HIGH PRECISION GPS NETWORK IN BRAZIL

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1 State-of-the-Art GPS Positioning

New receivers and highly sophisticated software, have made surveying by using the Global Positioning System (GPS) a highly effective geodetic technique. With a pair of geodetic GPS receivers and a commercial software package, one can now easily obtain relative positioning accuracies of the order of a few millimetres and 1 or 2 parts per million (ppm). This can be done quickly, reliably, cheaply, in 3-d, and by operators with only minimal training. It is therefore easy to understand why GPS surveying is quickly replacing more traditional surveying instruments and techniques, such as triangulation, trilateration, traversing and levelling. With the increasing popularity of GPS surveying, the prices of geodetic receivers and software are also coming down. One can now buy a pair of receivers and a standard commercial software package for about $ 20,000 or less.

The applications of GPS surveying are now very numerous and diverse. GPS surveying is used in land and engineering surveying, setting-out, levelling, control surveying, positioning for Geographical Information System (GIS), structural deformation monitoring, offshore and hydrographic surveying. In addition to these standard surveying applications, GPS now offers a new potential for very high precision positioning and heighting in geophysics and oceanography. One can now determine the relative positions and heights of a large number of points, situated hundreds and thousands of kilometres apart, to hitherto unheard of accuracies of a few centimetres or even millimetres. However, this requires the adoption of special field observational procedures and computational strategies, which are broadly known as 'fiducial GPS'.

2 Fiducial GPS and the IGS Network

The fiducial GPS technique involves the observation of simultaneous (dual frequency) carrier phase measurements at a network of fiducial stations, whose coordinates are known to a very high order accuracy in a global reference frame, and a number of new stations whose coordinates are required. Full details of the method are given by Ashkenazi et al (1989), and only a brief outline is given here.

The fiducial process involves the computation of a theoretical (integrated) orbit for each of the satellites, based on the forces acting on it. The forces modelled include gravitational attraction (of the moon, sun and the planets, and earth and ocean tides), surface forces (e.g. solar radiation) and other perturbing influences. The theoretical orbit for each satellite is computed by numerical integration of the acceleration vector, starting from a initial state vector (3-d position and velocities) obtained from a previous broadcast or the precise ephemeris. These theoretical orbits are improved during the network adjustment. The complete set of carrier phase measurements from all the stations is adjusted by least squares, holding the 3-d coordinates of a minimum of three fiducial stations fixed, and solving for the 3-d coordinates of the new stations, as well as for the corrections to the satellite orbits and other bias parameters. The resulting adjusted network of ground stations and satellite orbits is positioned, scaled and oriented to the reference frame defined by the adopted coordinates of the fiducial stations held fixed. The high accuracy of the coordinates of the fiducial stations are then transferred to the new stations, via the satellite orbits.

The International GPS Geodynamics Service (IGS) is a permanent international service established in 1990 by the International Association of Geodesy (IAG). The primary goals of the IGS are to provide the scientific community with high quality GPS orbits on a rapid basis, and earth rotation parameters of high resolution, to expand geographically the current International Terrestrial Reference Frame (ITRF) maintained by the International Earth Rotation Service (IERS), and lastly to monitor the global deformations of the earth's crust (Mueller, 1993). The IGS is based on about 40 permanent tracking GPS stations, forming a permanent GPS tracking network. The IGS network is therefore ideally suitable for the continuous global monitoring of GPS satellites at the tracking stations, and could therefore effectively provide fiducial station coordinates at the epoch of a fiducial GPS campaign. The formal start of IGS routine operations was on 1 January 1994.

3 GPS Campaigns in Brazil : A Summary

The first GPS experiments in Brazil were carried out in 1988. The main objectives were to introduce the GPS technology in Brazil and to start research in the field of GPS applications. Campos et al (1989) describe some early GPS projects in Brazil. One of these was the re-occupation of part of the Southern Brazilian First Order Geodetic Network, and another a GPS Metropolitan Geodetic Network for cadastral purposes in Curitiba-PR. Fortes and Blitzkow (1989) also report on tests which were carried out, comparing GPS and the classical Brazilian network.

