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NOTAS BREVES DE PESQUISA & DESENVOLVIMENTO TÉCNICO
SHORT RESEARCH & TECHNICAL DEVELOPMENT NOTES

HIGH PRECISION GPS NETWORK WITH PRECISE EPHEMERIDES AND EARTH BODY TIDE MODEL

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The permanent GPS network of the International GPS Service for Geodynamics (IGS) provides a global data set of precise GPS measurements, which is invaluable in the development of algorithms and software for very high accuracy GPS positioning. The intensive EPOCH'92 campaign expanded the core network to include densification in many regions of the world. This project has involved the analysis of data from the Brazilian GPS network, with selected connections to the IGS Global Network. In this preliminary report we discuss the initial data processing, demonstrating a level of relative positioning accuracies of better than 10 ppb in height differences, typically the worst positional component. Besides the normal standard used in the processing of a GPS network, it involved an Earth body tide model.

Key words: GPS; Precise ephemerides; Earth body tide model.

REDE GPS DE ALTA PRECISÃO USANDO EFEMÉRIDES PRECISAS E MODELO DE MARÉ TERRESTRE - *A rede GPS do IGS (International GPS Service for Geodynamics) proporciona uma série de dados GPS global preciso, os quais são de grande valor para o desenvolvimento de algoritmos e programas computacionais para posicionamento GPS de alta precisão. A campanha intensiva denominada EPOCH '92 expandiu o núcleo da rede permitindo densificar muitas regiões do mundo. Neste projeto analisou-se os dados de uma rede brasileira com conexões para a rede global IGS. No artigo discute-se o processamento dos dados que demonstraram um nível de precisão relativa melhor que 10 ppb (partes por bilhão) para diferenças de altitudes, normalmente a pior componente. Além dos procedimentos normais do processamento de uma rede GPS, incluiu-se um modelo para Maré Terrestre.*

Palavras-chave: *GPS; Efemérides precisas; Modelo de Maré Terrestre.*

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INTRODUCTION

The last 10 years have seen a steady rise in the level of relative positioning accuracies achieved by the Global Positioning System (GPS). A fundamental development was the adoption of fiducial GPS techniques, and the subsequent methods for ambiguity resolution over very long baselines. Since then, refinements in data processing techniques and physical modelling have gradually been introduced. Only a few years ago, the goal of many research groups was to achieve, reliable and repeatable accuracies at the one part-per-million (ppm) level. Current results are now demonstrating relative positioning capabilities at the level of few parts-per-billion (ppb).

The permanent GPS network of the International GPS Service for Geodynamics (IGS) provides a global data set of precise GPS measurements, which is invaluable in the development of algorithms and software for very high accuracy GPS. The intensive EPOCH'92 campaign expanded the core network to include densification in may regions of the world. This project has involved the analysis of data from the Brazilian GPS network, with selected connections to the IGS Global Network. In this preliminary report we discuss the initial data processing, demonstrating a level of relative positioning accuracies better than 10 ppb in height differences, typically the worst positional component.

To achieve the level of precision described above, the fiducial GPS technique was applied, and a set of models had to be taken into account. The main aim was to investigate the influence of Earth Body Tides (EBT) on the processing of very large network.

IGS EPOCH '92 CAMPAIGN: BRAZILIAN STATIONS

IGS was established in 1993, by the International Association of Geodesy (IAG), to provide support to geodetic and geophysical research activities with GPS. The first IAG test campaign, Epoch '92, was held from 14 June to 23 September 1992 and showed the near real-time capability of the global GPS community to retrieve data and compute products such as satellite ephemerides and Earth rotation parameters (Noll & Dube, 1993).

The Brazilian participation in the Epoch '92 campaign involved the Regional Center (Bergamini, 1993). It included several organizations, namely the Federal University of Paraná (UFPr), Brazilian Institute of Geography and Statistics (IBGE), the University of São Paulo (USP), the Paulista State University (UNESP) and the National Institute for Space Research (INPE). They cooperated with the international scientific community and provided GPS data to the geodetic community in Brazil for the establishment of new GPS stations. Three stations (Paraná, Presidente Prudente and Brasilia) were continuously occupied during 14 days of the IGS Epoch '92 Campaign.

In order to connect the stations occupied in Brazil during the Epoch '92 campaign to an international reference frame, e.g. IERS Terrestrial Reference Frame (ITRF), the GPS data were processed with other stations outside Brazil, which were also occupied during this campaign. These stations were Santiago in Chile, and Goldstone and Richmond in the United States. The stations of this network are shown in Fig. 1.

