5 Ambiguity Resolution parameters:

Carrier phase measurements are affected by the ambiguity term $\mathbf{n_f}$, an unknown number of complete wavelengths between satellite and the receiver antenna. The unknown number of cycles in the observation equations (3), (4), in page no 44. are the initial phase ambiguity parameters. They have to be estimated in the first step as real valued parameters. However, it is known that these parameters actually have to be integer numbers. We have to resolve ambiguity parameters while estimating Very long baselines. In our processing we use narrow lane ambiguity which is L3 combination for measurement bias. Resolving ambiguities means to assign correct integer numbers to the real valued estimates.

Fig (10 a)Estimated VeryLongBaselines (from Hyderabad) accuracy



By fixing / resolving, does the solution improve? The answer strongly depends on how well the unknown ambiguity parameters are resolved and the number of measurements. It is already shown in the expression in page no (47), that the

Degree of freedom (f) = No. of observation (n) - No. of unknowns (u).

In our processing, Double Difference (D.D) is the basic observable. From **Table No (4) and (5)** (see in Appendix), we can see clearly that Number of D.D observations are always more than the Degree of freedom. Mervart, 1995 has studied the effect of ambiguity resolution if only the receiver coordinates and the few troposphere parameters are estimated in a regional scales (European Network). We carried out ambiguity resolution in a similar manner. In our case, the only difference is that we have used long session of 24hrs and long base lines. For long baselines up to 2000km, it is possible to process both carriers L1 and L2 together and solve both ambiguities in the same run.

8.5.1: Adjustment of Ambiguities:

While trying to resolve and fix ambiguities beyond 2000km, the Double difference ambiguity parameters have large aposteriori rms errors. Hence among many available algorithms, **we used an option called 'NO' strategy,** by which ambiguity parameters estimated as real numbers will be pre eliminated before the normal equation matrix inversion. Pre elimination saves computing time as well as storage space. Since our network involves the baseline lengths more than 2000km, ambiguity parameters have to be estimated, i.e. **they cannot be fixed on their integer values.** The actual number of parameters in the solution process is shown in table no (8). (See in Appendix)

With these refined data analysis, the following results are obtained.

9.0 RESULTS and DISCUSSION:

The complete statistics of the quality of the processing is shown in **Table No.9. (See in Appendix)** HYDERABAD COORDINATES in ITRF96 reference frame were estimated and plotted in **Fig No.12a, 12b, 12c** from 97-98. The decrease in the X and Y component and the increase in the Z component clearly indicates that Indian plate moves towards North when projecting the coordinates from Cartesian to GEODETIC.

Individual epoch solutions in X, Y, Z for Hyderabad from 95-98 are plotted in **Fig13a, 13b, 13c.**

Tab.nos. 10 and 11 (See in Appendix) show the time series of ECEF and geodetic coordinates respectively. Time series of Geodetic coordinates from 95-98 are plotted **in Fig 14a, 14b and 14c**. Individual baseline vector evolution is shown in **Tab. No. 12** (see in Appendix).

Figs. 15 to 22 show the baseline plots between HYDERABAD and the other stations. The most significant result of this analysis is that the estimated baseline lengths between HYDERABAD and other IGS stations beyond HIMALAYA seem to be shortening.

This clearly indicates the phenomenon of shortening despite the influences like unmodelled errors such as atmospheric effects. Throughout our analysis for all the sessions, the RMS error per day was about 2cm which indicates the quality of processing and the quality of data. We computed the Weighted RMS or the scatter, which is indicative of the repeatability. **Tab. No 13** shows the estimated baseline lengths and rate of movement for the complete time span.

FIG 12 a . Hyderabad Station Coordinate X(M) (97-98)

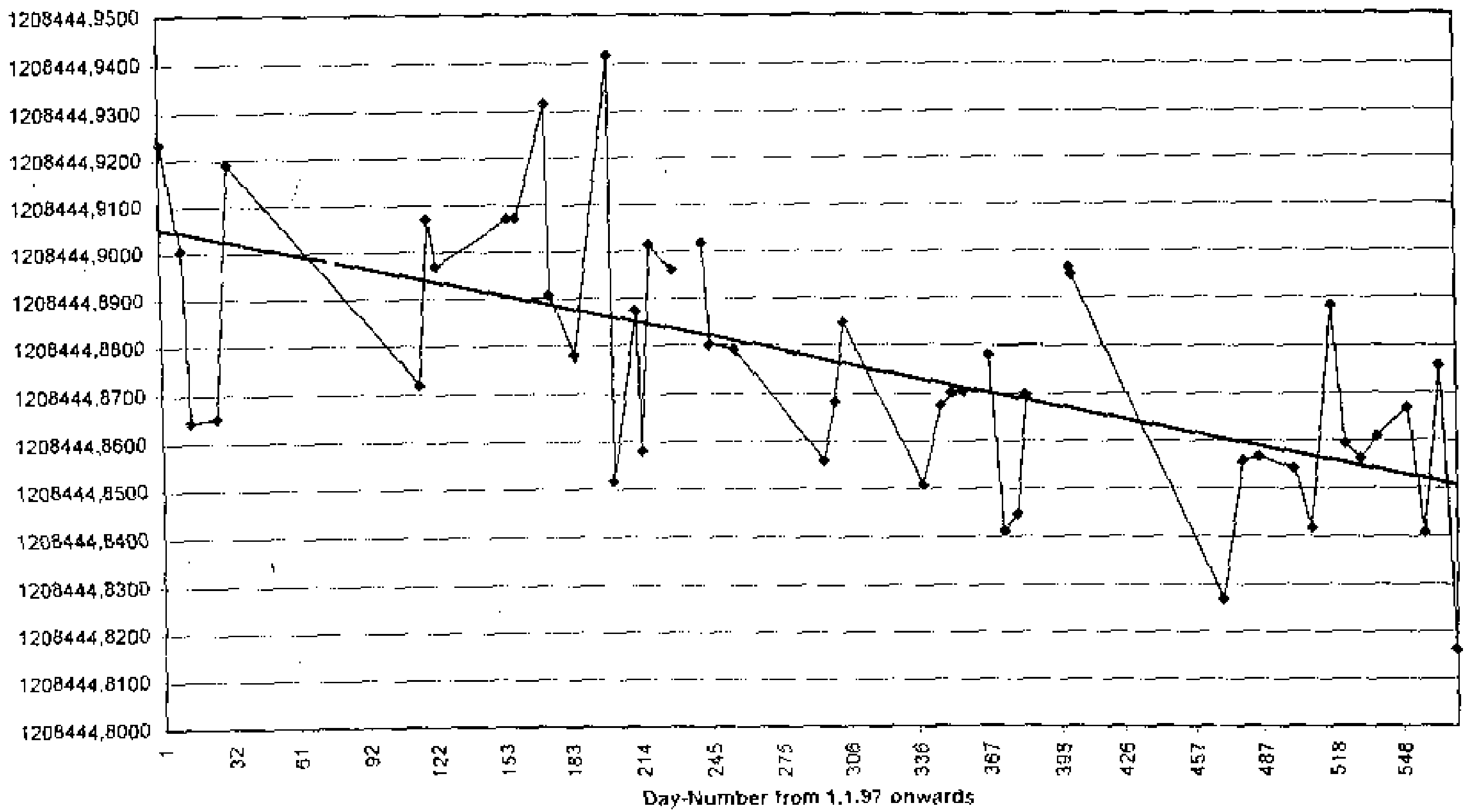


FIG. 12 b. Hyderabad Station Coordinate Y(M) (97-98)

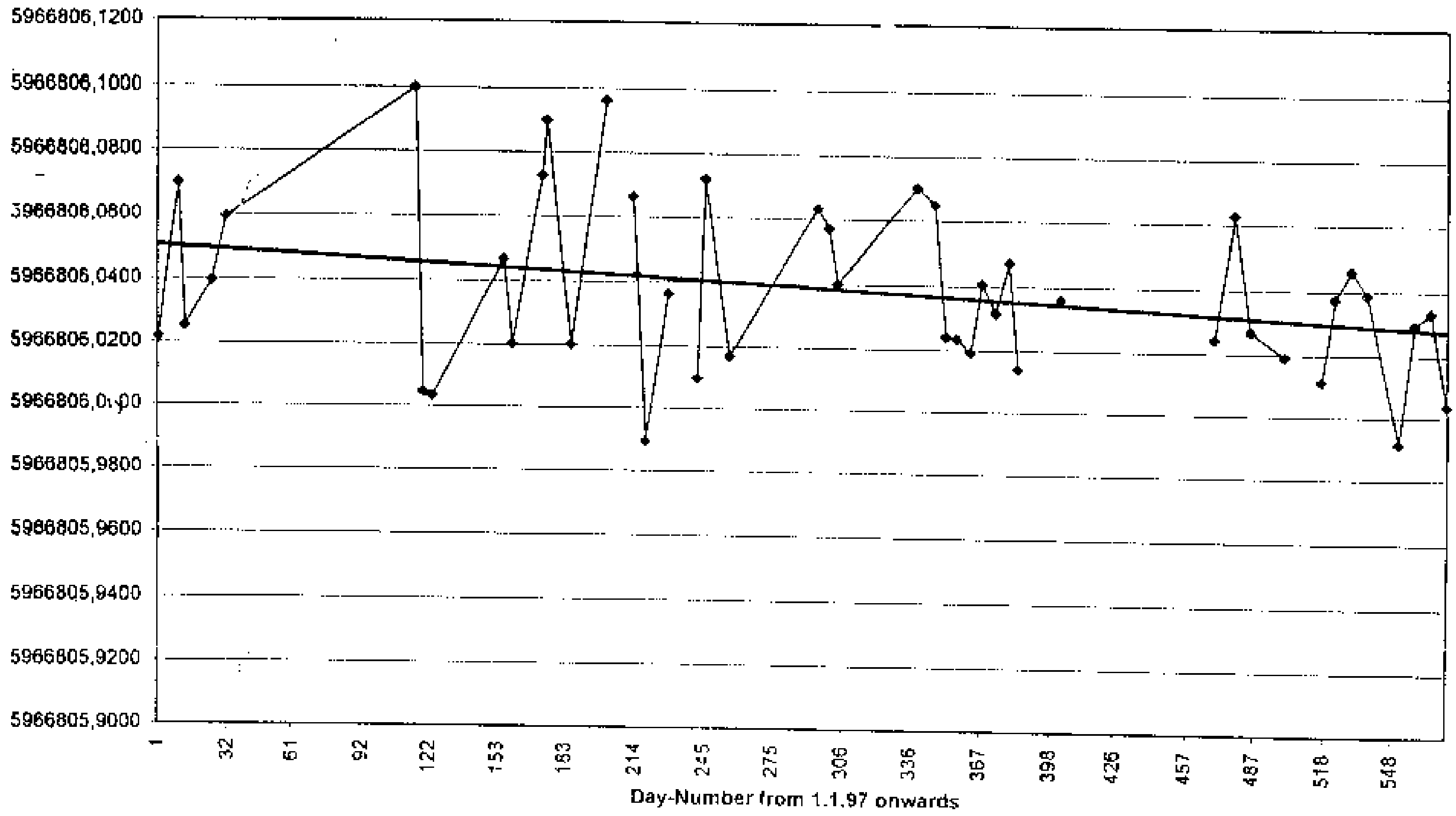
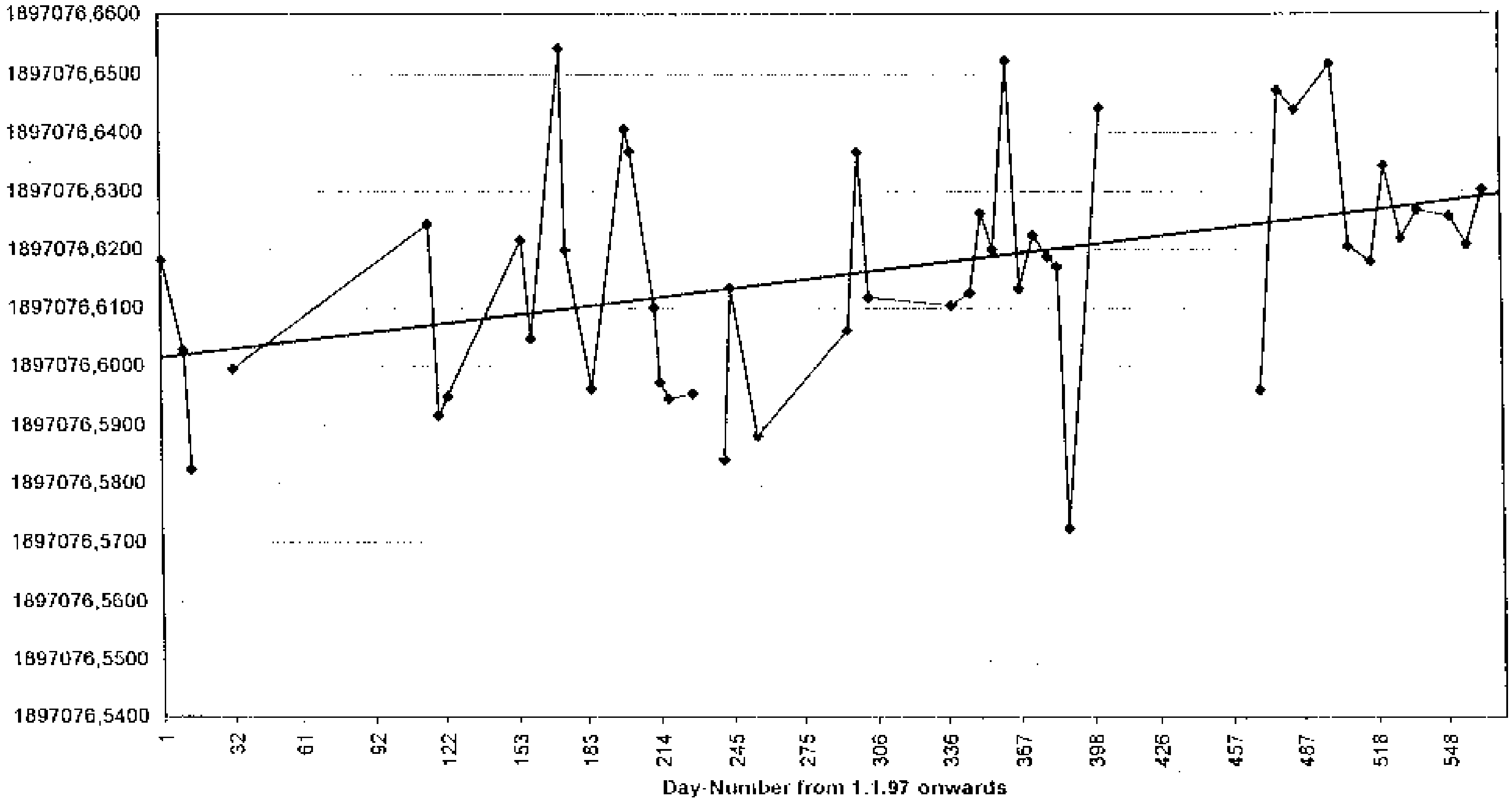
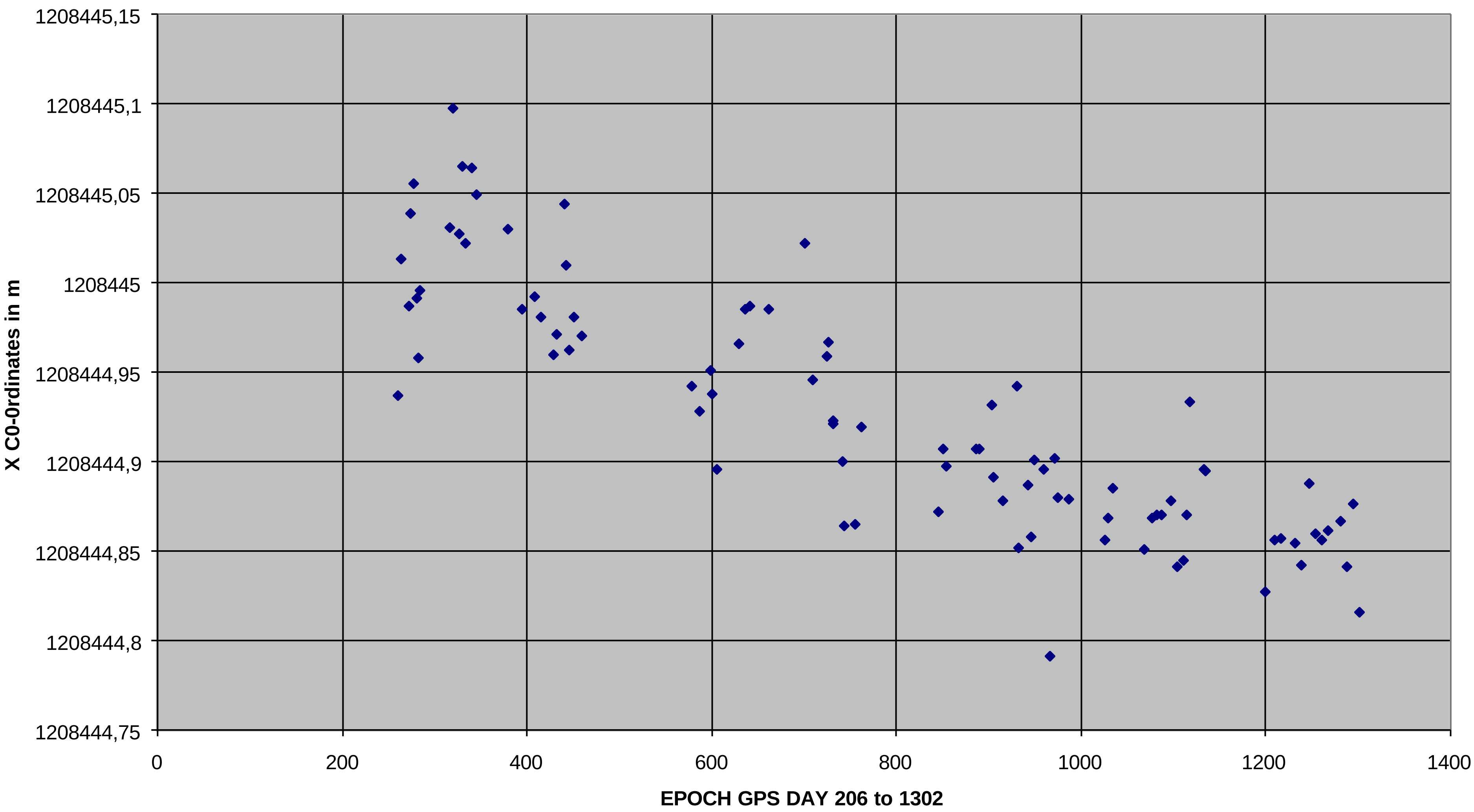