These first few GPS experiments were followed by more substantial GPS campaigns at national and international levels. Several institutions in Brazil participated in the following international campaigns: GIG91, BRASION91, BRASION92 and the IGS Epoch '92. At the national level, IBGE[1] proposed the establishment of a Brazilian Network for the continuous tracking of GPS satellites, referred to as RBMC (Fortes, 1991). The proposed network, with some 8 stations would have the characteristics of an Active Control System (ACS), like the Canadian system (Delikaraglou et al, 1986). Users could access data collected at these stations, either via communication links or off-line, with floppy disks. To date (March 1995), only three of these stations are operational.

IBGE has also made an effort to coordinate and collect GPS data obtained by users on various projects throughout Brazil. The aim was to include the results (expressed in terms of coordinate differences) in the adjustment of the classical network. This could then be used to improve the most recent Brazilian Geodetic System based on SAD-69, the South American Datum 1969.

Another local GPS project in Brazil is the São Paulo State Network (Blitzkow et al, 1993). It comprises 24 passive stations, at ranges of about 200 km, which has now been completely observed. Some IGS stations will also be included in the processing, which is currently being carried out.

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[1] Fundação Instituto Brasileiro de Geografia e Estatistica

At the South American continental level, the South American Geocentric Reference System (SIRGAS) project was created in 1993. Its aims are to define a new reference system for South America, to establish and maintain a basic reference network, and to define and realise a geocentric datum (SIRGAS, 1994). The total of GPS stations is about 800, of which 85 will be located in Brazil. The first campaign is expected to be held during May-June 1995.

For the project described in this paper, i.e. the " High Precision GPS Network in Brazil", we have used data collected during the IGS Epoch '92 Campaign in Brazil, Chile and the USA. The project is described in the following Chapter.

4 IGS Epoch '92 Campaign : Brazilian Stations

The Brazilian participation in the Epoch '92 campaign was as a regional centre (Bergamini, 1993). It included several Brazilian institutions, notably the Federal University of Paraná (UFPr), IBGE, the University of São Paulo (USP), the Paulista State University (UNESP) and the National Institute for Space Research (INPE).

Three of the stations (Paraná, Presidente Prudente and Brasilia) were continuously occupied during 14 days of the IGS Epoch '92 campaign. These stations belong to the proposed Brazilian network of continuous GPS tracking stations (RBMC). A further four stations in São Paulo State (Taquarussu, Ilha Solteira, Avanhandava and Salto Grande) were occupied for a of local project. Each one of these four stations was occupied for a period of 3 hours for each of 2 days. The station Chua, the origin of SAD-69, was occupied for a whole day.

In order to connect the stations occupied in Brazil during the IGS Epoch '92 campaign to an international reference frame, i.e. ITRF, the collected GPS data was processed jointly with GPS data from stations outside Brazil, which were also occupied during this campaign. These stations included Santiago in Chile, and Goldstone and Richmond in the United States. Figure 1 shows all the stations which were involved in the Project described in this paper.

Figure 1 : Brazilian Epoch '92 Campaign

Although the IGS Epoch '92 campaign involved 14 days of tracking data, we used no more than 7 days of GPS data for each of the stations. This provided us with a representative sample of the full data, for the purposes of this study. The tracking stations and the amount of data used, from the Brazilian Epoch '92 Campaign, to define the Brazilian High Precision Network (Brazilian HPN) are listed in the following Table 1.

