AN ASSESSMENT ON THE EFFECT OF TROPOSPHERIC DELAY ON GEODETIC POSITIONING USING GPS DATA COLLECTED BY THE RBMC NETWORK

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ABSTRACT

An assessment on the effect of tropospheric delay on geodetic positioning is presented. GPS data spanning various periods have been treated using a combination among the tropospheric models of Saastamoinen, Hopfield and Ifadis with the mapping functions of Saastamoinen, Hopfield, Ifadis, Lanyi and Herring. The GPS data used in this paper was collected by the Brazilian Network for Continuous Monitoring of GPS (RBMC). Three baselines were formed, namely, between Fortaleza (FORT) and Bom Jesus da Lapa (BOMJ), between Presidente Prudente (UEPP) and Viçosa (VICO) and between Presidente Prudente (UEPP) and Curitiba (PARA). Data covering 4 different periods have been processed, with elevation angles of 10 and 15 degrees. The adjusted co-ordinate components were compared with their corresponding SIRGAS values, considered here as "bench marks", and to their corresponding daily solutions average values. It can be seen a smaller variability with the mapping functions of Herring, Ifadis and Lanyi, combined with the wet tropospheric model of Ifadis.

Key words: tropospheric delay, geodetic positioning, Global Positioning System.

INTRODUCTION

Ranging to satellites is one of the measurements that may be used by space geodetic methods for orbit determination, or, inversely, for geodetic positioning and navigation. The Global Positioning System uses this type of measurement as its basic observable. GPS measurements

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are affected by many errors, one of them being the tropospheric delay. This error is one of the most difficult to be dealt with. One of the alternatives to tackle this problem resides in using a mathematical model based on the dynamics of the neutral atmosphere in terms of dry air pressure, air temperature and water vapour's pressure, the latter the most variable of all three parameters. Several studies have been carried out aiming at testing both the efficiency and the applicability of the many models and mapping functions available (*Janes et al.*, 1990; *Mendes & Langley*, 1994; *Mendes & Langley*, 1995; *Santerre et al.*, 1995). A common characteristic of such tests is that most of the data used comes from sites located in the Northern Hemisphere.

In Brazil, since 1996, GPS data has been continuously collected by the Brazilian Network for continuous monitoring of GPS, known by its Portuguese acronym as RBMC. This network, as shown in Figure 1, is composed of 9 stations, occupied by dual-frequency GPS receivers, covering both the geographic and the climatic regions of Brazil. Two of them are IGS stations. As many as 11 new stations are planned to become operational in the near future. The plethora of GPS data available from the RBMC network allows that comparisons among tropospheric models and mapping functions be carried out based on their impact on geodetic positioning. The idea is to gain some insight into the tropospheric models and mapping functions, with indications on their adequacy to the various climate types in Brazil.

MODELLING OF THE TROPOSPHERE

This paper deals with the tropospheric refraction, basically, with the change in direction that an electromagnetic wave suffers when propagating through a stratified medium, in the context, the troposphere. Here, the troposphere is regarded as the neutral atmosphere, i.e., as the part of the atmosphere without the presence of ionised particles. The tropospheric delay may be defined as the variation between the range effectively covered by the electromagnetic wave and the geometric distance between the emitter and receiver antennas. The tropospheric delay is divided into two components: a dry (or hydrostatic) component; and, a wet component. The dry component is related to the dry air, and represents around 90% of the delay. The wet component depends on the partial pressure of water vapour, which is extremely variable, resulting in its complex quantification.

The tropospheric delay ΔS_T may be written as (*Silva*, 1998):

$$\Delta S_T = \Delta S_{T_1} + \Delta S_{T_2} = 10^{-6} \int_0^{h_1} N_1 ds + 10^{-6} \int_0^{h_2} N_2 ds \ , \qquad (1)$$

where N represents the refraction index, and the subscripts 1 and 2 the dry and wet components, respectively. The tropospheric delay as given by equation (1) represents the delay in the zenith. However, the GPS signal depends on the elevation angle of the satellite. The relationship between tropospheric delay and elevation angle is given by a function known as mapping function. Generically speaking:

$$\Delta S_T(E) = F(E) \cdot \Delta S_T \ , \qquad (2)$$

where E is the elevation angle and $F(E)$ the mapping function. The mapping functions are also associated to both dry and wet components:

$$\Delta S_T(E) = F_1(E) \cdot \Delta S_{T_1} + F_2(E) \cdot \Delta S_{T_2} \ . \qquad (3)$$

The diagram portrayed by Figure 2 illustrates the decomposition of the tropospheric delay into model and mapping function, with dry and wet components. In this figure, d_{trop} represents the actual delay, $d_{trop}(z)$ the delay given by the model on the zenith, $d_{trop}(el)$ the delay given by the mapping function as a function of the elevation angle el, and D and W both the dry and wet components.

Figure 1 – The RBMC network

There are several models aimed at estimating the tropospheric delay, which can be associated to mapping functions. In this paper, the ones dealt with are: Hopfield (1969), Saastamoinen (1973), Lanyi (1984), Ifadis (1986) and Herring (1992).