FIG.12c Hyderabad Station Coordinate Z(M) (97-98)



Fig(13 a) Individual Epoch Solutions in X from Sep'95 to Sep'98



FIG(13 b) Individual Epoch Solutions in Y from Sep'95 to Sep'98

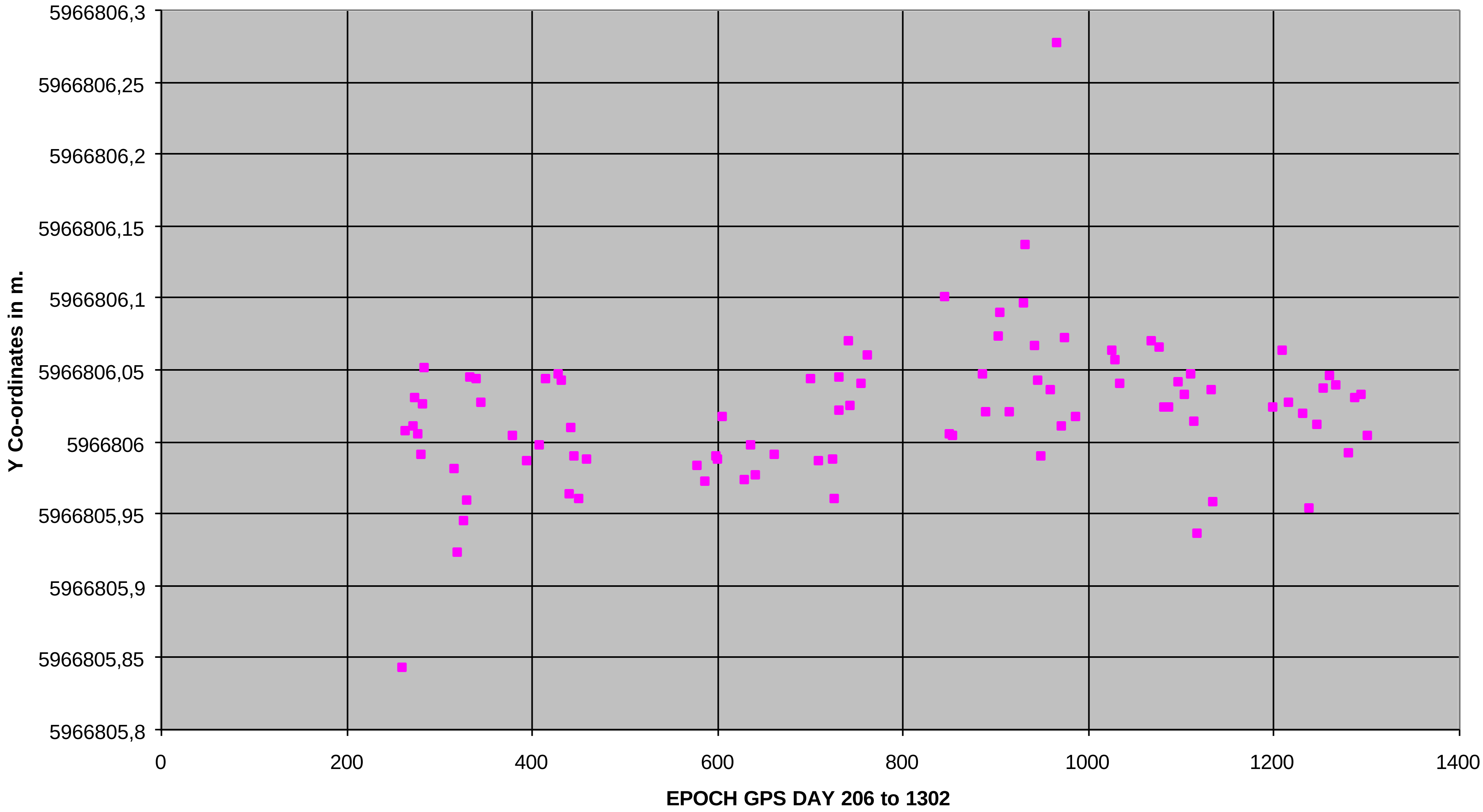


Fig (13 c) Individual Epoch Solutions in Z from Sep'95 to Sep'98

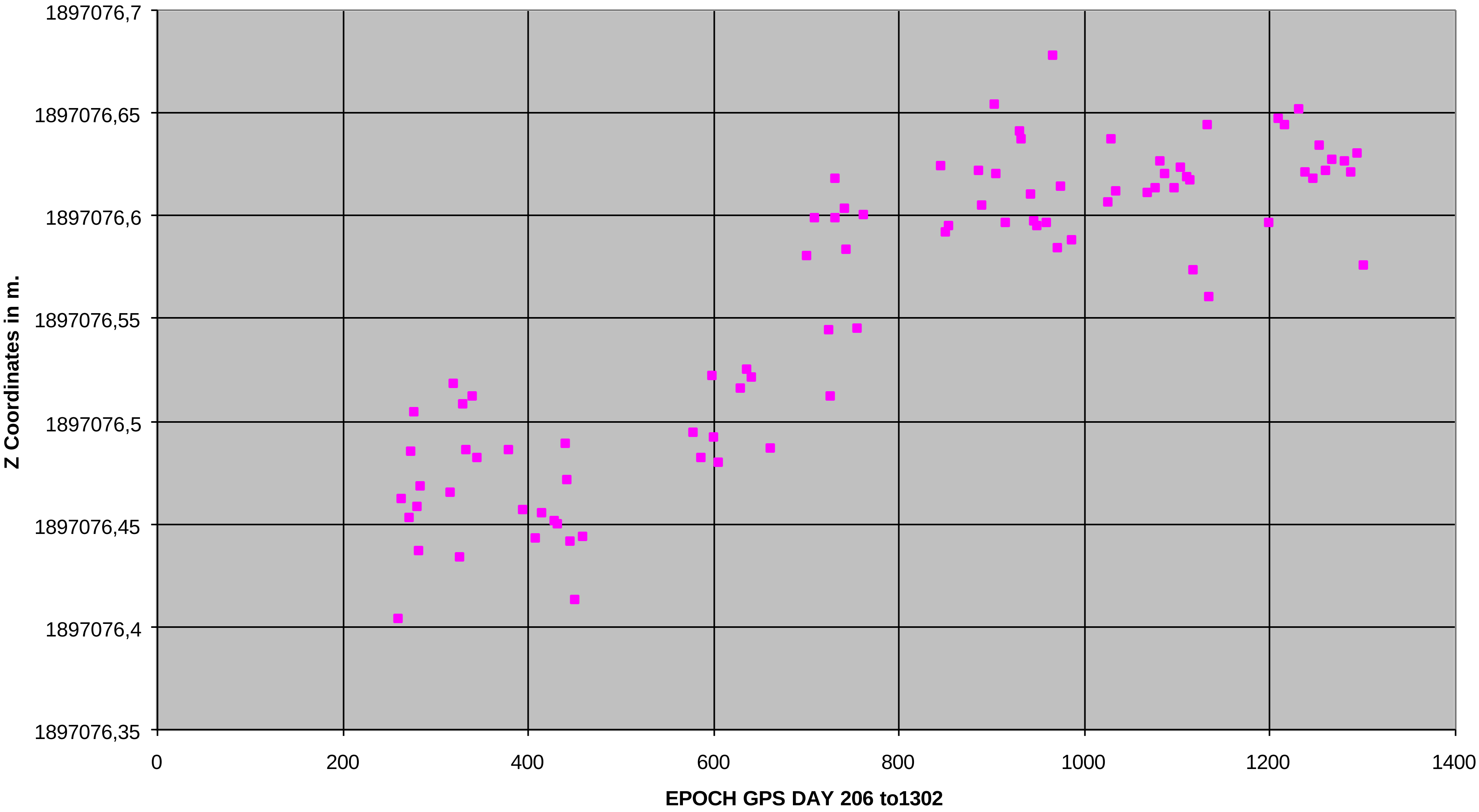
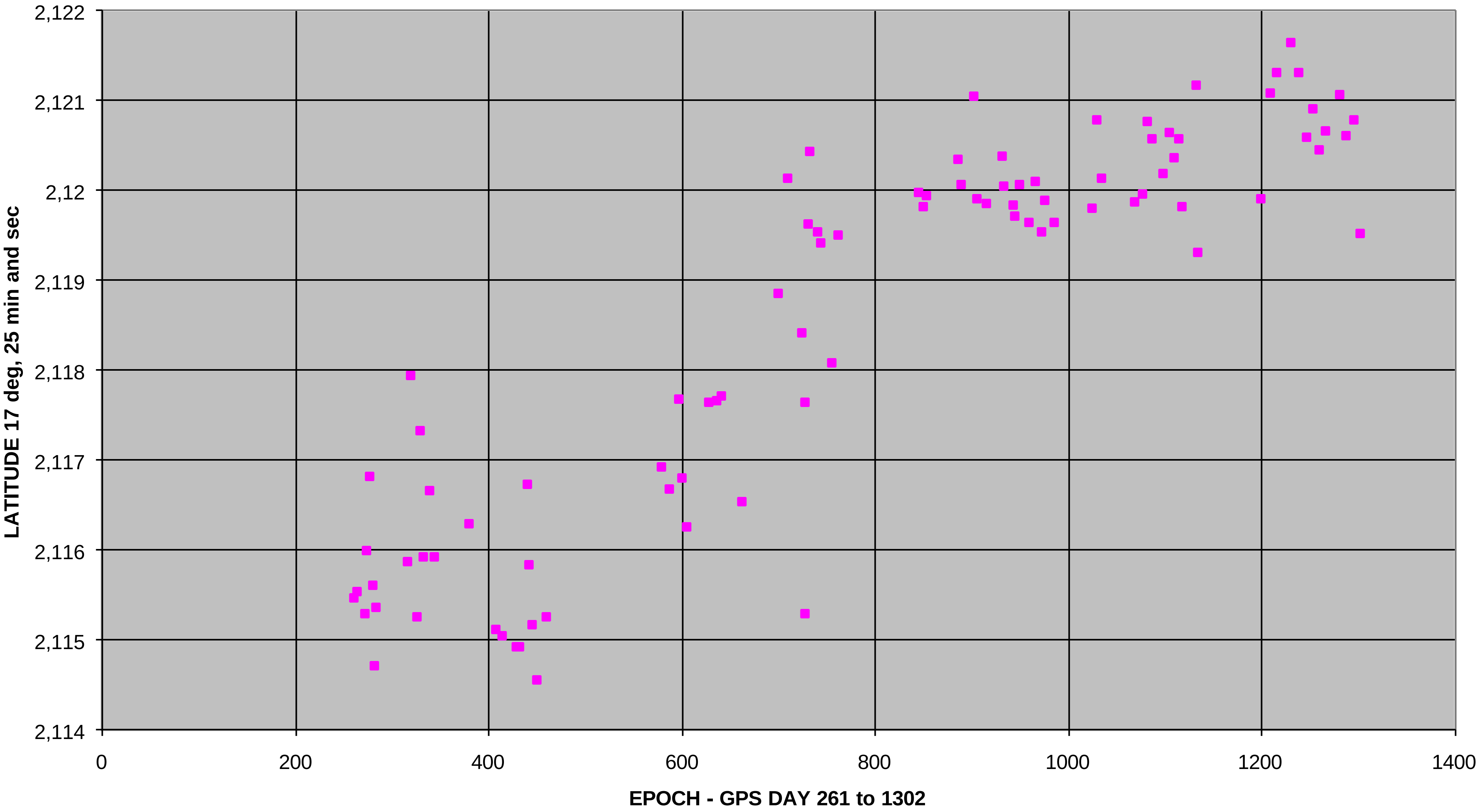