Figura 1 - Brazilian Epoch '92 Campaign.

Figure 1 - *Participação Brasileira na Campanha Epoch'92.*

The three Brazilian sites belonging to the IGS Epoch '92 campaign (BRAS, UEPP, PARA), and the other stations included in this processing are listed in Tab. 1. The receiver at station PARA was a Trimble 4000 SST (L1 and L2 carrier-phase with P-code). The other two receivers were Trimble 4000 SD with C/A-code (squaring type). The stations outside Brazil (SANT, RCM2, GOLD) are permanent IGS stations equipped with Rogue RN8 receivers.

Although more data were available for the stations belonging to the Epoch '92 campaign, only six days (208 - 213) were included in the processing. This may provide a representative sample for the purpose of this study.

Name	Site Location	Receiver
BRAS	Brasilia - DF Brazil	Trimble
PARA	Curitiba -PR Brazil	Trimble
UEPP	P. Prudente-SP Brazil	Trimble
SANT	Santiago – Chile	Rogue
RCM2	Richmond – USA	Rogue
GOLD	Goldstone – USA	Rogue

Table 1 - Stations of the Brazilian Epoch '92 Campaign.

Tabela 1 - *Estações Brasileiras na Campanha Epoch'92.*

SOFTWARE AND PROCESSING STRATEGIES

GPS Analysis Software (GAS)

The data were processed using GPS Analysis Software (GAS) developed at the University of Nottingham (Stewart et al., 1994). GAS process either double-difference carrier phase measurement or pseudo-ranges, formed with different base satellites for each baseline processed. This provides a capability to process very large GPS network or even a global GPS network.

The GPS network processing by GAS can be carried out either with the full fiducial technique (Ashkenazi et al., 1989) or by using the broadcast or the precise ephemerides for the satellites. In all cases, corrections for the effects of the Earth body tide (EBT) and Ocean tide loading (OTL) can be included in the processing. For the former case, the model recommended by the International Association of Geodesy was used (McCarthy, 1992). The effects of the ionosphere can be greatly reduced, by using the ionospheric free observable (Ffoulkes-Jones, 1990). For the tropospheric delay, GAS provides a series of modelling options. For example, one could define zenithal scale factors as unknown parameters in the adjustment. GAS also provides the option of 'fixing' the double-difference carrier phase integer ambiguities to their integer values. This is achieved by one of the two different techniques, namely the ambiguity search technique and the sequential bias fixing (Ffoulkes-Jones, 1990).

Processing Strategies

In order to determine the coordinates of the Brazilian Epoch'92 stations consistent with the ITRF, the effects of the body tides of the Earth were also investigated by considering their influence on the repeatability of the solutions, when processing different periods of data. To provide the connection to the ITRF, the coordinates of stations GOLD, RCM2 and SANT were held fixed at their known values, once they had been transformed to the epoch of the campaign. The coordinates were taken from a Jet Propulsion Laboratory (JPL) global, fiducial-free, GPS solution, which had been mapped onto the ITRF (Blewitt et al., 1993). The precise ephemerides of the satellites were also taken from JPL, and were held fixed in the subsequent processing at Nottingham. Tab. 2 shows the 5 baselines processed, together with the respective lengths.

Baseline	Length (km)
GOLD-BRAS	8,438
RCM2-BRAS	5,593
BRAS-UEPP	777
UEPP-PARA	430
PARA-SANT	2,234

Table 2 - Length of the baselines processed.

Tabela 2 - *Comprimento das Linhas de Base Processadas.*

The atmospheric modelling options used were based on standard processing techniques and experience at Nottingham. The ionospheric free phase observable was used and the double-difference ambiguities estimated as real values. The tropospheric refraction was modelled by applying the Magnet model. Additionally, two zenithal scale factors per-day-and-station were modelled, as a first order polynomial and estimated as unknown parameters in the network adjustment.

Each of the six days was divided into two sessions of 12 hours. The data was processed by adopting four different scenarios. Each day of the data set was either processed as a full 24 hour period, or as two consecutive 12 hours sessions. In both cases the effect of the Earth body tide (EBT) was investigated, by repeating the solution both with and without the correction implemented. Tab. 3 summarizes these four scenarios.

Scenarios	12 Hours	24 Hours	with EBT	without EBT
A	X			X
B		X		X
C	X		X	
D		X	X	

Table 3 - Tested Scenarios.