Name	Site location	Data Processed (Julian Day)	Receiver
BRAS	Brasilia - DF, BR	208-213 and 218 24 hours/day	Trimble
PARA	Curitiba - PR, BR	208-213 and 218 24 hours/day	Trimble
UEPP	P.Prudente-SP, BR	208-213 and 218 24 hours/day	Trimble
AVAN	Avanhandava-SP,BR	210 and 209 3 hours/day	Trimble
ILHA	Ilha Solt.-SP, BR	210 and 211 3 hours/day	Trimble
TAQU	Taquarussu- SP, BR	208 and 211 3 hours/day	Trimble
SALT	Salto Grande-SP,BR	208 and 209 3 hours/day	Trimble
CHUA	Minas Gerais, BR	218 - 24 hours	Trimble
SANT	Santiago -Chile	208-213 24 hours/day	Rogue
RCM2	Richmond - USA	208-213 24 hours/day	Rogue
GOLD	Goldstone - USA	208-213 24 hours/day	Rogue

Table 1:

Stations and Data Sets in the Brazilian HPN

A sample of 12 independent baselines and their corresponding lengths in km are listed in Table 2. They give an indication of the spread of the baseline lengths in our study.

Baselines	Length (km)	Baselines	Length (km)
SANT-PARA	2,234	UEPP-SALT	168
PARA-UEPP	430	CHUA-UEPP	432
UEPP-BRAS	777	CHUA-PARA	640
UEPP-ILHA	193	CHUA-BRAS	423
UEPP-AVAN	166	BRAS-RCM2	5,593
UEPP-TAQU	77	BRAS-GOLD	8,438

Table 2:

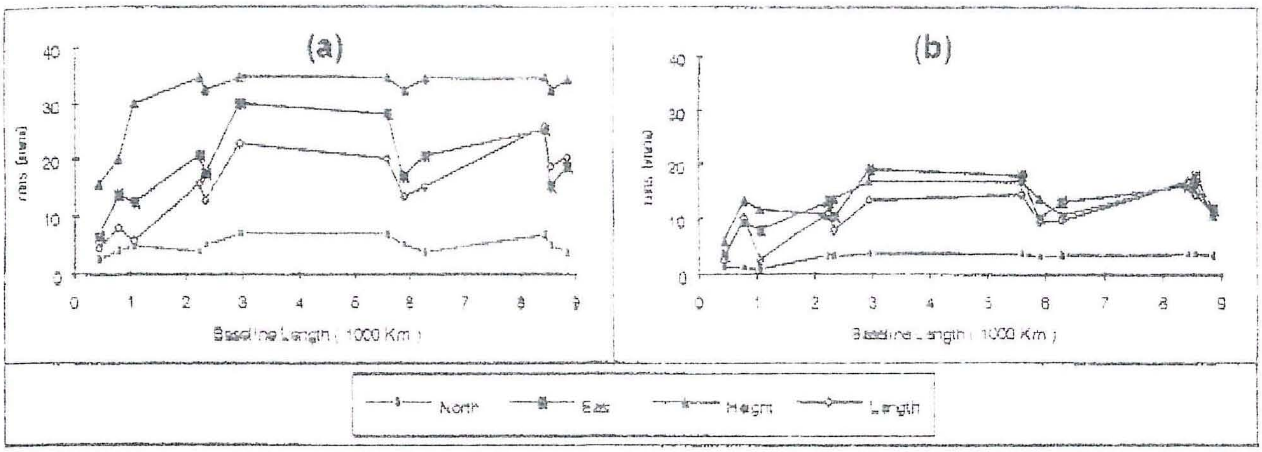
Sample Lengths of Processed Baselines

Only three of the stations all outside Brazil (SANT, RCM2 and GOLD), had known coordinates in the ITRF framework. Although these three stations are at very long distances away from the Brazilian stations, and therefore not very suitable, we nevertheless decided to use them as 'fiducial' stations, because of a lack of better alternatives.

5 High Precision Network In Brazil

The network, described in the previous section, has been adjusted by using the GPS Analysis Software (GAS), developed at the University of Nottingham (Stewart et al, 1994). The reference frame was defined by constraining the coordinates of the three fixed stations to their known ITRF93 values, with a standard error of ±10 cm. Additionally, the satellite positions were held fixed to values computed from a Jet Propulsion Laboratory (JPL) Precise Ephemeris. The atmosphere (i.e. ionosphere and troposphere) was modelled by standard Nottingham techniques. We used the ionospheric free phase observable, and modelled the tropospheric refraction by applying the Magnet model. Within Magnet, we used two zenithal scale factors per day-and-station, modelled as a first order polynomial, and estimated as unknown parameters in the network adjustment. The effects of the earth body tides (EBT) were also modelled using the IERS standards (McCarthy, 1992).