Fig (14 a) Time series of Geodetic coordinates from Sep'95 to Sep'98



Fig(14 b) Time Series of Geodetic Co-ordinates from Sep'95 to Sep'98

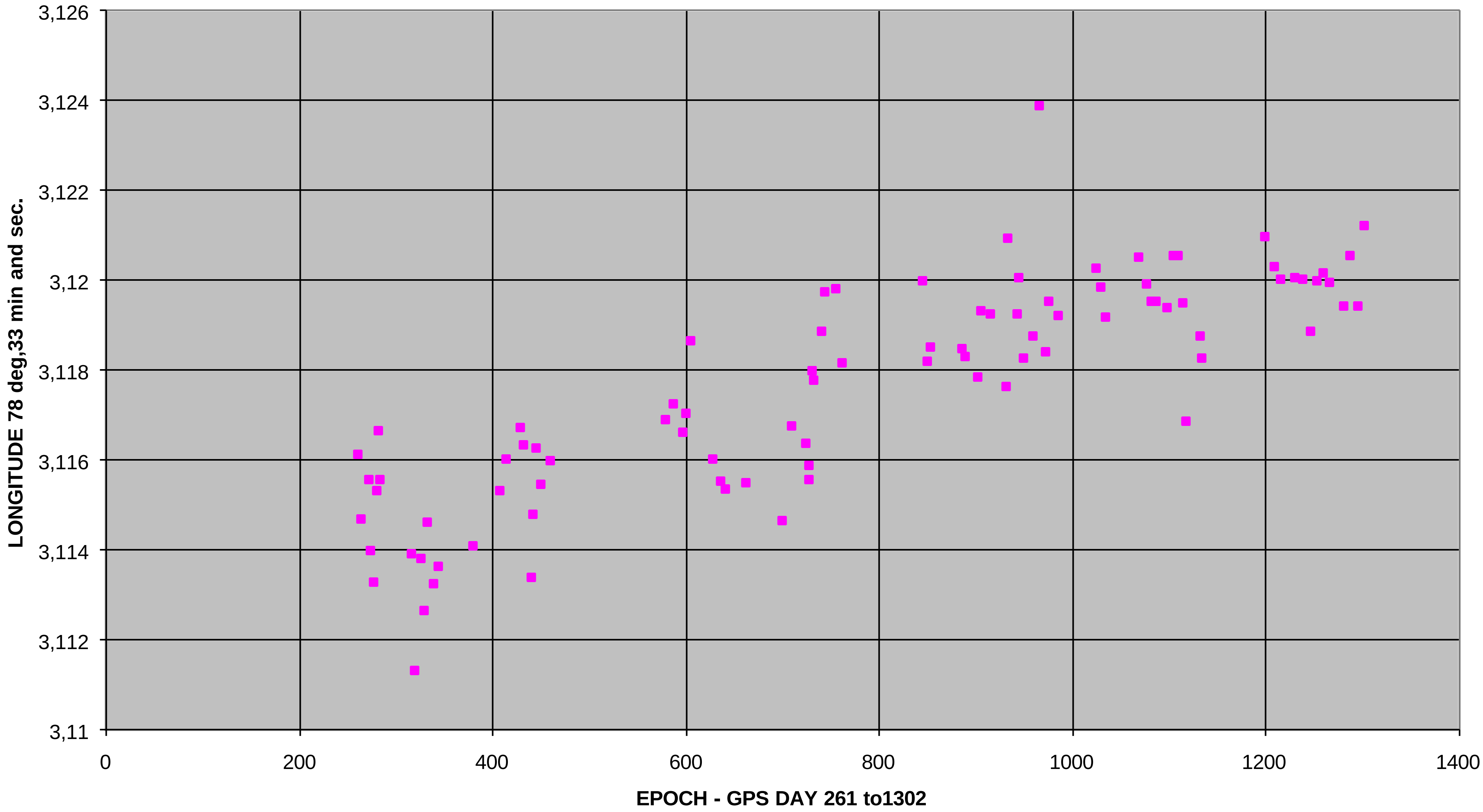


Fig (14C) Time series of Geodetic Coordinates from sep'95 to sep'98

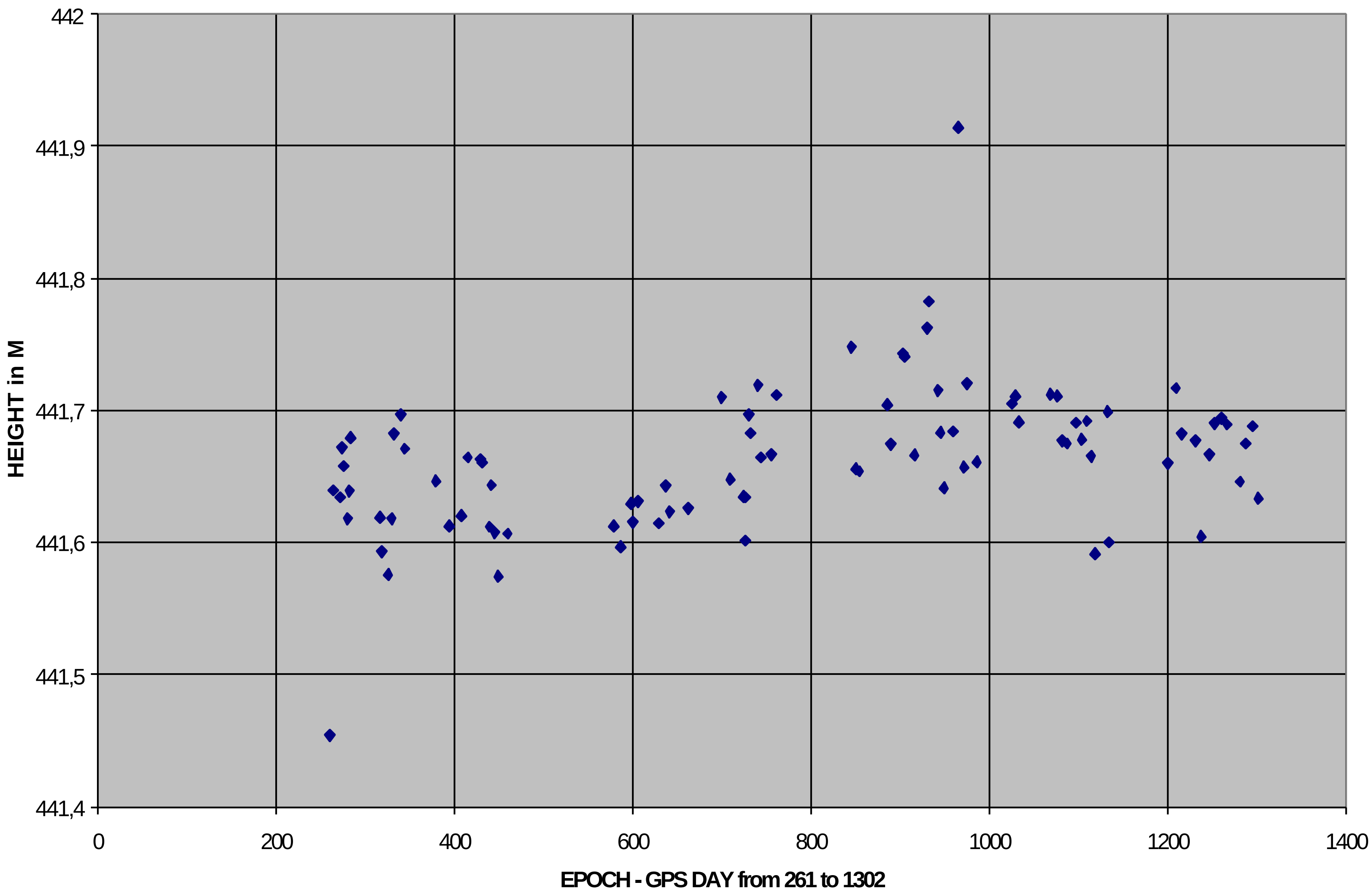


Figure 15: Baselinelength Hyderabad-Bangalore

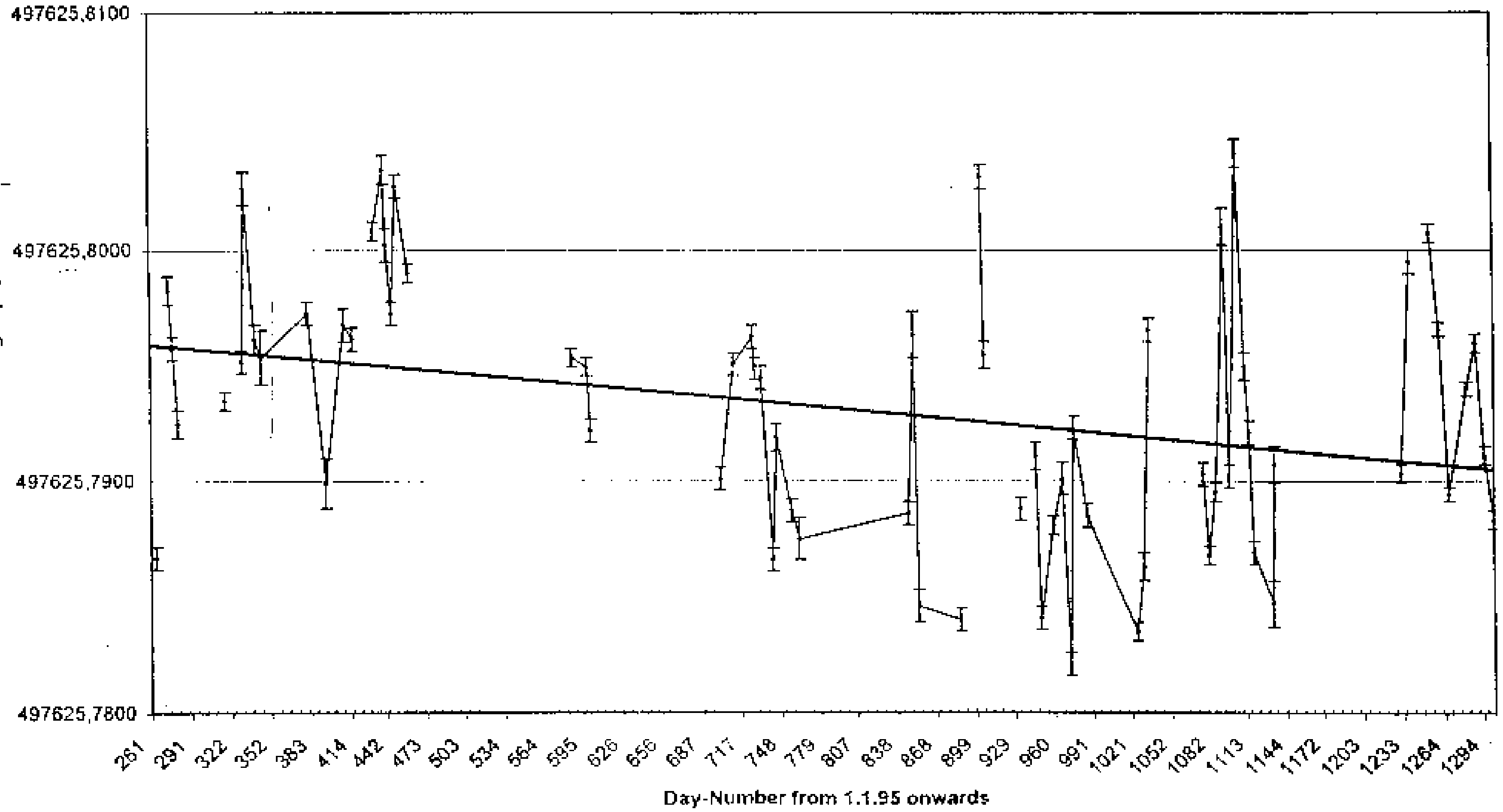


Figure16: Baselinelength Hyderabad-Lhasa

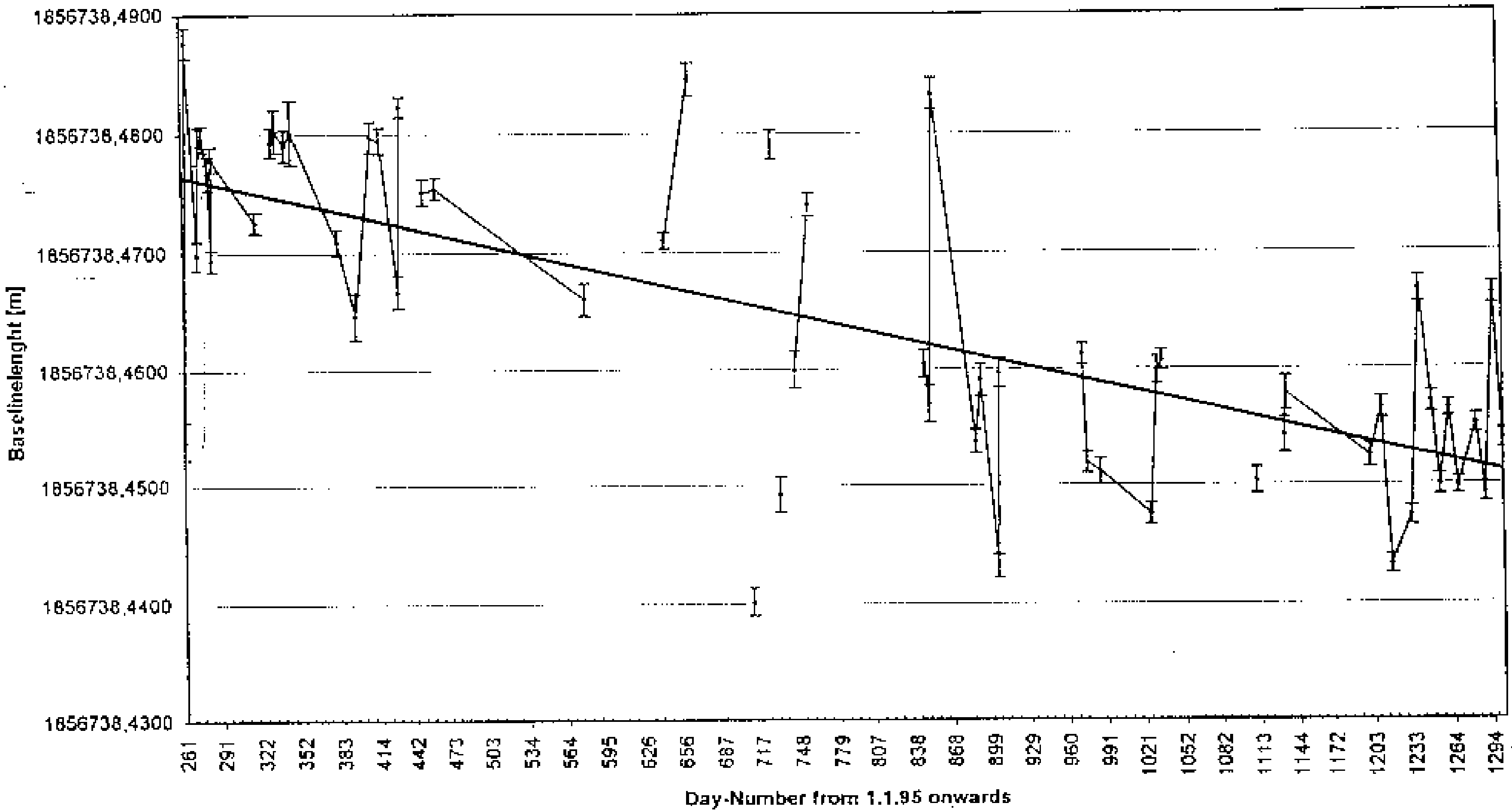


Figure I7: Baselinelength Hyderabad-Irkutsk

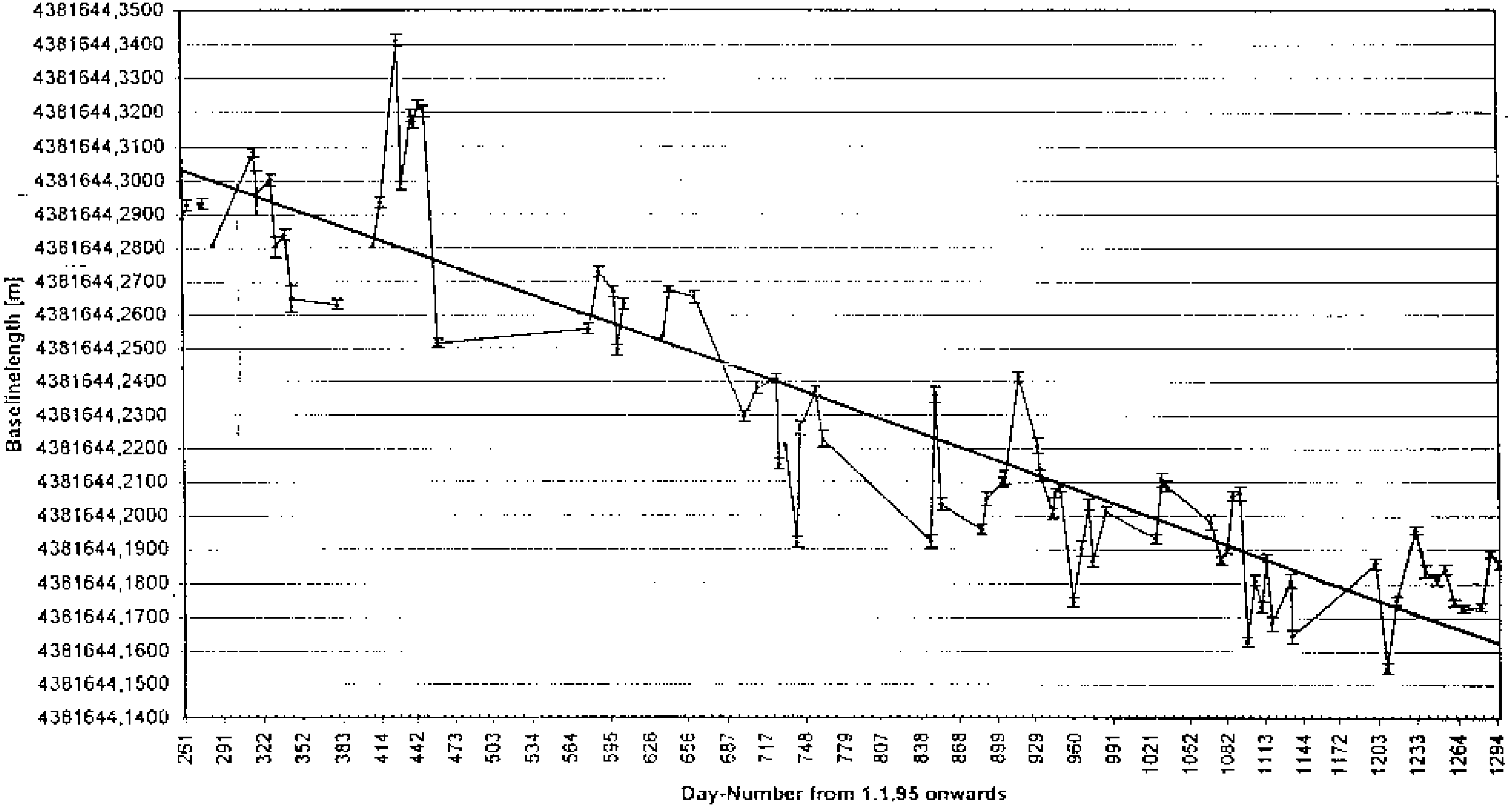


Figure 18: Baselinelength Hyderabad-Kitab

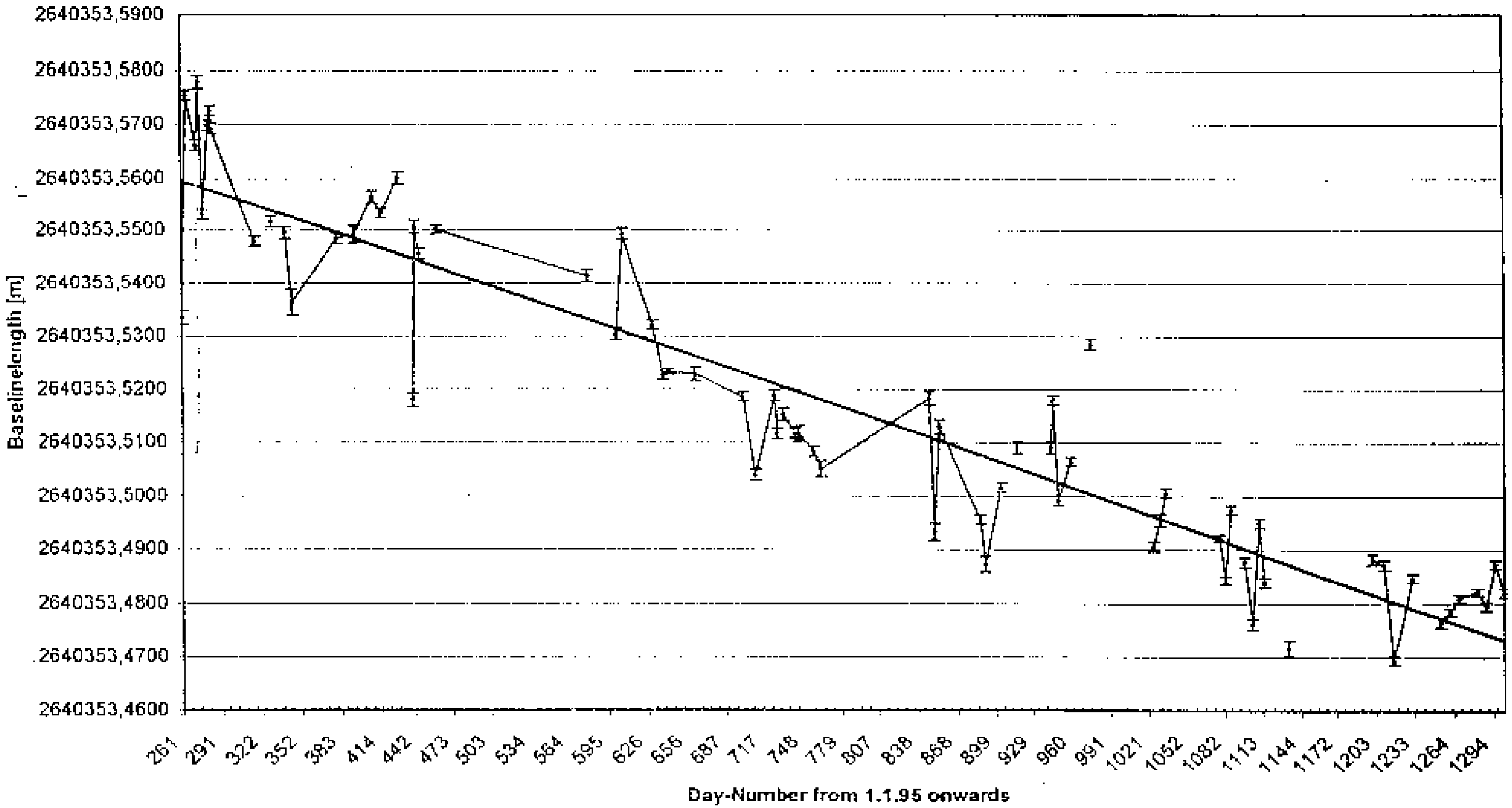


Figure I9: Baselinelength Hyderabad-Shanghai

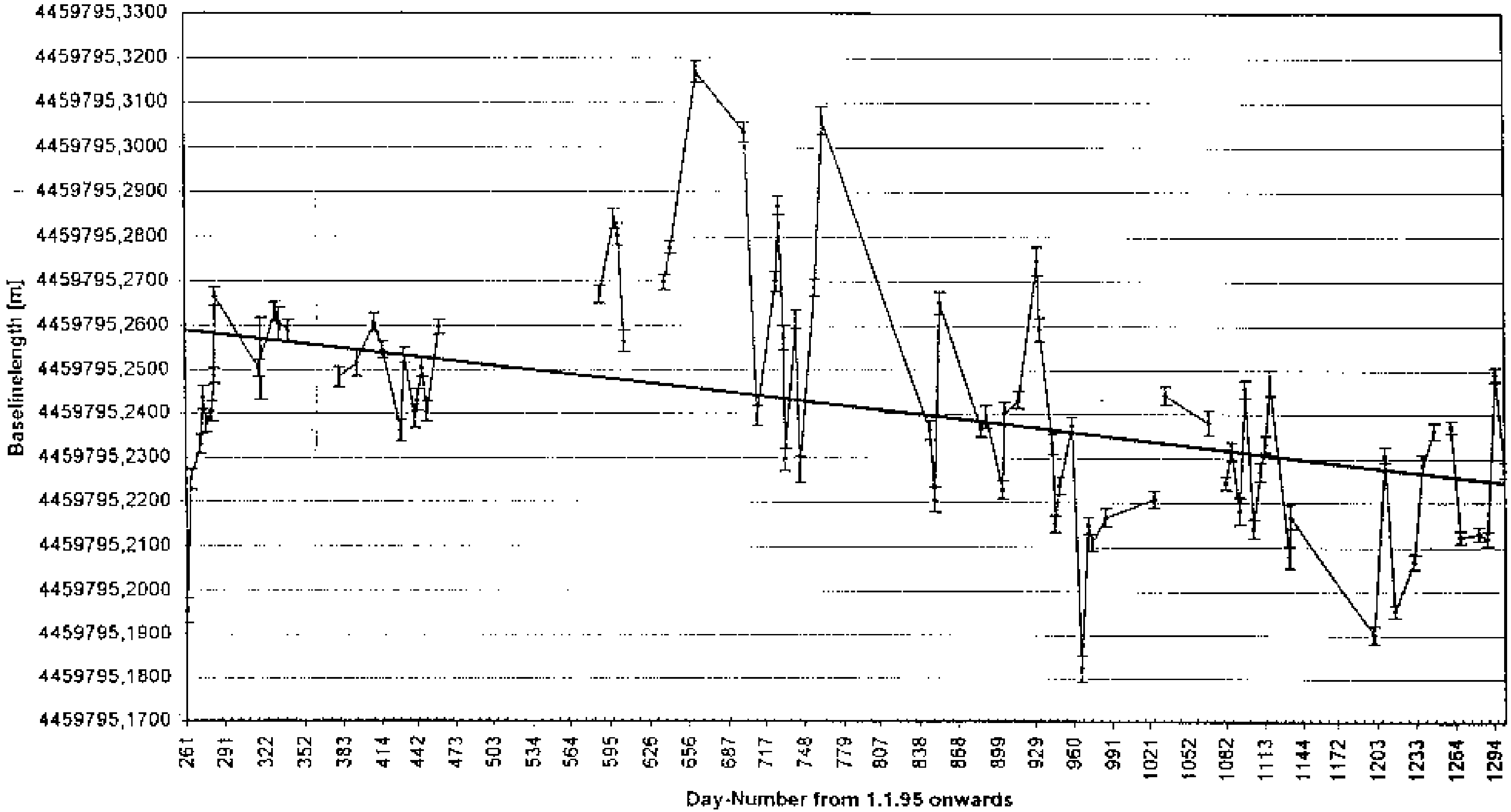


Figure 20:Baselinelength Hyderabad-Wettzell

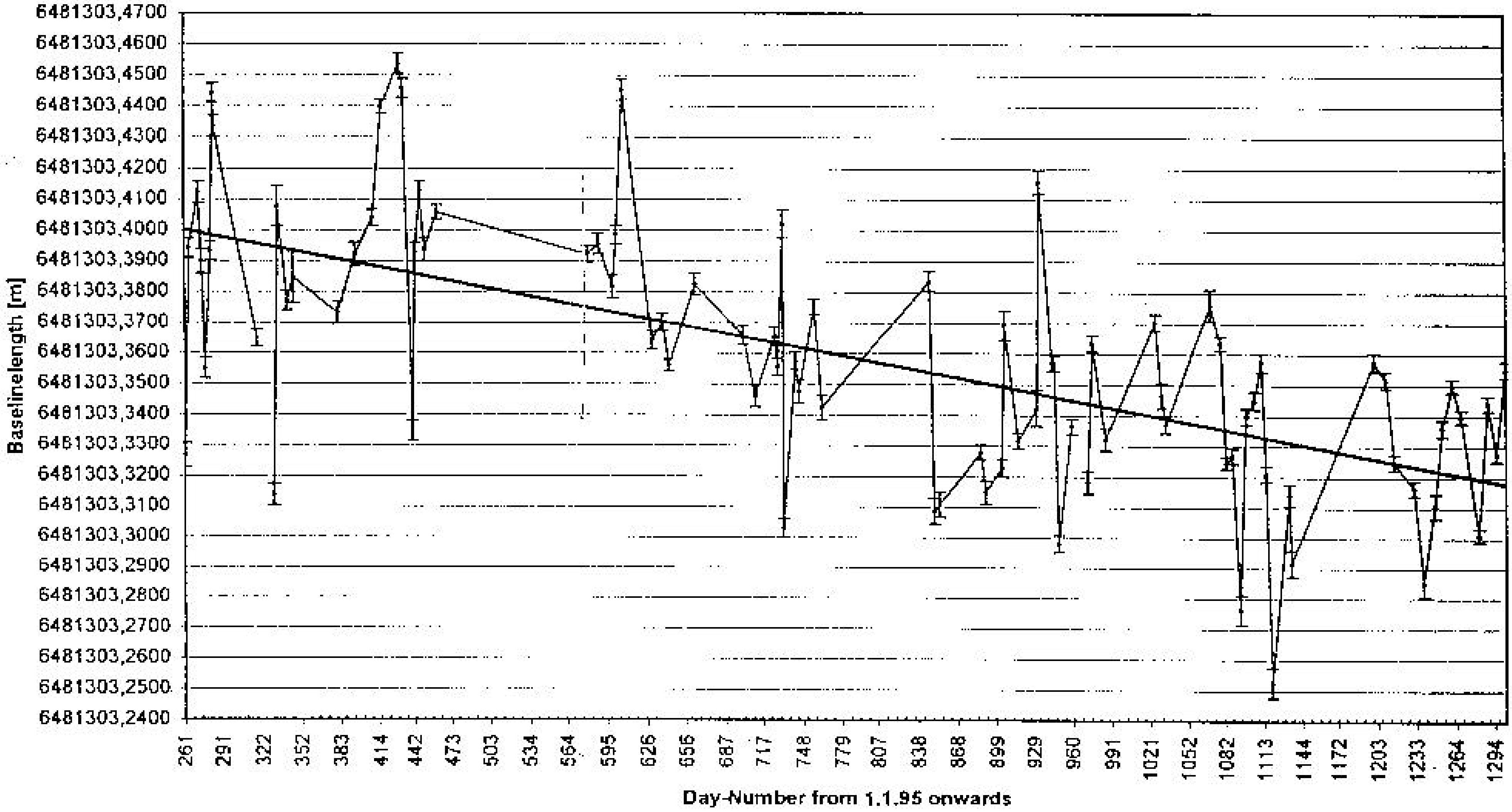


Figure 21: Baselinelength Hyderabad-Yaragadee

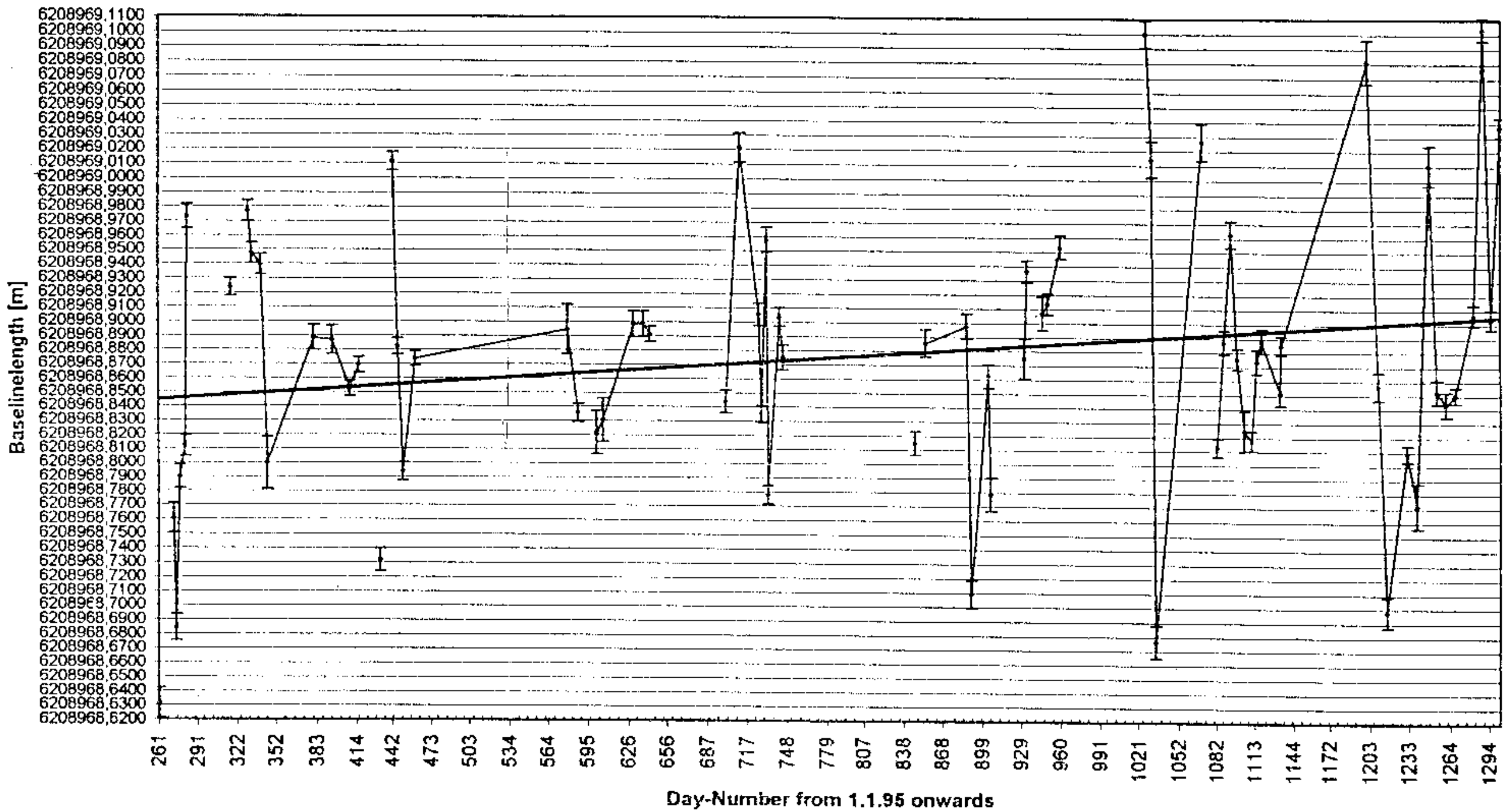


FIG22: **Baseline Hyderabad-Hartebeesthock**

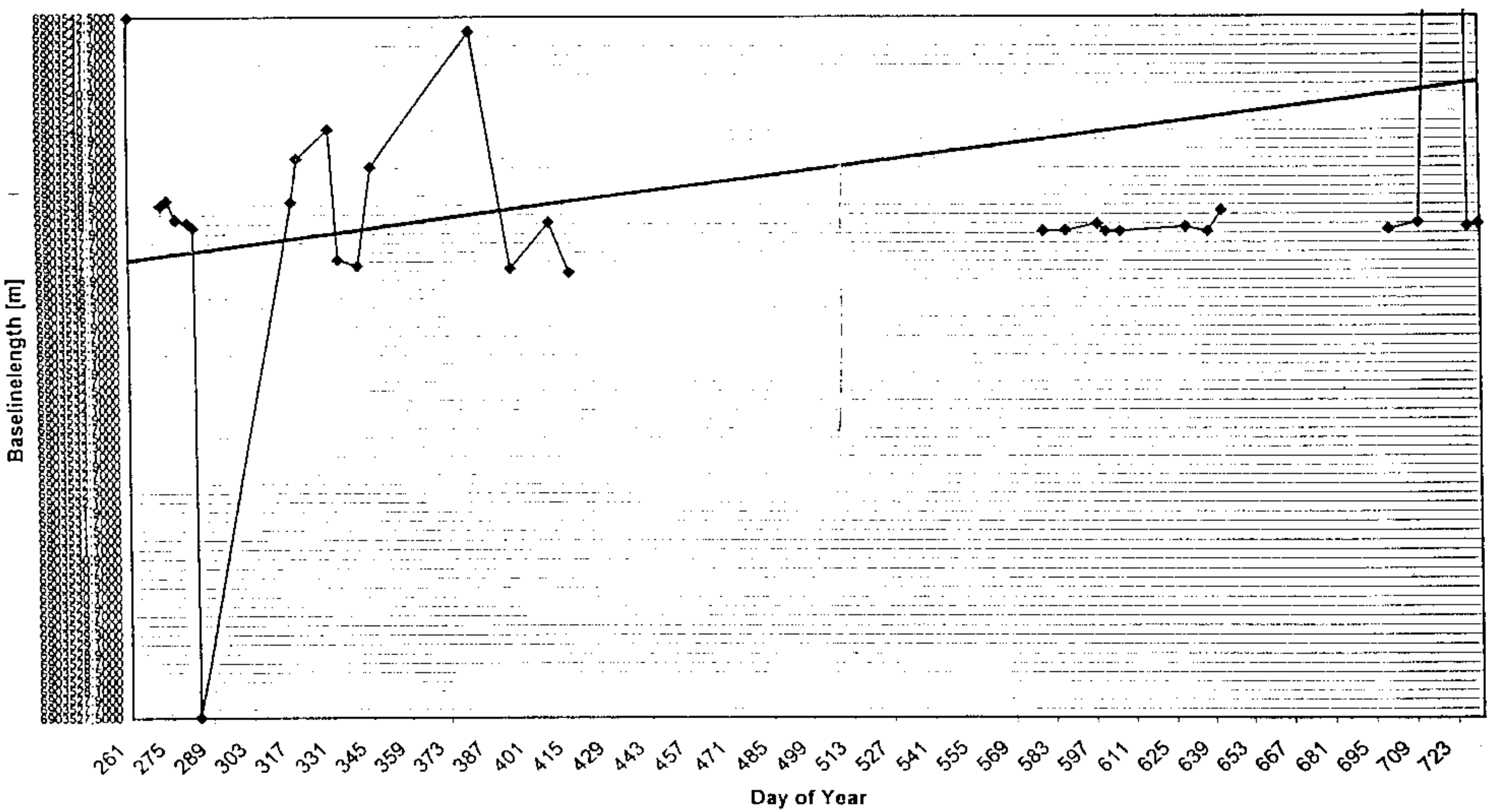


Table No. (13)

ESTABLISHED BASELINES FROM HYDERABAD.

TO	DISTANCE (m)	RATE OF MOVEMENT cm/yr.
BANGALORE	**497,625.7973 +/- 0.005m**	**-0.2**
SHANGHAI	**4,459,795.2676+/- 0.02m**	**-1.2**
LHASA	**1,856,738.4828 +/- 0.008m**	**-0.8**
IRKUTZK	**4,381,644.3411 +/- 0.018m**	**-5.0**
KITAB	**2,640,353.5811 +/- 0.011m**	**-3.0**
WETTZELL	**6,481,303.4206 +/- 0.03m**	**-2.9**
YARRAGADEE	**6,208,968.8295+/- 0.09m**	**+2.12**
HARTEBEE-STHOEK	**6,903,538.00**	**(increasing trend)**

The estimated baseline distances are as follows:

- **HYD to IRKUTZK** : **4381644.3411m +/- 0.018m** and it is shortening at a rate of 5.0 cm/year which fits the NUVEL model.

- **HYD to LHASA** : **1856738.4828m +/- 0.008m** and it is shortening at a rate of 0.8 cm/year.

- **HYD to BANGALORE**: **497625.7973m +/- 0.005m** and it is shortening at a rate of 2 mm/year. (It clearly indicates the inner plate stability between HYDERABAD AND BANGALORE). Table Nos. 4 and 5 clearly indicate the variation in HYDERABAD coordinates is similar to Bangalore coordinates. Total shortening of 6mm/yr for a baseline length of 498625.7973 m for 3 years results in only 2 mm/yr which indicates the inner plate stability**. This value provides the first constraint on the inner plate stability of INDIAN PLATE.**