Tabela 3 *- Experimentos Testados.*

RESULTS AND DISCUSSION

The repeatability of each of the baseline components of the different solutions was computed. This simply represents the scatter of the estimated daily values about their weighted mean value, for each individual baseline (Overgaouw et al., 1994) and provides an indication of the consistency of the results.

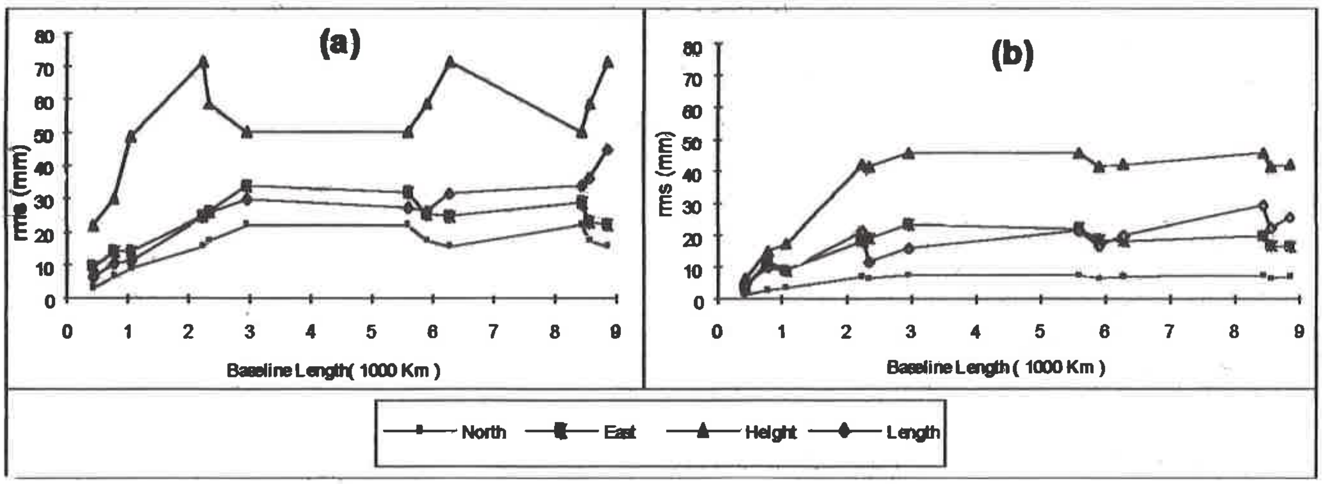

Figure 2(a) - 12 hours solution;
Figure 2(b) - 24 hours solution;
Repeatability without Earth Body Tides corrections.

Figura 2(a) *- Solução com 12 horas;*
Figura 2(b) *- Solução com 24 horas;*
Repetibilidades sem correções de Maré Terrestre.

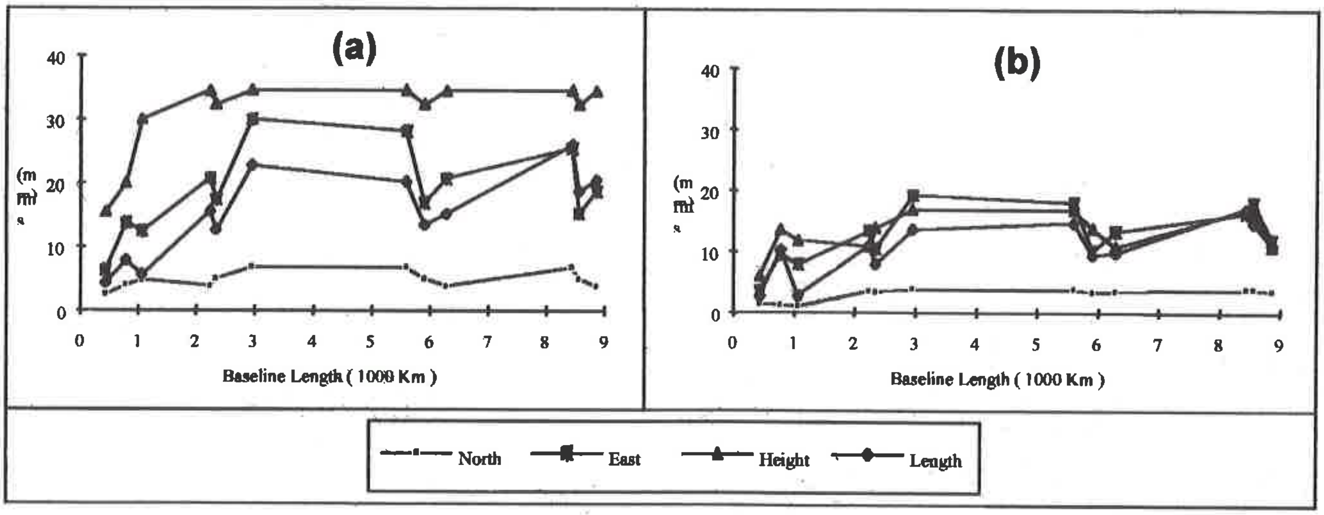

Figure 3(a) - 12 hours solution;
Figure 3(b) - 24 hours solution;
Repeatability with Earth body tide corrections.