For the purpose of this analysis, we only considered those stations which observed for at least 6 full days. The processing was carried out as two separate exercises, i.e. one involving six 24-hour data sets, and the other twelve 12-hour data sets respectively. The results obtained are illustrated in terms of repeatabilities (i.e. rms differences from the mean). The rms (mm) for the twelve 12-hour data sets, for varying baseline lengths, are shown in Figure 2(a), and those corresponding to the six 24-hour data sets, are drawn in Figure 2(b). Clearly, the latter displays a significant improvement, due to the averaging out and the cancelling of long term (24 hour) bias terms, such as ocean tide loading.



GPS Precision over Long Baselines

Figure 2(a): 12-hour solution Figure 2(b): 24-hour solution

The precisions illustrated in Figure 2(b), correspond to 10 to 20 mm in all three coordinate components, for baselines of up to 9,000 km in length. To comprehend this level of precision, which we achieved in our tests, one should remember that a 10 mm rms error, over a 10,000 km long line, corresponds to one-part-per billion (1 in 10^9) of the baseline length! We also found that, on average, the rms of the height component was twice that of the two horizontal components.

Finally, as an external check, we compared the coordinates obtained for station Chua, as part of our IGS Epoch '92 solution, with the corresponding coordinates obtained in earlier Transit-Doppler campaign (Fortes et al, 1990). The differences of coordinates between the two solutions, as given in Table 3, are remarkable in that they are well below the 1m level, i.e. the accuracy of absolute WGS84 coordinates obtained by using the Transit-Doppler system.

ΔX	ΔY	ΔZ
-0.379	-0.425	0.192

Table 3:
ITRF minus WGS84 Coordinates (m) for Station Chua

6 Potential Applications with the Brazilian Network

This study has demonstrated the ease with which one can obtain very high precision 3-d coordinates by using Fiducial GPS and the IGS precise ephemeris. These coordinates could, in turn, be used as fiducial stations coordinates, for further GPS densification networks. High precision fiducial GPS networks have many scientific and engineering applications. We shall list some of them here.

(a) The continuos monitoring of crustal dynamics in tectonically unstable regions.

(b) The precise measurement of vertical land settlements at tide gauge sites, used to monitor changes in the mean-sea-level and river estuaries (Ashkenazi et al, 1993a).

(c) The setting-out and deformation monitoring of long pipelines.

(d) The establishment of high precision local geodetic control network for large civil engineering projects.

(e) The definition of a geodetic reference system for a Passive or Active Control System.

(f) The establishment of local GPS control networks for monitoring the deformation of civil engineering structures, such as reservoirs and dams (Ashkenazi et al, 1993b).

7 Conclusions

The experiments carried out with the IGS Epoch '92 GPS data set led to the following achievements and conclusions.

(a) We obtained a new set of coordinate values for a sparse High Precision Brazilian GPS Network, consisting of 5 stations in the State of São Paulo, 1 station in the State of Paraná, 1 station in Brasilia, and Chua, the datum point of SAD-69.

(b) These coordinate values are referenced to and expressed in terms of ITRF93, the global IERS geodetic reference framework.

(c) Although we only used an IGS Precise Ephemeris, we achieved some remarkable levels of precision, expressed in terms of repeatabilities of day-to-day solutions. The rms differences from the mean range from 10 to 20 mm, over baselines of up to 9,000 km.

(d) The rms differences in height were, on average, twice as large as the rms differences in horizontal coordinate components.

(e) The newly computed ITRF93 coordinates of Chua, the origin of SAD-69, differ from the currently used WGS84 values by -0.340, -0.421, 0.171 m in X, Y and Z geocentric coordinates respectively. These differences are remarkably small, as they are well below the 1 m level, the accuracy of Transit-Doppler derived absolute positions, using the Transit-Doppler Precise Ephemeris.

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