- **HYD to KITAB** : **2640353.5811m +/- 0.011m** and it is shortening at a rate of 3.0 cm/year.

  - **HYD to WETTZELL**: **6481303.4206m +/- 0.03m** and it is shortening at a rate of 2.3 cm/year.

During 1995 to 96 the marker named WETT was available. Then there was a change in the marker by name WTZT. Both the markers had overlapping observations during 1996. Hence we computed the baseline to WETT marker in 1994 ref.frame and baseline to WTZT in 1996 ref.frame. The baseline distances were tied to have the continuity and to match with both the reference frames.

- **HYD to SHANGHAI : 4459795.2676m +/- 0.02m** and it is shortening at a rate of 1.2 cm/year.

- **HYD to HARTEBEESTHOCK: 6903538.0000m**

In this marker continuous data was not available for the time scan we have analyzed. There was a new marker but old and new were not connected. Hence we could not estimate the trend for the complete period.

- **HYD to YARRAGADEE**: **6208968.8295m +/- 0.09m** and it is increasing at a rate of 2.12 cm/year.

The baseline distance to Yarragadee seems to be increasing for the time period we have chosen to analyze. Since the distance is very long, we are not able to calculate the rate of movement very accurately. If we increase the time span and include more number of stations in between Hyderabad and Yarragadee, we will have more reliable results.

VELOCITY VECTOR:

In our solutions the velocity vectors are obtained in the NUVEL1 frame, i.e. in a no net rotation (NNR) reference frame that is essentially North-America-fixed (Demets, 1994). This frame is also used to constrain the IGS and ITRF solutions (Boucher and Altamini, IERS technical note 1994,1996). Because our intention was to study the Indian plate motion with respect to the Eurasian plate, we have transformed the NUVEL based results into a Eurasia fixed frame. This was done with a program based on the kinematic plate rotation models ( ) and supplied with the NUVEL1 plate rotation parameters. To demonstrate the importance of the distinction between reference frames, we present our results in both frames (Fig.23). In the NUVEL1 frame, both Bangalore and Hyderabad display NE motion of 5 mm/y.