Figura 3(a) *- Solução com 12 horas;*
Figura 3(b) *- Solução com 24 horas;*
Repetibilidade com correções de Maré Terrestres.

Fig. 2 (a) shows the repeatability for scenario A, which was obtained from 12 solutions of 12 hours each. The height component, which is typically the worst one, shows rms (root mean square) of about 70 mm. In Fig. 2 (b) , which shows scenario B, i.e. the 24 hour solutions, the same value has been reduced to 50 mm. Neither scenario A or B includes the Earth body tide corrections. However, as solution B is computed over a 24 hour period, this reduction may be attributed to the Earth body tide and ocean tidal loading effects partially cancelling out, over the longer period.

In scenarios C and D, Earth body tide corrections have been applied. The resulting rms of the height component of scenario C reduces from 70 mm (in scenario A) to about 35 mm, as illustrated in Figure 3(a). This also represents an improvement over the 24 hour solutions without Earth body tide (scenario B), but predominantly for the longer baselines, over 1000 km.

Once Earth body tide corrections are applied to the six 24-hour solutions, the rms in the height component reduces to only 20 mm, as shown in Figure 3(b). This constitutes an improvement with respect to the 12-hour solution (in scenario C) of the order of 10 mm for all baselines. It might be due to the ocean tide loading cancelling out over the longer period. No corrections for ocean tide loading were applied during these preliminary experiments. To summarize, the final scenario, involving six 24-hour solutions with Earth body tide corrections applied, provides an average rms of the order of 8 ppb for the worst component (height). The repeatability of the length component is better than that of the height by a factor of 2, i.e. an average rms for lengths of the order of 4 ppb applied in this experiments.

CONCLUSIONS

It has been shown that one can achieve very high position and height accuracies, by using an IGS Precise Ephemerides, such as that provided by JPL. This has been tested by using data from the Brazilian Epoch '92 GPS Campaign, supplemented with a number of other IGS sites, thus creating long baselines extending up to 9000 km.

In this preliminary set of tests, the intention was to determine the accuracies which could be achieved by using the IGS Precise Ephemeris, and the simplest of modelling options in current practice. The results showed that for the highest precision, the corrections derived from an Earth body tide model have to be taken into account in the processing. At such case, precision at the ppb level can be achieved.

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A rede GPS do IGS (International GPS Service for Geodynamics) proporciona uma série de dados GPS global preciso, os quais são de grande valor para o desenvolvimento de algoritmos e programas computacionais para posicionamento GPS de alta precisão. Um dos algoritmos de fundamental importância envolve a técnica fiducial bem como a solução de ambigüidade. Durante a fase de validação do IGS, realizou-se a campanha intensiva denominada EPOCH '92 que expandiu o núcleo da rede permitindo a densificação de muitas regiões do mundo. Durante esta campanha, três estações foram ocupadas no Brasil. Neste projeto analisou-se os dados destas estações com conexões para a rede global IGS, via três estações, duas nos Estados Unidos da América e uma no Chile. Para o processamento utilizou-se o programa GAS (GPS Analysis Software), desenvolvido na Universidade de Nottingham, UK. GAS permite o processamento de redes GPS globais, usando a técnica fiducial com correções ou não de maré terrestre. A observável básica pode ser a dupla diferença de fase da portadora ou da pseudo-distância, com várias opções de modelos para a troposfera. Fundamentalmente, as estratégias para o processamento dos dados, incluíram efemérides precisas e a aplicação ou não de modelos de maré terrestres, considerando intervalos de 12 e 24 horas. Utilizou-se a combinação linear que reduz consideravelmente os efeitos da refração ionosférica (ionospheric free observable). Alguns dos resultados obtidos demonstraram nível de precisão relativa da ordem de 10 ppb (partes por bilhão) para diferenças de altitudes, normalmente a pior componente. Além dos procedimentos normais do processamento de uma rede GPS, incluiu-se um modelo para Maré Terrestre.

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