The agreement of both observed vectors with NUVEL1 at the present accuracy level implies that there is no need for a correction of the actual rotational parameters of the Indian plate. In the Eurasia fixed frame, both the vectors have a more northerly direction, which align them perpendicular to the Himalayan arc. This is in harmony with the geotectonic scenario of the Indian plate pushing into Eurasia and increasing the rise of Himalaya.

This provided an additional information on the present-day kinematic picture of Indian Plate. From our analysis, the relative motion of India with respect to Eurasia turns out to be 37mm/y +/-2mm/y in NNE direction. The baseline between Bangalore and Hyderabad shows a contraction of 6 mm +/- 2 mm over the past 3 years, yielding a first estimate for the inner stability of the Indian plate of 2 mm/y +/-1 mm/y.

DISCUSSION:

To include a new station in an existing global network, different strategies can be used. The best and most universal approach is that to use the data from a large set (30 to 50) of well distributed global IGS sites. They perform a combined analysis for orbit, Earth rotation parameters and site coordinates including their velocities (Larson et al. 1997). This type of global solution, which has to be stabilized by introducing several a priori constraints, yields a consistent set of parameters, but requires considerable computer resources. In our solution we chose the 'second' best approach relying on the accuracy of the IGS products. We introduced the IGS orbits and the Earth rotation parameters for the entire processing. The new station at Hyderabad, central India, has begun collecting data since 1995, shortly after the start of permanent GPS measurements at the site of Bangalore, southern India. The Hyderabad data were taken at a rate of one to two days per week and have been processed together with the data from Bangalore and several other IGS stations on the Eurasian plate for the period from Sept. 1995 to Sept. 1998. Apart from this, we used minimal constraints; i.e. we fixed Wettzell to its position and motion in the ITRF96, which is consistent with IGS for the period considered. For the other nine stations the coordinates and velocities in all three components were determined.

The processing of the 300 epochs was done in a semi-automatic way using the Bernese Processing Engine (BPE). Special care was taken to eliminate incomplete or otherwise defective data sets before the final run. Two different types of solution were performed, the first one by an epoch by epoch solution which shows the time evolution of coordinates and baseline lengths, and the second one for simultaneous coordinate and velocity vector estimation using the ADDNEQ-module of the Bernese software. The first solution was helpful to visualize the repeatability of the results for each epoch and to derive realistic error estimates for the site motions.

Our processing of global network solution involves estimation of short baseline of **500Km** to Very long baseline of **7000Km** lengths. To qualify the level of significance of the derived rate, the most important three baseline lengths are discussed. The shortest baseline is between **Hyderabad** and **Bangalore.** The baseline length at the beginning epoch (264/95GPS Day) was **497625.7867m** and at the last epoch (206/98 GPS Day) was **497625.7883m**.When we linear fit this data, the rate of change/year is **-0.002m**. When we analyze this change in length with the short-term and long-term repeatability the following conclusions emerged:

1) Throughout our estimation, the single day solution's rms, which is a measure of short-term repeatability, remained in **sub-mm** level.
2) The calculated long-term repeatability stays within **mm** level.
3) Therefore the change in length is comparable with both the kinds of repeatability.
4) Hence we qualitatively can conclude that the results obtained is very good for short base line measurements.

Then the medium baseline lengths, between **Hyderabad** and **Irkutzk** between the first and last epochs, were **4381644.2889m** and **4381644.1855m** respectively. The linear fit of this data resulted in the following conclusions:

1) The rate of change/year is estimated to be **–0.05m**.

2) The short- term repeatability is of the order of **mm.**

3) The long- term repeatability is about **0.018m**. (order of **cm**)

5) Therefore the change in length is proportional to both the kinds of repeatability.

Hence once again we can qualitatively conclude that the estimation of even medium baseline length and the rate of change is consistently good.

Then the very important observation of our analysis regarding the estimation of very long baseline between **Hyderabad** and **Yarragadee** is being discussed here. The baseline lengths between the first (261/95GPS Day) and last (206/98GPS Day) epochs were estimated to be **6208968.6315m**.and **6208969.0369m**.respectively.Using linear fit, when the rate of change/year was calculated, it was found to be **+2.12cm**. The short-term repeatability is of the order of **cm.,** whereas the long-term repeatability is found to be **0.09m**,which according to our observation is a poor result. Though the rate of change is proportional, the quality of estimation of this very long baseline can be improved with many more number of data sets.

Finally we conclude that one common factor in our analysis is the difference between the short-term and long-term repeatabilities is of the order of **one** in short, medium, and very long baseline measurements.

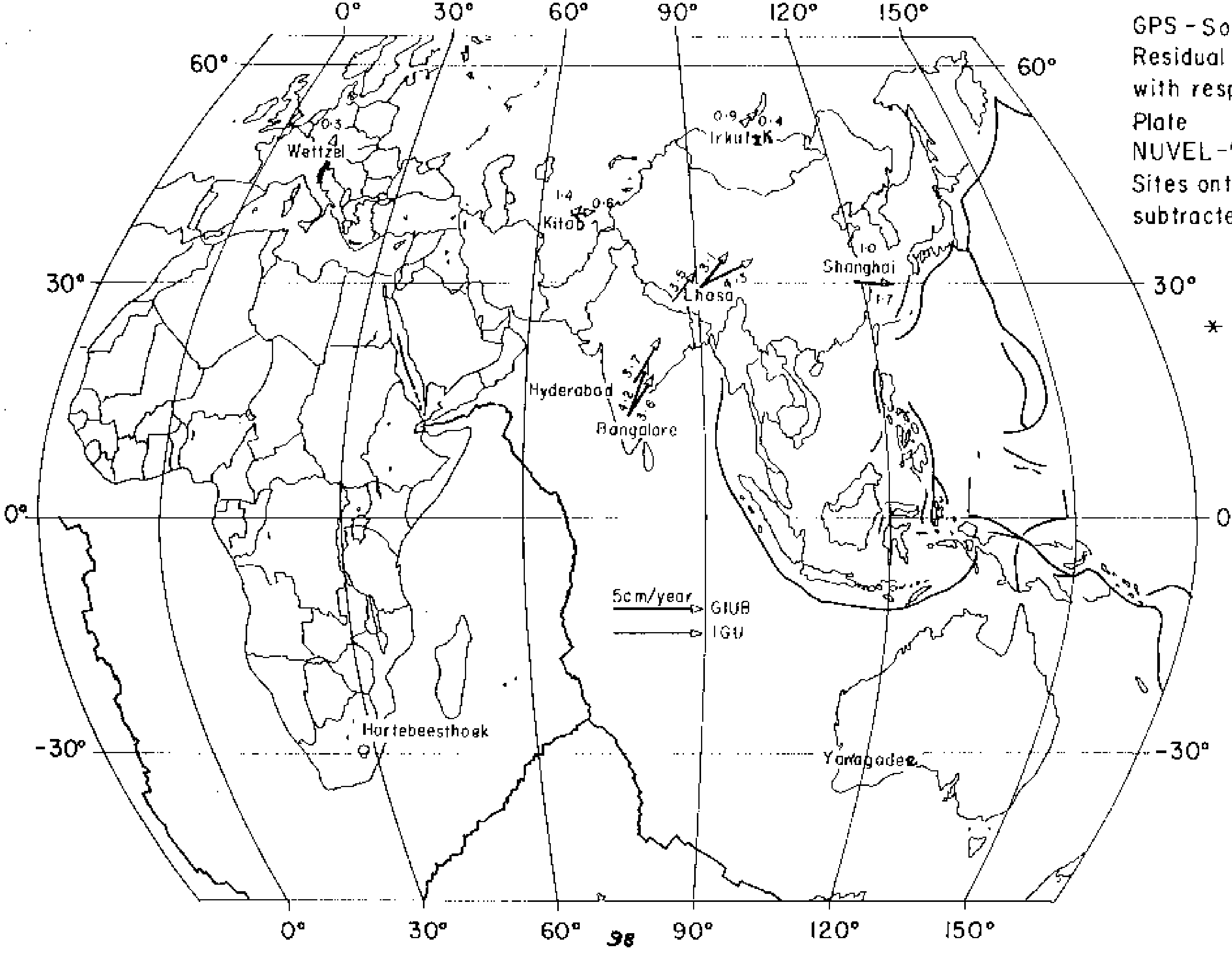
Considering the baseline measurements between Hyderabad and Yarragadee, which is very long, in isolation, unless we have more number of data sets as already mentioned, the results obtained as of now will not have any tangible contribution to plate motion studies.

In our solutions the velocity vectors are obtained in the NUVEL1 frame, i.e. in a no net rotation (NNR) reference frame that is essentially North-America-fixed. (Demets. 1994). This frame is also used to constrain the IGS and ITRF solutions (Boucher and Altamimi, IERS technical note 1994,1996). Because our intention was to study the Indian plate motion with respect to the Eurasian plate, we have transformed the NUVEL based results into a Eurasia fixed frame. This was done with a program based on the kinematic plate rotation models () and supplied with the NUVEL1 plate rotation parameters. To demonstrate the importance of the distinction between reference frames, we present our results in both frames **(Fig23.**)

In the NUVEL1 frame, both Bangalore and Hyderabad display NE motion of 5 mm/y. The agreement of both observed vectors with NUVEL1 at the present accuracy level implies that there is no need for a correction of the actual rotational parameters of the Indian plate. In the Eurasia fixed frame, both the vectors have more northerly direction, which align them perpendicular to the Himalayan arc. This is in harmony with the geotectonic scenario of the Indian plate pushing into Eurasia and increasing the rise of Himalaya.

Up to now, the inner stability of the Indian plate could not be determined directly because of the lack of other stations on the Indian plate itself. The only result so far has been derived from GPS observations taken at Katmandu (NAGA) in Nepal. This site is located in the foothills of the Himalayas and is believed to be within the deforming zone between India and Eurasia. The contraction found by Bilham et al. on the line between Bangalore and Katmandu is 5.0 +/- 1.5mm/y. From our measurements

FIG 23: Velocity Vectors Of select-stations.



GPS - Solutions
Residual Site Motions
with respect to Eurasian
Plate
NUVEL-1A Velocities of all
Sites on the Eurasian Plate
subtracted

* India included
SHG (VLBI): +8mm
SHG (GPS, IGS):
+10 mm

on the 500 km baseline between Bangalore and Hyderabad, we derive a shortening of 2.0 +/- 1mm/y. This value provides a first constraint on the inner stability of the Indian plate. Of course, more years of regular measurements and more GPS stations in other parts of the Indian subcontinent are urgently needed to firm up these results.

The motion of the Indian plate should not be discussed without looking at the effects of the intrusion of the Indian plate into Eurasia. In our analysis we have used Wettzell as a representative of a large number of GPS sites in the western part of Eurasia and we included all other Eurasian stations for which continuous data were available from mid-1996 onwards. The difficulty in using the Eurasian plate as a stable reference is, that among the central and eastern IGS stations there is none that can be considered untouched by the advance of the Indian plate.

In particular, the station of Lhasa in Tibet appears to be driven to a large extent by the effects of this process, showing an ENE motion of 31 mm/y. This and the pattern of motion of the other central and eastern sites seems to support the extrusion model proposed by Peltzer and Tapponnier (1988). By the same token, the degree of convergence between India and Tibet cannot be much larger than 10 to 15 mm/y, an amount that is reached for example by the stations of Simikot, Rongbuk and Tingri in Northern Nepal and Southern Tibet as reported by Bilham et al (1995). These stations belong to a regional GPS network in the southern Himalayas.

The most significant result of our analysis is the baseline vectors from Hyderabad to other stations beyond Himalaya are shortening and to the stations in Australia and Africa are increasing. This phenomenon is fitting into the basic theory of Indian Plate motion. Velocity vectors thus computed for all the stations are comparable with NUVEL -1A reference frame global plate model.

10.CONCLUSION:

We have analyzed 3 years of GPS data from sep'95 to Sep'98. With just three years time span of data, we were able to obtain the rate of movement with only GPS data. **GPS - GEODESY** has proved to be an important tool to assess the intercontinental baseline vectors and their changes. Our study on Indian Plate kinematics revealed that our GPS velocities are comparable with NUVEL-1A absolute plate motion model NNR-A but on Eurasia we have an E-W scaling effect ~ 20% in our velocity solution with respect to IGS

The results we have achieved conform with NUVEL model as far as the plate movement is concerned. Though the Global data centers routinely produce velocity vectors, **our analysis is able to show the significant details of how well the actual measurements are fitting with the individual baseline vector evolution**

In particular we are able to recognize the substantial difference between the formal errors and the repeatability estimated from the linear fit. This difference clearly shows that there is still significant amount of systematic errors present in the analysis, which tend to average out only over longer periods of time (five to ten years). This emphasizes that the campaigns have to be continued for several more years to increase the reliability of the results.

Inclusion of more number of stations between **AFRICA, AUSTRALIA and INDIA** in our future data processing and analysis will enable us to estimate the velocity vectors between these plates accurately.

With various applications like GPS for Geodynamics, Space geophysics, oceanography, ionosphere, and atmosphere studies, timing, local and large scale surveys for crustal deformation studies, GPS will be an indispensable tool in the next millennium.

APPENDIX

TABLE NO. 2. DATA USED FOR OUR PROCESSING									
GPS DAY	HYDE	IISC	LHAS	IRKT	KIT3	SHAO	YAR1	WETT	HART
261/95	A	NA	A	NA	A	A	A	A	A
264/95	A	A	A	A	A	A	NA	A	NA
272/95	A	NA	A	A	A	A	A	A	A
274/95	A	A	A	NA	A	A	A	A	A
277/95	A	A	A	A	A	A	A	A	A
281/95	A	A	A	A	A	A	A	A	A
283/95	A	NA	A	NA	A	A	A	A	A
284/95	A	NA	A	NA	A	A	A	A	A
317/95	A	A	A	A	A	A	A	A	A
319/95	A	NA	A	A	A	A	A	A	A
324/95	A	A	A	A	A	A	A	A	A
326/95	A	NA	A	A	A	A	A	A	A
330/95	A	A	A	A	A	A	A	A	A
333/95	A	A	A	A	NA	A	A	A	A
338/95	A	A	A	A	A	A	A	A	A
340/95	A	A	A	A	A	A	A	A	A
345/95	A	A	A	A	A	A	A	A	A
352/95	A	A	A	A	A	A	A	A	A
015/96	A	A	A	A	A	A	A	A	A
022/96	A	A	A	A	A	A	A	A	A
029/96	A	A	A	A	A	A	A	A	A
043/96	A	A	A	NA	A	A	A	A	A
050/96	A	A	A	A	A	A	A	A	A
064/96	A	NA	A	A	A	A	A	A	NA
067/96	A	A	A	A	NA	A	A	A	NA
075/96	A	A	NA	A	A	A	NA	A	NA
077/96	A	A	NA	A	A	A	A	A	NA
081/96	A	A	NA	A	A	A	A	A	NA
085/96	A	A	A	A	NA	A	A	A	NA
095/96	A	A	A	A	A	A	A	A	NA
214/96	A	NA	A	A	A	NA	A	A	A
222/96	A	A	NA	A	NA	A	A	A	A
233/96	A	A	NA	A	NA	A	NA	A	A
236/96	A	A	NA	A	A	A	A	A	A
241/96	A	NA	NA	A	A	A	A	A	A
264/96	A	NA	NA	A	A	NA	A	A	A
272/96	A	NA	NA	NA	A	A	A	A	A
277/96	A	NA	A	A	A	A	A	A	A
297/96	A	NA	A	A	A	A	NA	A	NA
335/96	A	A	NA	A	A	A	A	A	A
345/96	A	A	A	A	A	A	A	A	A
360/96	A	A	NA	A	A	A	A	A	A
362/96	A	A	A	A	A	A	A	A	A
366/96	A	A	NA	A	NA	A	A	A	A
001/97	A	A	A	NA	A	A	A	A	A
010/97	A	A	NA	A	A	A	A	A	A
013/97	A	A	A	A	A	A	A	A	A

025/97	A	A	A	A	A	A	NA	A	A
031/97	A	A	A	A	A	A	NA	A	A
115/97	A	A	A	A	A	A	A	A	A
119/97	A	A	A	A	A	A	NA	A	A
123/97	A	A	A	A	A	A	A	A	A
155/97	A	A	A	A	A	A	A	A	A
159/97	A	A	A	A	A	A	A	A	A
172/97	A	A	A	A	A	A	A	A	NA
174/97	A	A	A	A	NA	A	A	A	NA
185/97	A	NA	NA	A	A	A	A	A	NA
200/97	A	NA	NA	A	NA	A	A	A	NA
202/97	A	A	NA	A	NA	A	A	A	NA
212/97	A	NA	NA	A	A	A	NA	A	NA
214/97	A	A	NA	A	A	A	A	A	NA
218/97	A	A	NA	A	A	A	A	A	NA
228/98	A	A	NA	A	A	A	A	A	NA
235/97	A	A	NA	A	NA	A	NA	A	NA
241/97	A	A	A	A	NA	A	NA	A	NA
244/97	A	A	A	A	A	A	NA	A	NA
255/97	A	A	A	A	NA	A	NA	A	NA
294/97	A	A	A	A	A	A	A	A	NA
299/97	A	A	A	A	A	NA	A	A	NA
303/97	A	A	A	A	A	A	A	A	NA
338/97	A	A	NA	A	NA	A	A	A	NA
346/97	A	A	NA	A	A	NA	NA	A	NA
351/97	A	A	NA	A	A	A	A	A	NA
356/97	A	A	NA	A	A	A	A	A	NA
362/97	A	A	NA	A	NA	A	A	A	NA
002/98	A	A	NA	A	A	A	A	A	NA
008/98	A	A	NA	A	A	A	A	A	NA
014/98	A	A	A	A	A	A	A	A	NA
018/98	A	A	NA	A	A	A	A	A	NA
022/98	A	A	NA	A	NA	A	A	A	NA
037/98	A	A	A	A	A	A	A	A	NA
038/98	A	A	A	A	NA	A	A	A	NA
104/98	A	NA	A	A	A	A	A	A	NA
113/98	A	NA	A	A	A	A	A	A	NA
120/98	A	NA	A	A	A	A	A	A	NA
135/98	A	A	A	A	A	A	A	A	NA
142/98	A	A	A	A	NA	A	A	A	NA
151/98	A	NA	A	A	NA	A	A	A	NA
157/98	A	A	A	A	A	NA	A	A	NA
164/98	A	A	A	A	A	A	A	A	NA
171/98	A	A	A	A	A	A	A	A	NA
185/98	A	A	A	A	A	A	A	A	NA
192/98	A	A	A	A	A	A	A	A	NA
199/98	A	A	A	A	A	A	A	A	NA
206/98	A	A	A	A	A	A	A	A	NA

TABLE NO 4. FORMAL (RMS) ERRORS OF COORDINATES OF HYDERABAD.

GPS DAY	POSTFIT NOISE(σ) cm	No D.D OBS	Deg. freedom	σx m	σy m	σz m	σlat sec	σlon sec	σht sec
261/95	0.49	33196	32585	.0040	.0041	.0036	.0031	.0040	.0045
264/95	0.38	48532	47930	.0031	.0031	.0030	.0026	.0031	.0035
272/95	0.44	43455	42901	.0031	.0033	.0030	.0027	.0031	.0036
274/95	0.51	47660	46942	.0039	.0039	.0038	.0032	.0039	.0043
277/95	0.46	58912	58165	.0032	.0030	.0031	.0027	.0032	.0034
281/95	0.41	57710	56839	.0031	.0030	.0029	.0026	.0031	.0034
283/95	0.41	36696	36294	.0028	.0028	.0027	.0024	.0028	.0030
284/95	0.47	36228	35744	.0032	.0031	.0032	.0029	.0032	.0035
317/95	0.40	57753	57043	.0027	.0026	.0027	.0024	.0027	.0028
319/95	1.47	44759	44054	.0121	.0116	.0110	.0097	.0120	.0128
326/95	0.42	44043	43398	.0032	.0036	.0032	.0028	.0033	.0038
330/95	0.42	54886	54178	.0031	.0037	.0034	.0029	.0032	.0040
333/95	0.45	42108	41394	.0061	.0092	.0096	.0076	.0068	.0106
340/95	0.41	64348	63480	.0030	.0033	.0030	.0025	.0031	.0036
345/95	1.08	54558	53803	.0076	.0081	.0075	.0066	.0077	.0088
015/96	0.42	56149	55342	.0033	.0033	.0035	.0031	.0033	.0036
022/96	13.31	48837	48000	.1504	.2340	.1747	.1436	.1625	.2470
029/96	0.44	53782	52899	.0039	.0045	.0033	.0027	.0039	.0048
043/96	0.28	41923	41142	.0026	.0031	.0022	.0019	.0026	.0033
050/96	0.31	55515	54705	.0024	.0027	.0023	.0019	.0024	.0030
064/96	0.38	45377	44876	.0029	.0034	.0026	.0022	.0030	.0036
075/96	0.38	37350	36821	.0030	.0039	.0030	.0025	.0029	.0043
077/96	0.35	43992	43367	.0031	.0032	.0028	.0024	.0031	.0035
081/96	0.37	45843	45255	.0028	.0030	.0027	.0023	.0028	.0033
085/96	0.34	41228	40662	.0037	.0041	.0046	.0037	.0039	.0047

TABLE NO. 4. Contd..

095/96	0.31	52901	52266	.0021	.0025	.0021	.0018	.0021	.0027
214/96	0.24	30859	30249	.0026	.0032	.0021	.0017	.0026	.0034
222/96	0.29	34325	33819	.0031	.0036	.0037	.0031	.0032	.0041
233/96	0.32	28762	28347	.0035	.0045	.0047	.0037	.0035	.0053
236/96	0.37	40728	40152	.0028	.0035	.0028	.0023	.0028	.0038
241/96	0.35	34221	33659	.0029	.0036	.0029	.0024	.0030	.0039
264/96	0.35	26876	26482	.0026	.0030	.0027	.0024	.0026	.0033
272/96	0.32	36740	36277	.0024	.0025	.0024	.0021	.0025	.0027
277/96	0.24	59628	58936	.0017	.0019	.0016	.0014	.0017	.0020
297/96	0.39	40719	40210	.0030	.0041	.0029	.0031	.0024	.0044
335/96	0.43	47121	46524	.0029	.0031	.0031	.0028	.0026	.0036
345/96	0.46	52909	52206	.0033	.0035	.0033	.0029	.0033	.0038
360/96	0.43	43853	43233	.0028	.0032	.0029	.0025	.0029	.0035
362/96	0.35	51128	50468	.0027	.0031	.0028	.0024	.0027	.0034
366/96	0.39	30649	30136	.0045	.0049	.0050	.0041	.0045	.0056
001/97	0.34	40338	39645	.0029	.0033	.0028	.0023	.0030	.0036
010/97	0.37	46699	46057	.0025	.0031	.0027	.0022	.0025	.0034
013/97	0.42	51086	50360	.0036	.0038	.0032	.0027	.0036	.0041
025/97	0.32	47803	47236	.0023	.0029	.0023	.0019	.0022	.0032
031/97	0.55	48938	48383	.0040	.0044	.0038	.0033	.0040	.0048
115/97	0.37	53244	52651	.0027	.0040	.0025	.0020	.0027	.0043
119/97	0.45	52242	51718	.0033	.0054	.0032	.0025	.0034	.0057
123/97	0.44	50194	49613	.0036	.0047	.0034	.0028	.0037	.0050
155/97	0.29	51979	51397	.0021	.0031	.0020	.0017	.0021	.0034
159/97	0.44	64909	64133	.0030	.0048	.0029	.0024	.0031	.0051
172/97	0.39	57275	56731	.0025	.0033	.0025	.0021	.0025	.0036
174/97	0.43	44134	43655	.0045	.0051	.0052	.0044	.0046	.0056
185/97	0.31	33591	33208	.0021	.0034	.0022	.0018	.0020	.0036
200/97	0.46	21613	21271	.0052	.0063	.0062	.0053	.0054	.0069
202/97	0.33	32024	31573	.0039	.0039	.0043	.0036	.0040	.0044
212/97	0.35	32277	31961	.0025	.0034	.0026	.0021	.0025	.0037
214/97	0.32	41421	40935	.0022	.0031	.0023	.0019	.0021	.0035
218/97	0.39	46273	45772	.0025	.0031	.0025	.0021	.0024	.0034

TABLE NO. 4. Contd..

228/97	0.35	45378	44904	.0022	.0027	.0023	.0020	.0022	.0030
235/97	0.41	28729	28393	.0045	.0066	.0056	.0045	.0046	.0073
241/97	0.31	38316	37922	.0034	.0044	.0041	.0034	.0036	.0050
244/97	0.33	48159	47734	.0022	.0034	.0024	.0020	.0022	.0037
255/97	0.31	38709	38285	.0035	.0039	.0040	.0033	.0036	.0044
294/97	0.39	56184	55638	.0025	.0028	.0024	.0021	.0025	.0030
299/97	0.52	47303	46827	.0034	.0042	.0035	.0030	.0034	.0046
303/97	0.44	56633	56142	.0026	.0029	.0027	.0023	.0026	.0032
338/97	0.39	30058	29617	.0043	.0061	.0053	.0043	.0045	.0067
346/97	0.28	33736	33341	.0020	.0025	.0020	.0017	.0019	.0028
351/97	0.27	45300	44783	.0018	.0021	.0019	.0016	.0018	.0024
356/97	0.37	45417	44924	.0023	.0026	.0024	.0020	.0022	.0029
362/97	0.37	30038	29535	.0046	.0054	.0052	.0043	.0048	.0060
002/98	0.41	48980	48509	.0024	.0030	.0026	.0022	.0024	.0033
008/98	0.38	43737	43242	.0026	.0031	.0026	.0023	.0025	.0034
014/98	0.39	57261	56713	.0026	.0032	.0025	.0021	.0026	.0035
018/98	0.33	43333	42828	.0022	.0028	.0022	.0019	.0022	.0031
022/98	0.35	29752	29314	.0044	.0056	.0053	.0043	.0047	.0062
037/98	0.36	52746	52087	.0031	.0042	.0027	.0022	.0031	.0045
038/98	0.36	46254	45598	.0039	.0050	.0045	.0036	.0040	.0056
104/98	0.33	33857	33490	.0027	.0034	.0028	.0023	.0026	.0038
113/98	0.31	41024	40611	.0021	.0032	.0022	.0018	.0021	.0034
120/98	0.30	44380	43954	.0020	.0027	.0020	.0017	.0020	.0028
135/98	0.34	55540	55051	.0021	.0025	.0021	.0019	.0021	.0027
142/98	0.43	40957	40525	.0044	.0049	.0051	.0045	.0046	.0054
151/98	0.33	32656	32270	.0035	.0043	.0041	.0035	.0037	.0047
157/98	0.36	43712	43265	.0025	.0028	.0026	.0023	.0026	.0031
164/98	0.29	55877	55320	.0019	.0021	.0019	.0017	.0020	.0023
171/98	0.31	56876	56315	.0020	.0022	.0019	.0017	.0020	.0024
185/98	0.31	54029	53500	.0021	.0022	.0020	.0017	.0021	.0024
192/98	0.32	54268	53732	.0021	.0024	.0021	.0018	.0022	.0026
199/98	0.34	56014	55448	.0022	.0026	.0022	.0019	.0022	.0028
206/98	0.33	52495	51933	.0023	.0027	.0022	.0019	.0023	.0030

TAB. NO 5. FORMAL (RMS) ERRORS OF COORDINATES OF BANGALORE.

GPS DAY	POSTFIT NOISE(σ) cm	No D.D OBS	Deg. freedom	σx m	σy m	σz m	σlat m	σlon m	σht m
263/95	0.59	23802	23353	.0046	.0049	.0047	.0044	.0047	.0050
264/95	0.38	48532	47930	.0032	.0035	.0030	.0027	.0032	.0037
269/95	0.43	45800	45199	.0031	.0033	.0030	.0028	.0032	.0035
274/95	0.51	47660	46942	.0039	.0041	.0037	.0034	.0040	.0044
277/95	0.46	58912	58165	.0032	.0033	.0031	.0029	.0033	.0035
281/95	0.41	57710	56839	.0032	.0034	.0029	.0027	.0032	.0036
317/95	0.40	57753	57043	.0028	.0028	.0027	.0025	.0028	.0029
330/95	0.42	54886	54178	.0032	.0040	.0034	.0031	.0033	.0041
333/95	0.45	42108	41394	.0062	.0091	.0097	.0084	.0070	.0100
340/95	0.41	64348	63480	.0032	.0035	.0030	.0027	.0032	.0037
345/95	1.08	54558	53803	.0077	.0087	.0076	.0070	.0078	.0090
352/95	0.49	44315	43765	.0035	.0038	.0033	.0030	.0035	.0040
015/96	0.42	56149	55342	.0034	.0036	.0036	.0033	.0034	.0038
022/96	13.31	48837	48000	.1525	.2368	.1762	.1534	.1674	.2430
029/96	0.44	53782	52899	.0046	.0050	.0033	.0029	.0047	.0052
043/96	0.28	41923	41142	.0028	.0033	.0022	.0020	.0028	.0034
050/96	0.31	55515	54705	.0026	.0031	.0023	.0020	.0025	.0033
057/96	0.34	24991	24561	.0040	.0041	.0047	.0042	.0042	.0045
067/96	0.32	44912	44437	.0032	.0033	.0038	.0034	.0034	.0036
075/96	0.38	37350	36821	.0033	.0048	.0030	.0027	.0032	.0051
077/96	0.35	43992	43367	.0032	.0035	.0028	.0025	.0032	.0038
081/96	0.37	45843	45255	.0029	.0034	.0027	.0025	.0029	.0036
085/96	0.34	41228	40662	.0038	.0043	.0046	.0041	.0040	.0046
095/96	0.31	52901	52266	.0023	.0027	.0021	.0019	.0023	.0028

TABLE NO. 5. Contd..

222/96	0.29	34325	33819	.0032	.0037	.0038	.0033	.0033	.0040
233/96	0.32	28762	28347	.0036	.0047	.0047	.0041	.0037	.0052
236/96	0.37	40728	40152	.0030	.0039	.0028	.0025	.0031	.0041
257/96	0.40	44169	43687	.0029	.0035	.0029	.0026	.0029	.0037
303/96	0.42	44311	43833	.0029	.0035	.0028	.0026	.0029	.0036
335/96	0.43	47121	46524	.0029	.0033	.0031	.0028	.0029	.0036
345/96	0.46	52909	52206	.0033	.0038	.0033	.0031	.0034	.0039
360/96	0.43	43853	43233	.0030	.0038	.0029	.0027	.0030	.0039
362/96	0.35	51128	50468	.0029	.0034	.0028	.0025	.0029	.0036
366/96	0.39	30649	30136	.0046	.0051	.0050	.0045	.0046	.0056
001/97	0.34	40338	39645	.0030	.0037	.0028	.0025	.0031	.0038
010/97	0.37	46699	46057	.0026	.0035	.0027	.0024	.0026	.0037
013/97	0.42	51086	50360	.0037	.0041	.0032	.0029	.0037	.0043
025/97	0.32	47803	47236	.0024	.0034	.0023	.0020	.0024	.0036
031/97	0.55	48938	48383	.0042	.0051	.0039	.0035	.0043	.0054
032/97	0.50	30090	29703	.0052	.0053	.0062	.0056	.0053	.0059
115/97	0.37	53244	52651	.0028	.0037	.0024	.0022	.0028	.0039
119/97	0.45	52242	51718	.0035	.0051	.0030	.0026	.0036	.0052
123/97	0.44	50194	49613	.0036	.0047	.0034	.0028	.0037	.0050
155/97	0.29	51979	51397	.0023	.0035	.0020	.0018	.0023	.0037
159/97	0.44	64909	64133	.0030	.0042	.0028	.0025	.0031	.0044
172/97	0.39	57275	56731	.0026	.0034	.0024	.0022	.0026	.0036
174/97	0.43	44134	43655	.0045	.0050	.0051	.0047	.0048	.0053
202/97	0.33	32024	31573	.0040	.0040	.0043	.0039	.0041	.0044
214/97	0.32	41421	40935	.0023	.0035	.0023	.0020	.0021	.0038
218/97	0.39	46273	45772	.0025	.0036	.0025	.0023	.0025	.0038
228/97	0.35	45378	44904	.0022	.0030	.0023	.0021	.0022	.0031
235/97	0.41	28729	28393	.0046	.0064	.0056	.0049	.0048	.0068
241/97	0.31	38316	37922	.0035	.0046	.0041	.0036	.0037	.0048
244/97	0.33	48159	47734	.0022	.0036	.0024	.0021	.0022	.0038
255/97	0.31	38709	38285	.0036	.0043	.0039	.0035	.0038	.0045
294/97	0.39	56184	55638	.0025	.0032	.0024	.0022	.0026	.0033
299/97	0.52	47303	46827	.0035	.0047	.0035	.0032	.0036	.0048

TABLE NO. 5. Contd..

303/97	0.44	56633	56142	.0027	.0035	.0027	.0025	.0027	.0037
338/97	0.39	30058	29617	.0044	.0064	.0053	.0047	.0047	.0067
346/97	0.28	33736	33341	.0021	.0030	.0020	.0018	.0020	.0032
351/97	0.27	45300	44783	.0019	.0025	.0019	.0017	.0018	.0026
356/97	0.37	45417	44924	.0024	.0031	.0024	.0022	.0023	.0033
362/97	0.37	30038	29535	.0049	.0056	.0052	.0046	.0051	.0060
002/98	0.41	48980	48509	.0025	.0033	.0026	.0024	.0025	.0036
008/98	0.38	43737	43242	.0027	.0036	.0026	.0024	.0026	.0038
014/98	0.39	57291	56713	.0027	.0036	.0025	.0033	.0027	.0038
018/98	0.33	43333	42828	.0023	.0033	.0023	.0020	.0023	.0035
022/98	0.35	29752	29314	.0045	.0059	.0053	.0046	.0049	.0062
037/98	0.36	52746	52087	.0032	.0037	.0025	.0023	.0033	.0038
038/98	0.36	46254	45598	.0040	.0046	.0044	.0039	.0042	.0048
135/98	0.34	55540	55051	.0022	.0030	.0021	.0020	.0022	.0031
142/98	0.43	40957	40525	.0045	.0055	.0052	.0047	.0047	.0058
157/98	0.36	43712	43265	.0026	.0032	.0026	.0024	.0026	.0034
164/98	0.29	55877	55320	.0020	.0025	.0019	.0018	.0020	.0026
171/98	0.31	56876	56315	.0021	.0026	.0019	.0018	.0021	.0027
185/98	0.31	54029	53500	.0021	.0025	.0020	.0018	.0022	.0026
192/98	0.32	54268	53732	.0022	.0027	.0021	.0019	.0023	.0028
199/98	0.34	56014	55448	.0023	.0031	.0022	.0020	.0023	.0032
206/98	0.33	52495	51933	.0023	.0031	.0023	.0020	.0024	.0032

TABLE NO 8 . AMBIGUITY RESOLUTION

	TOTAL NUMBER OF		AMBIGUITIES	
GPSDAY	PARAMETERS	PRE ELIMINATED	NO OF PARAMETERS	PRE ELIMINATED
104/95	310	292	208	208
187/95	165	156	108	108
257/95	284	269	197	197
261/95	379	361	277	277
264/95	484	466	382	382
269/95	406	385	289	289
272/95	407	386	290	290
274/95	500	479	383	383
277/95	522	498	390	390
281/95	642	618	510	510
283/95	312	294	210	210
284/95	315	297	213	213
317/95	517	493	385	385
319/95	534	513	417	417
324/95	465	441	333	333
326/95	443	422	326	326
330/95	523	499	391	391
333/95	504	483	387	387
338/95	508	484	376	376
340/95	669	642	522	522
345/95	514	490	382	382
352/95	412	391	295	295
015/96	596	572	464	464
022/96	650	626	518	518
029/96	685	661	553	553
043/96	657	636	540	540
050/96	630	606	498	498
057/96	297	264	192	192
064/96	413	395	311	311
067/96	382	364	280	280
075/96	457	442	370	370
077/96	520	502	418	418
081/96	447	429	345	345
085/96	466	448	364	364
095/96	526	505	409	409

TABLE NO. 8. Contd..

214/96	429	411	327	327
222/96	392	374	290	290
229/96	311	293	209	209
233/96	305	290	218	218
236/96	454	433	337	337
241/96	409	391	307	307
257/96	375	354	258	258
264/96	261	246	174	174
272/96	320	302	218	218
277/96	525	501	393	393
283/96	326	308	224	224
297/96	391	373	289	289
303/96	364	346	262	262
335/96	442	421	325	325
345/96	528	504	396	396
360/96	410	389	293	293
362/96	532	508	400	400
366/96	405	387	303	303
001/97	572	551	455	455
010/97	511	490	394	394
013/97	630	606	498	498
025/97	491	470	374	374
031/97	472	451	355	355
033/97	314	296	212	212
115/97	498	474	366	366
119/97	466	445	349	349
123/97	486	462	354	354
155/97	489	465	357	357
159/97	670	643	523	523
172/97	450	429	333	333
174/97	422	404	320	320
185/97	309	294	222	222
200/97	248	236	176	176
202/97	358	343	271	271
212/97	284	272	212	212
214/97	412	394	310	310
218/97	404	386	302	302
228/97	371	353	269	269
235/97	272	260	200	200
241/97	346	331	259	259
244/97	381	363	279	279
255/97	362	347	275	275
279/97	207	195	135	135
294/97	427	406	310	310
299/97	407	389	305	305

TABLE NO. 8. Contd..

303/97	399	378	282	282
338/97	380	365	293	293
346/97	371	359	299	299
351/97	424	406	322	322
356/97	412	394	310	310
002/98	388	370	286	286
008/98	429	411	327	327
014/98	494	473	377	377
018/98	429	411	327	327
022/98	370	355	283	283
037/98	551	527	419	419
038/98	560	539	443	443
104/98	310	292	208	208
113/98	343	325	241	241
120/98	341	323	239	239
135/98	294	373	277	277
142/98	346	328	244	244
151/98	285	270	198	198
157/98	364	346	262	262
164/98	435	414	318	318
171/98	438	417	321	321
185/98	422	401	305	305
192/98	434	413	317	317
199/98	439	418	322	322
206/98	433	412	316	316

TABLE No.9

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################################################################################
# Statistics of the processed sessions of the camnpaigns INDIA95 to INDIA98
################################################################################
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Quality Check Criteria:

Number of Observations in the file		1400
Minutes with observations		840
% observations in file to expected obs.		60

Session	Year	# Stations	# bad Stations	Comment
170	1995	9	2	Not processed, Wettzell bad
187		6	2	o.k.

Changed Check Criteria: Number of Observations in the file 1200

Session	Year	# Stations	# bad Stations	Comment
257	1995	7	1	o.k.
261		8	1	o.k.
263		8	2	o.k.
264		9	2	o.k.
269		9	1	o.k.
272		8	0	o.k.
274		9	1	o.k.
277		9	0	o.k.
281		9	0	o.k.
283		8	1	o.k.
284		8	1	o.k.
317		9	0	o.k.
319		9	2	o.k.
324		9	0	not o.k.
326		8	0	o.k.
330		9	0	o.k.
333		8	0	o.k.
338		9	0	not o.k.
340		9	0	o.k.
345		9	0	o.k.
001	1996	9	2	o.k.
008		9	2	Not processed, Wettzell bad
015		9	0	o.k.
022		9	0	not o.k., bad RMS
029		9	0	o.k.
036		9	3	IISC: sampling intervall at ε Session not o.k.
043		9	0	o.k.
050		9	0	o.k.
057		8	2	o.k.
064		8	1	o.k.
067		7	0	o.k.
075		7	2	o.k.
077		7	0	o.k.
081		7	0	o.k.
085		7	0	o.k.
095		8	0	o.k.
214		8	1	o.k.
222		7	0	o.k.
229		7	1	o.k.
233		7	1	o.k.
236		8	0	o.k.
241		8	1	o.k.
257		9	1	o.k.
264		6	0	o.k.
272		9	1	o.k.
277		9	0	o.k.
283		8	1	o.k.
297		9	2	o.k.

TABLE NO.9. Contd

303		9	2	o.k.
335		9	1	o.k.
341		9	1	Wettzell marked
345		9	0	o.k.
354		9	2	no satellite clocks found for
360		9	1	o.k.
362		9	0	o.k.
366		8	1	o.k.
001	1997	8	0	o.k.
010		8	0	o.k.
013		9	0	o.k.
025		9	1	o.k.
031		9	1	o.k.
032		8	1	o.k.
115		9	0	o.k.
119		8	0	o.k.
123		9	0	o.k.
155		9	0	o.k.
159		10	0	o.k. with HRAO
172		8	0	o.k.
174		7	0	o.k.
185		8	2	o.k.
200		6	1	o.k.
202		6	0	o.k.
212		6	1	o.k.
214		7	0	o.k.
218		7	0	o.k.
228		8	1	o.k.
235		6	1	o.k.
241		7	1	o.k.
244		8	1	o.k.
255		6	0	o.k.
279		6	1	o.k.
294		8	0	o.k.
299		8	1	o.k.
303		8	0	o.k.
338		6	0	o.k.
346		5	0	o.k.
351		7	0	o.k.
355		7	0	no satellite clock found for s
356		7	0	o.k.
362		6	0	o.k.
002	1998	7	0	o.k.
008		7	0	o.k.
014		8	0	o.k.
018		8	1	o.k.
022		6	0	o.k.
037		9	0	with HRAO
038		8	0	with HRAO
104		7	0	o.k.
113		7	0	o.k.
120		7	0	o.k.
135		8	0	o.k.
142		7	0	o.k.
151		6	0	o.k.
157		7	7	o.k.

		TABLE NO.10 TIME SERIES OF ECEF COORDINATES				
GPS DAY	X-coord in m	rms	Y-coord in m	rms	Z-coord in m	rms
from sep 95		in m		in m		in m
261	1208444,937	0,004	5966805,843	0,0041	1897076,074	0,0036
264	1208445,013	0,0031	5966806,007	0,0031	1897076,462	0,003
272	1208444,987	0,0031	5966806,01	0,0033	1897076,453	0,003
274	1208445,039	0,0039	5966806,03	0,0039	1897076,485	0,0038
277	1208445,055	0,0032	5966806,005	0,003	1897076,504	0,0031
281	1208444,991	0,0031	5966805,991	0,003	1897076,458	0,0029
283	1208444,958	0,0028	5966806,026	0,0028	1897076,437	0,0027
284	1208444,996	0,0032	5966806,051	0,0031	1897076,468	0,0032
317	1208445,031	0,0027	5966805,981	0,0026	1897076,465	0,0027
319	1208445,097	0,0121	5966805,923	0,0116	1897076,518	0,011
326	1208445,027	0,0032	5966805,945	0,0036	1897076,434	0,0032
330	1208445,065	0,0031	5966805,959	0,0037	1897076,508	0,0034
333	1208445,022	0,0061	5966806,044	0,0092	1897076,486	0,0096
340	1208445,064	0,003	5966806,043	0,0033	1897076,512	0,003
345	1208445,049	0,0076	5966806,027	0,0081	1897076,482	0,0075
380	1208445,03	0,0033	5966806,004	0,0033	1897076,486	0,0035
387	1208418,54	0,1504	5966805,223	0,234	1897101,316	0,1747
394	1208444,985	0,0039	5966805,986	0,0045	1897076,457	0,0033
408	1208444,992	0,0026	5966805,997	0,0031	1897076,443	0,0022
415	1208444,981	0,0024	5966806,043	0,0027	1897076,455	0,0023
429	1208444,96	0,0029	5966806,047	0,0034	1897076,451	0,0026
432	1208444,971	0,0031	5966806,042	0,0032	1897076,45	0,0038
440	1208445,044	0,003	5966805,963	0,0039	1897076,489	0,003
442	1208445,01	0,0031	5966806,009	0,0032	1897076,471	0,0028
446	1208444,962	0,0028	5966805,99	0,003	1897076,441	0,0027
450	1208444,981	0,0037	5966805,96	0,0041	1897076,413	0,0046
460	1208444,97	0,0021	5966805,987	0,0025	1897076,444	0,0021
579	1208444,942	0,0026	5966805,983	0,0032	1897076,494	0,0021
587	1208444,928	0,0031	5966805,972	0,0036	1897076,482	0,0037
598	1208444,951	0,0035	5966805,99	0,0045	1897076,522	0,0047
601	1208444,938	0,0028	5966805,987	0,0035	1897076,492	0,0028
606	1208444,896	0,0029	5966806,017	0,0036	1897076,48	0,0029
629	1208444,966	0,0026	5966805,973	0,003	1897076,516	0,0027
637	1208444,985	0,0024	5966805,997	0,0025	1897076,525	0,0024
642	1208444,987	0,0017	5966805,977	0,0019	1897076,521	0,0016
662	1208444,985	0,003	5966805,991	0,0041	1897076,487	0,0029
700	1208445,022	0,0029	5966806,043	0,0031	1897076,58	0,0031
710	1208444,946	0,0033	5966805,986	0,0035	1897076,599	0,0033
725	1208444,959	0,0028	5966805,987	0,0032	1897076,544	0,0029
727	1208444,967	0,0027	5966805,96	0,0031	1897076,512	0,0028
731	1208444,921	0,0045	5966806,044	0,0049	1897076,599	0,005
732	1208444,923	0,0029	5966806,022	0,0033	1897076,618	0,0028
741	1208444,9	0,0025	5966806,07	0,0031	1897076,603	0,0027
744	1208444,864	0,0036	5966806,025	0,0038	1897076,583	0,0032
756	1208444,865	0,0023	5966806,04	0,0029	1897076,545	0,0023
762	1208444,919	0,004	5966806,06	0,0044	1897076,6	0,0038
846	1208444,872	0,0027	5966806,1	0,004	1897076,624	0,0025

Table No. 10 contd..

850	1208444,907	0,0033	5966806,005	0,0054	1897076,592	0,0032
854	1208444,897	0,0036	5966806,004	0,0047	1897076,595	0,0034
886	1208444,907	0,0021	5966806,047	0,0031	1897076,622	0,002
890	1208444,907	0,003	5966806,02	0,0048	1897076,605	0,0029
903	1208444,932	0,0025	5966806,073	0,0033	1897076,654	0,0025
905	1208444,891	0,0045	5966806,09	0,0051	1897076,62	0,0052
916	1208444,878	0,0021	5966806,02	0,0034	1897076,596	0,0022
931	1208444,942	0,0052	5966806,096	0,0063	1897076,641	0,0062
933	1208444,852	0,0039	5966806,137	0,0039	1897076,637	0,0043
943	1208444,887	0,0025	5966806,066	0,0034	1897076,61	0,0026
945	1208444,858	0,0022	5966806,042	0,0031	1897076,597	0,0023
949	1208444,901	0,0025	5966805,99	0,0031	1897076,595	0,0025
959	1208444,896	0,0022	5966806,036	0,0027	1897076,596	0,0023
966	1208444,791	0,0045	5966806,277	0,0066	1897076,678	0,0056
972	1208444,902	0,0034	5966806,01	0,0044	1897076,584	0,0041
975	1208444,88	0,0022	5966806,072	0,0034	1897076,614	0,0024
986	1208444,879	0,0035	5966806,017	0,0039	1897076,588	0,004
1025	1208444,856	0,0025	5966806,063	0,0028	1897076,606	0,0024
1030	1208444,868	0,0034	5966806,057	0,0042	1897076,637	0,0035
1034	1208444,885	0,0026	5966806,04	0,0029	1897076,612	0,0027
1069	1208444,851	0,0043	5966806,07	0,0061	1897076,611	0,0053
1077	1208444,868	0,002	5966806,065	0,0025	1897076,613	0,002
1082	1208444,87	0,0018	5966806,024	0,0021	1897076,626	0,0019
1087	1208444,87	0,0023	5966806,024	0,0026	1897076,62	0,0024
1098	1208444,878	0,0024	5966806,041	0,003	1897076,613	0,0026
1104	1208444,841	0,0026	5966806,032	0,0031	1897076,623	0,0026
1110	1208444,845	0,0026	5966806,047	0,0032	1897076,619	0,0025
1114	1208444,87	0,0022	5966806,014	0,0028	1897076,617	0,0022
1118	1208444,933	0,0044	5966805,936	0,0056	1897076,573	0,0053
1133	1208444,896	0,0031	5966806,036	0,0042	1897076,644	0,0027
1134	1208444,895	0,0039	5966805,958	0,005	1897076,56	0,0045
1200	1208444,827	0,0027	5966806,024	0,0034	1897076,596	0,0028
1209	1208444,856	0,0021	5966806,063	0,0032	1897076,647	0,0022
1216	1208444,857	0,002	5966806,027	0,0027	1897076,644	0,002
1231	1208444,854	0,0021	5966806,019	0,0025	1897076,652	0,0021
1238	1208444,842	0,0044	5966805,954	0,0049	1897076,621	0,0051
1247	1208444,888	0,0035	5966806,012	0,0043	1897076,618	0,0041
1253	1208444,86	0,0025	5966806,037	0,0028	1897076,634	0,0026
1260	1208444,856	0,0019	5966806,046	0,0021	1897076,622	0,0019
1267	1208444,861	0,002	5966806,039	0,0022	1897076,627	0,0019
1281	1208444,867	0,0021	5966805,992	0,0022	1897076,626	0,002
1288	1208444,841	0,0021	5966806,03	0,0024	1897076,621	0,0021
1295	1208444,876	0,0022	5966806,033	0,0026	1897076,63	0,0022
1302	1208444,816	0,0023	5966806,004	0,0027	1897076,576	0,0022

TABLE NO.11Time series of Geodetic coordinates										
GPS DAY	HEIGHT	RMS		LATITUDE		RMS		LONGITUDE		RMS
EPOCH	in M	in M	DE G	MIN	SEC	in Sec	DEG	MIN	SEC	in sec
261	441,454	0,0045	17	25	2,115449	0,0031	78	33	3,116096	0,004
264	441,6394	0,0035	17	25	2,115534	0,0026	78	33	3,114653	0,0031
272	441,6342	0,0036	17	25	2,115273	0,0027	78	33	3,115558	0,0033
274	441,6721	0,0043	17	25	2,115988	0,0032	78	33	3,113951	0,0039
277	441,6577	0,0034	17	25	2,1168	0,0027	78	33	3,113261	0,0032
281	441,6182	0,0034	17	25	2,115605	0,0026	78	33	3,115296	0,0031
283	441,6392	0,003	17	25	2,114706	0,0024	78	33	3,116625	0,0028
284	441,6791	0,0044	17	25	2,115345	0,0013	78	33	3,11554	0,0032
317	441,6191	0,0028	17	25	2,115853	0,0024	78	33	3,113908	0,0027
319	441,5931	0,0128	17	25	2,117929	0,0097	78	33	3,111314	0,012
326	441,5756	0,0038	17	25	2,115242	0,0028	78	33	3,113778	0,0033
330	441,6179	0,004	17	25	2,117314	0,0029	78	33	3,112634	0,0032
333	441,6822	0,0106	17	25	2,115921	0,0076	78	33	3,114608	0,0068
340	441,6968	0,0036	17	25	2,116644	0,0025	78	33	3,11322	0,0031
345	441,6707	0,0088	17	25	2,115918	0,0066	78	33	3,113606	0,0077
380	441,6465	0,0036	17	25	2,116285	0,0031	78	33	3,114063	0,0033
387	443,3319	0,247	17	25	2,945524	0,1436	78	33	3,988474	0,1625
394	441,6122	0,0048	17	25	2,115663	0,0027	78	33	3,115466	0,0039
408	441,6203	0,0033	17	25	2,115097	0,0019	78	33	3,115291	0,0026
415	441,6643	0,003	17	25	2,115031	0,0019	78	33	3,115984	0,0024
429	441,663	0,0036	17	25	2,114916	0,0022	78	33	3,116691	0,003
432	441,6605	0,0037	17	25	2,114908	0,0031	78	33	3,116313	0,0033
440	441,6118	0,0043	17	25	2,116726	0,0025	78	33	3,113351	0,0029
442	441,6434	0,0035	17	25	2,115819	0,0024	78	33	3,114779	0,0031
446	441,6075	0,0033	17	25	2,115163	0,0023	78	33	3,116248	0,0028
450	441,5741	0,0047	17	25	2,114539	0,0037	78	33	3,115424	0,0039
460	441,6066	0,0027	17	25	2,11525	0,0018	78	33	3,115969	0,0021
579	441,6124	0,0034	17	25	2,11692	0,0017	78	33	3,116873	0,0026
587	441,5967	0,0041	17	25	2,116667	0,0031	78	33	3,117241	0,0032
598	441,6294	0,0053	17	25	2,117672	0,0037	78	33	3,116604	0,0035
601	441,6153	0,0038	17	25	2,116795	0,0023	78	33	3,117013	0,0028
606	441,6314	0,0039	17	25	2,116245	0,0024	78	33	3,118619	0,003
629	441,6146	0,0033	17	25	2,117633	0,0024	78	33	3,115986	0,0026
637	441,6429	0,0027	17	25	2,117643	0,0021	78	33	3,115514	0,0025
642	441,6233	0,002	17	25	2,117699	0,0014	78	33	3,115336	0,0017
662	441,6261	0,0044	17	25	2,116534	0,0024	78	33	3,11548	0,0031
700	441,71	0,0036	17	25	2,118834	0,0026	78	33	3,114623	0,0028
710	441,6478	0,0038	17	25	2,120121	0,0029	78	33	3,116754	0,0033
725	441,6344	0,0035	17	25	2,118395	0,0025	78	33	3,116337	0,0029
727	441,6014	0,0034	17	25	2,117623	0,0024	78	33	3,115865	0,0027
727	441,6342	0,0036	17	25	2,115273	0,0027	78	33	3,115558	0,0031
731	441,6967	0,0056	17	25	2,119613	0,0041	78	33	3,117973	0,0045
732	441,6827	0,0036	17	25	2,120423	0,0023	78	33	3,117742	0,003
741	441,7191	0,0034	17	25	2,119529	0,0022	78	33	3,118827	0,0025
744	441,6642	0,0041	17	25	2,119398	0,0027	78	33	3,119722	0,0036

TABLE NO. 11. Contd..

756	441,6664	0,0032	17	25	2,118077	0,0019	78	33	3,119786	0,0022
762	441,7116	0,0048	17	25	2,119492	0,0033	78	33	3,118142	0,004
846	441,748	0,0043	17	25	2,119969	0,002	78	33	3,11997	0,0027
850	441,6557	0,0057	17	25	2,119801	0,0025	78	33	3,118166	0,0034
854	441,6537	0,005	17	25	2,119928	0,0028	78	33	3,1185	0,0037
886	441,704	0,0034	17	25	2,120328	0,0017	78	33	3,118451	0,0021
890	441,6743	0,0051	17	25	2,120052	0,0024	78	33	3,118269	0,0031
903	441,743	0,0036	17	25	2,121039	0,0021	78	33	3,117812	0,0025
905	441,7409	0,0056	17	25	2,119892	0,0044	78	33	3,119282	0,0046
916	441,6661	0,0036	17	25	2,119849	0,0018	78	33	3,119242	0,002
931	441,7625	0,0069	17	25	2,120377	0,0053	78	33	3,11763	0,0054
933	441,7826	0,0044	17	25	2,120043	0,0036	78	33	3,120898	0,004
943	441,7152	0,0037	17	25	2,119821	0,0021	78	33	3,119239	0,0025
945	441,6833	0,0035	17	25	2,119709	0,0019	78	33	3,120048	0,0021
949	441,6414	0,0034	17	25	2,120044	0,0021	78	33	3,118252	0,0024
959	441,6843	0,003	17	25	2,119635	0,002	78	33	3,118746	0,0022
966	441,9142	0,0073	17	25	2,120084	0,0045	78	33	3,123863	0,0046
972	441,6572	0,005	17	25	2,119528	0,0034	78	33	3,118379	0,0036
975	441,7204	0,0037	17	25	2,11988	0,002	78	33	3,119519	0,0022
986	441,661	0,0044	17	25	2,11963	0,0033	78	33	3,119181	0,0036
1025	441,7053	0,003	17	25	2,119788	0,0021	78	33	3,12026	0,0025
1030	441,7109	0,0046	17	25	2,120767	0,003	78	33	3,119808	0,0034
1034	441,6909	0,0032	17	25	2,120129	0,0023	78	33	3,119148	0,0026
1069	441,7122	0,0067	17	25	2,119864	0,0043	78	33	3,120477	0,0045
1077	441,7109	0,0028	17	25	2,11995	0,0017	78	33	3,119886	0,0019
1082	441,6772	0,0024	17	25	2,120755	0,0016	78	33	3,119521	0,0018
1087	441,6749	0,0029	17	25	2,120569	0,002	78	33	3,11951	0,0022
1098	441,6905	0,0033	17	25	2,120183	0,0022	78	33	3,119374	0,0024
1104	441,6778	0,0034	17	25	2,120626	0,0023	78	33	3,12054	0,0025
1110	441,692	0,0035	17	25	2,120352	0,0021	78	33	3,120526	0,0026
1114	441,6651	0,0031	17	25	2,120568	0,0019	78	33	3,119468	0,0022
1118	441,5911	0,0062	17	25	2,119803	0,0043	78	33	3,116842	0,0025
1133	441,6988	0,0045	17	25	2,121151	0,0022	78	33	3,118733	0,0031
1134	441,6001	0,0056	17	25	2,119299	0,0036	78	33	3,11826	0,004
1200	441,6603	0,0038	17	25	2,119899	0,0023	78	33	3,120961	0,0026
1209	441,7169	0,0034	17	25	2,121065	0,0018	78	33	3,12027	0,0021
1216	441,6826	0,0028	17	25	2,121304	0,0017	78	33	3,119992	0,002
1231	441,6771	0,0027	17	25	2,121624	0,0019	78	33	3,120025	0,0021
1238	441,6047	0,0054	17	25	2,121303	0,0045	78	33	3,119992	0,0046
1247	441,6664	0,0047	17	25	2,120585	0,0035	78	33	3,118848	0,0037
1253	441,6901	0,0031	17	25	2,120899	0,0023	78	33	3,119964	0,0026
1260	441,6941	0,0023	17	25	2,120437	0,0017	78	33	3,120132	0,002
1267	441,6892	0,0024	17	25	2,120647	0,0017	78	33	3,119931	0,002
1281	441,6461	0,0024	17	25	2,121054	0,0017	78	33	3,119411	0,0021
1288	441,6751	0,0026	17	25	2,120595	0,0018	78	33	3,120541	0,0022
1295	441,6881	0,0028	17	25	2,120779	0,0019	78	33	3,119395	0,0022
1302	441,6332	0,003	17	25	2,119504	0,0019	78	33	3,121178	0,0023

TABLE No. 12. Individual Baseline Vector Evolution.

		HYDE-KIT3 555 205	HYDE-IISC 555 207	HYDE-LHAS 555 204	HYDE-IRKT 555 208	HYDE SHAO 555 206	HYDE-YAR1 555 552		HYDE-WETT 555-4	HYDE-HART 555-556
261	261	2640353,5334		1856738,4539		4459795,1954	6208968,6315	6481303,3266	6481303,3266	6903542,4896
264	264	2640353,5754	497625,7867	1856738,4878	4381644,2889	4459795,2250		6481303,3942	6481303,3942	
272	272	2640353,5681		1856738,4698	4381644,2929	4459795,2329	6208968,7605	6481303,4123	6481303,4123	6903538,4844
274	274	2640353,5779	497625,7983	1856738,4790		4459795,2435	6208968,6845	6481303,3899	6481303,3899	6903538,5969
277	277	2640353,5530	497625,7958	1856738,4796	4381644,2932	4459795,2378	6208968,7899	6481303,3549	6481303,3549	6903538,1938
281	281	2640353,5697	497625,7925	1856738,4767	4381644,2934	4459795,2405	6208968,8121	6481303,3932	6481303,3932	6903538,1289
283	283	2640353,5728		1856738,4694		4459795,2486	6208968,9732	6481303,4443	6481303,4443	6903538,0171
284	284	2640353,5691		1856738,4779		4459795,2666		6481303,4334	6481303,4334	6903527,5031
317	317	2640353,5479	497625,7935	1856738,4726	4381644,2808	4459795,2503	6208968,9236	6481303,3648	6481303,3648	6903538,5622
319	319				4381644,3083	4459795,2524			6481303,2664	6903539,4917
330	330	2640353,5516	497625,7952	1856738,4793	4381644,2964	4459795,2631	6208968,9770	6481303,3138	6481303,3138	6903540,1208
333	333		497625,8026	1856738,4802	4381644,3002	4459795,2604	6208968,9474	6481303,4077	6481303,4077	6903537,3278
340	340	2640353,5495	497625,7962	1856738,4790	4381644,2803	4459795,2589	6208968,0395	6481303,3771	6481303,3771	6903537,1989
345	345	2640353,5363	497625,7954	1856738,4801	4381644,2839		6208968,7996	6481303,3846	6481303,3846	6903539,3127
360	15	2640353,5484	497625,7973	1856738,4709	4381644,2649	4459795,2483	6208968,8883	6481303,3731	6481303,3731	6903542,1956
394	29	2640353,5492	497625,7899	1856738,4646	4381644,2631	4459795,2516	6208968,8867	6481303,3920	6481303,3920	6903537,1371
408	43	2640353,5563	497625,7968	1856738,4797		4459795,2607	6208968,8523	6481303,4040	6481303,4040	6903538,1288
415	50	2640353,5532	497625,7962	1856738,4794	4381644,2805	4459795,2545	6208968,8690	6481303,4397	6481303,4397	6903537,0505
429	64	2640353,5601		1856738,4667	4381644,2936	4459795,2361		6481303,4536	6481303,4536	
432	67		497625,8008	1856738,4822	4381644,3412	4459795,2532	6208968,7316	6481303,4458	6481303,4458	
440	75	2640353,5179	497625,8034		4381644,2984	4459795,2392		6481303,3345	6481303,3345	
442	77	2640353,5506	497625,8002		4381644,3191	4459795,2430	6208969,0111	6481303,3929	6481303,3929	
446	81	2640353,5456	497625,7973		4381644,3170	4459795,2505	6208968,8821	6481303,4129	6481303,4129	
450	85		497625,8027	1856738,4751	4381644,3222	4459795,2404	6208968,7937	6481303,3936	6481303,3936	
460	95	2640353,5501	497625,7990	1856738,4754	4381644,3202	4459795,2597	6208968,8735	6481303,4058	6481303,4058	
578	214	2640353,5414		1856738,4660	4381644,2515		6208968,8944	6481303,3922	6481303,3922	6903537,9361
587	222		497625,7954		4381644,2557	4459795,2670	6208968,8354	6481303,3955	6481303,3955	6903537,9490
598	233		497625,7950		4381644,2729	4459795,2841		6481303,3816	6481303,3816	6903538,0861
601	238	2640353,5304	497625,7922		4381644,2609	4459795,2806	6208968,8217	6481303,3985	6481303,3985	6903537,9289
606	241	2640353,5493			4381644,2494	4459795,2565	6208968,8304	6481303,4452	6481303,4452	6903537,9324
629	264	2640353,5320			4381644,2633		6208968,8984	6481303,3641	6481303,3641	6903538,0202
637	272	2640353,5226				4459795,2698	6208968,8985	6481303,3701	6481303,3701	6903537,9271
642	277	2640353,5233		1856738,4710	4381644,2534	4459795,2776	6208968,8914	6481303,3560	6481303,3560	6903538,3687
662	297	2640353,5229		1856738,4844	4381644,2676	4459795,3168		6481303,3825	6481303,3825	
700	335	2640353,5185	497625,7901		4381644,2652	4459795,3035	6208968,8435	6481303,3658	6481303,3658	6903537,9700
710	345	2640353,5040	497625,7951	1856738,4401	4381644,2206	4459795,2304	6208969,0214	6481303,3462	6481303,3462	6903538,1077
725	360	2640353,5188	497625,7963		4381644,2379	4459795,2700	6208968,9054	6481303,3655	6481303,3655	6903565,2036
727	382	2640353,5117	497625,7949	1856738,4790	4381644,2408	4459795,2670	6208968,8350	6481303,3555	6481303,3555	6903538,0270
731	366				4381644,2153	4459795,2573	6208968,9576	6481303,4020	6481303,4020	6903538,0778
732	1	2640353,5152	497625,7945	1856738,4492		4459795,2295	6208968,7777	6481303,3028	6481302,5838	6903538,0159
741	10	2640353,5117	497625,7866		4381644,2211	4459795,2614	6208968,9036	6481303,3574	6481302,6384	6903537,8763
744	13	2640353,5116	497625,7919	1856738,4599	4381644,1920	4459795,2273	6208968,8751	6481303,3475	6481302,6285	6903537,9654
756	25	2640353,5083	497625,7887	1856738,4740	4381644,2261	4459795,2687		6481303,3753	6481302,6563	6903537,8741
762	31	2640353,5051	497625,7875		4381644,2370	4459795,3060		6481303,3424	6481302,6234	6903538,2388
846	115	2640353,5182	497625,7886	1856738,4604	4381644,2228	4459795,2363	6208968,8147	6481303,3835	6481302,6645	6903538,1716
850	119	2640353,4932	497625,7964	1856738,4569	4381644,1923	4459795,2205		6481303,3085	6481302,5895	6903538,0590
854	123	2640353,5126	497625,7846	1856738,4832	4381644,2360	4459795,2651	6208968,8855	6481303,3107	6481302,5917	6903538,0047
888	155	2640353,4955	497625,7840	1856738,4537	4381644,2032	4459795,2366	6208968,8976	6481303,3277	6481302,6087	6903538,5608
890	159	2640353,4872		1856738,4590	4381644,1956	4459795,2392	6208968,7091	6481303,3148	6481302,5958	6903538,7677
903	172	2640353,5015	497625,8031	1856738,4431	4381644,2048	4459795,2228	6208968,8624	6481303,3227	6481302,6037	
905	174		497625,7955	1856738,4596	4381644,2098	4459795,2401	6208968,7786	6481303,3693	6481302,6503	
918	185	2640353,5090			4381644,2111	4459795,2431		6481303,3315	6481302,6125	
931	200				4381644,2413	4459795,2748	6208968,8750	6481303,3423	6481302,6233	
933	202		497625,7888		4381644,2208	4459795,2592	6208968,9361	6481303,4157	6481302,6967	
943	212	2640353,5090			4381644,2119	4459795,2331		6481303,3569	6481302,6379	

TABLE NO. 12. Contd..

945	214	2640353,5179	497625,7911		4381644,2009	4459795,2152	6208968,9068	6481303,3569	6481302,6379
949	218	2640353,4991	497625,7841		4381644,2068	4459795,2237	6208968,9135	6481303,2979	6481302,5789
959	228	2640353,5064	497625,7881		4381644,2084	4459795,2374	6208968,9530	6481303,3363	6481302,6173
966	235		497625,7901		4381644,1745	4459795,1822			6481302,8142
972	241		497625,7821	1856738,4612	4381644,1902	4459795,2148		6481303,3181	6481302,5991
975	244	2640353,5285	497625,7923	1856738,4519	4381644,2032	4459795,2110		6481303,3633	6481302,6443
986	255		497625,7885	1856738,4511	4381644,1864	4459795,2166		6481303,3320	6481302,6130
1025	294	2640353,4905	497625,7835	1856738,4475	4381644,2012	4459795,2207	6208969,0998	6481303,3702	6481302,6512
1030	299	2640353,4955	497625,7863	1856738,4598	4381644,1932		6208969,0144	6481303,3463	6481302,6273
1034	303	2640353,5005	497625,7966	1856738,4607	4381644,2107	4459795,2442	6208968,6764	6481303,3370	6481302,6180
1069	338				4381644,2086	4459795,2380	6208969,0263	6481303,3760	6481302,6570
1077	346	2640353,4921	497625,7903		4381644,1980			6481303,3634	6481302,6444
1082	351	2640353,4844	497625,7868		4381644,1868	4459795,2244	6208968,8128	6481303,3244	6481302,6054
1087	356	2640353,4974	497625,7895		4381644,1900	4459795,2315	6208968,8871	6481303,3267	6481302,6077
1093	362		497625,8010		4381644,2058	4459795,2181	6208968,9626	6481303,2762	6481302,5572
1098	2	2640353,4876	497625,7902		4381644,2066	4459795,2456	6208968,6756	6481303,3397	6481302,6207
1104	8	2640353,4761	497625,8041		4381644,1629	4459795,2141	6208968,8245	6481303,3449	6481302,6259
1110	14	2640353,4949	497625,7950	1856738,4503	4381644,1811	4459795,2270	6208968,8174	6481303,3572	6481302,6382
1114	18	2640353,4839	497625,7921		4381644,1732	4459795,2332	6208968,8737	6481303,3210	6481302,6020
1118	22		497625,7869		4381644,1876	4459795,2471	6208968,8882	6481303,2525	6481302,5335
1133	37	2640353,4718	497625,7847	1856738,4542	4381644,1683	4459795,2078	6208968,8512	6481303,3141	6481302,5951
1134	38		497625,7907	1856738,4578	4381644,1609	4459795,2188	6208968,8850	6481303,2915	6481302,5725
1200	104	2640353,4862		1856738,4524	4381644,1644	4459795,1902	6208969,0813	6481303,3574	6481302,6384
1209	113	2640353,4872		1856738,4565	4381644,1858	4459795,2308	6208968,8563	6481303,3516	6481302,6326
1216	120	2640353,4694		1856738,4432	4381644,1549	4459795,1956	6208968,8975	6481303,3247	6481302,6057
1231	135	2640353,4847	497625,7903	1856738,4473	4381644,1750	4459795,2068	6208968,8086	6481303,3163	6481302,5973
1238	142		497625,7995	1856738,4667	4381644,1958	4459795,2286	6208968,7718	6481303,2851	6481302,5661
1247	151			1856738,4570	4381644,1836	4459795,2362	6208969,0105	6481303,3105	6481302,5915
1253	157	2640353,4765	497625,8007	1856738,4499	4381644,1612		6208968,8525	6481303,3359	6481302,6169
1260	164	2640353,4785	497625,7966	1856738,4564	4381644,1841	4459795,2371	6208968,8434	6481303,3498	6481302,6308
1267	171	2640353,4810	497625,7894	1856738,4498	4381644,1743	4459795,2123	6208968,8501	6481303,3397	6481302,6207
1281	185	2640353,4822	497625,7940	1856738,4551	4381644,1726	4459795,2130	6208968,9087	6481303,3009	6481302,5819
1288	192	2640353,4798	497625,7960	1856738,4492	4381644,1731	4459795,2119	6208969,1033	6481303,3441	6481302,6251
1295	199	2640353,4673	497625,7911	1856738,4663	4381644,1888	4459795,2490	6208968,9034	6481303,3273	6481302,6083
1302	206	2640353,4620	497625,7883	1856738,4538	4381644,1855	4459795,2273	6208969,0367	6481303,3550	6481302,6360

Y=mX+b

2640353,5811	497625,7973	1856738,4628	4381644,3411	4459795,2676	6208968,8295	6481303,4206	b
-8,28655E-05	-5,26129E-06	-2,43296E-05	-0,000137151	-3,31323E-05	5,81534E-05	-7,89101E-05	m
0,010772709	0,005214162	0,008951741	0,018638041	0,023017726	0,093462082	0,031843375	scatter
-0,030245903	-0,001920371	-0,008880311	-0,050060087	-0,012093303	0,021225975	-0,028802173	movement rate (µm/Year)

ANNEXURE -1

WEBSITES accessed for the following topics:

1. **GPS system concept, principle and applications.**

   http://igscb.jpl.nasa.gov/links.html

2. **IGS - Central Bureau Information :**

WWW - http://igscb.jpl.nasa.gov

FTP - http://igscb.jpl.nasa.gov or (128.149.70.171)

3.IGS Global data centers:

SIO - http://lox.ucsd.edu

CDDIS - http://cddisa .gsfc.nasa.gov/gps_datasum.html

IGN - http:// igs.ensg.ign.fr

3. **IGS Analysis Data Centers**

CODE - http://www.cx.unibe.ch/aiub.igs.html

JPL - http:// milhouse.jpl.nasa.gov/eng/jpl_hp2.html

ESOC - http:// nng.esoc.esc.de/gps/gps.html

GFZ - http:// gfz-potsdam.de/pb1/IGS/IGS.html

NOAA- http ://www.ngs.noaa.gov/GPS/GPS.html

NRcan - http ://www.geod.nrcan.gc.ca/products.html.public/

4. **Contributing agencies for IGS:**

   http://igscb.jpl.nasa.gov/organization/contorgs.html

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