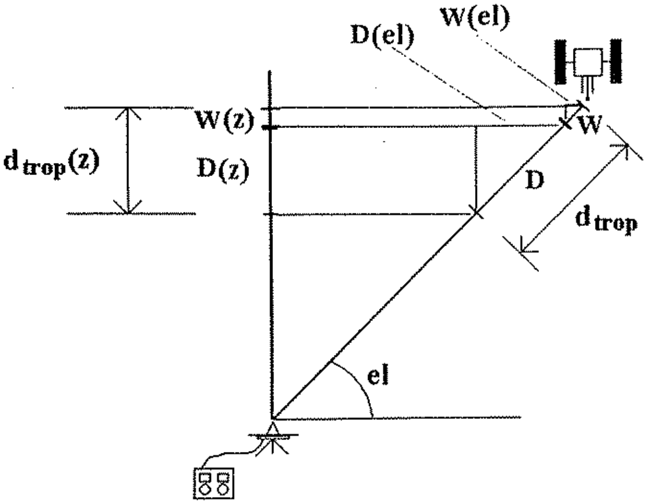

Figure 2 – A non-mathematical illustration of the tropospheric delay

PROCESSING STRATEGIES

For the study described in this paper, three baselines were formed, namely, between Fortaleza and Bom Jesus da Lapa (baseline FOBO, with length around 1,172 km), between Presidente Prudente and Viçosa (baseline UEVI, with length around 987 km) and between Curitiba and Presidente Prudente (baseline PAUE, with length around 430 km). Data covering 4 different periods have been chosen: period 1, from March 11th to 19th; period 2, from April 1st to 8th; period 3, from August 1st to 8th; and, finally, period 4, from July 1st to 8th, all in 1997. Due to some RBMC operational reasons, period 4 was not taken into consideration for baselines FOBO and PAUE, as well as periods 1 and 2 for baseline UEVI.

The GPS data was processed using the software suite DIPOP, developed at the University of New Brunswick, Canada (*Santerre et al*, 1987; *Santos*, 1995). For the data processing, either default meteorological data or meteorological data actually collected at the sites during the data gathering were used as input. The latter is the case for period 3. For the processing of the GPS data, two elevation angles were used, 10° and 15°. Also, the ionosphere-free combination between L1 and L2 carrier phases were formed. It should be mentioned that the GPS data was collected in a 30 seconds interval, daily.

ANALYSIS OF THE RESULTS

The final results were organised in terms of days, period and combination, in order to ease up their analysis. The adjusted co-ordinate components and length of baselines were compared with their corresponding SIRGAS (Geocentric Reference System for South America) values, considered here as "bench marks", and also to their mean value, i.e., to the average of the daily solutions. Figures 3 to 10 show an analysis based on the results of baseline PAUE, using actual meteorological data collected at these sites. In all of the figures the horizontal axis indicate the combination number (as in Table 1) whereas the vertical axis point out an average difference, in millimetres. Also, they all refer to an

Table 1 shows the combinations among models and mapping functions tested with the GPS data used.

combination	models		mapping functions	
	dry	wet	dry	wet
1	Saastamoinen	Saastamoinen	Ifadis	Ifadis
2	Saastamoinen	Saastamoinen	Saastamoinen	Saastamoinen
3	Saastamoinen	Saastamoinen	Hopfield	Hopfield
4	Hopfield	Hopfield	Hopfield	Hopfield
5	Hopfield	Hopfield	Ifadis	Ifadis
6	Hopfield	Hopfield	Saastamoinen	Saastamoinen
7	Hopfield	Hopfield	Herring	Herring
8	Saastamoinen	Saastamoinen	Herring	Herring
9	Saastamoinen	Saastamoinen	Lanyi	Lanyi
10	Hopfield	Hopfield	Lanyi	Lanyi
11	Hopfield	Ifadis	Ifadis	Ifadis
12	Saastamoinen	Ifadis	Ifadis	Ifadis
13	Hopfield	Ifadis	Herring	Herring
14	Hopfield	Ifadis	Lanyi	Lanyi
15	Saastamoinen	Ifadis	Herring	Herring
16	Saastamoinen	Ifadis	Lanyi	Lanyi
17	Saastamoinen	Ifadis	Saastamoinen	Saastamoinen
18	Saastamoinen	Ifadis	Hopfield	Hopfield
19	Hopfield	Ifadis	Saastamoinen	Saastamoinen
20	Hopfield	Ifadis	Hopfield	Hopfield

Table 1 – Combination among tropospheric models and mapping functions

elevation angle of either 10 or 15 degrees. Figures 3 and 4 show the average difference with respect to SIRGAS, for the verticalcomponent. A closer solution to the SIRGAS value are obtained with the combinations which use the wet model of Ifadis. Figures 5 and 6 also refer to the vertical component, with the average difference with respect to the mean value. It can be seen that a better agreement among the solutions is arrived at using the wet model of Ifadis, combined with the mapping functions of Ifadis, Herring and Lanyi. Figures 7 and 8 show the average difference with respect to SIRGAS, for the length component, and Figures 9 and 10 portray the average difference to a mean value. The results are not as clear as with the vertical component, but they seem to corroborate the same conclusion.

The analysis seems to indicate that a less variability around an average value is found with the mapping functions of Herring, Ifadis and Lanyi, especially when they combine with the wet tropospheric model of Ifadis. Additional analyses of the results are shown in *Silva* (1998).

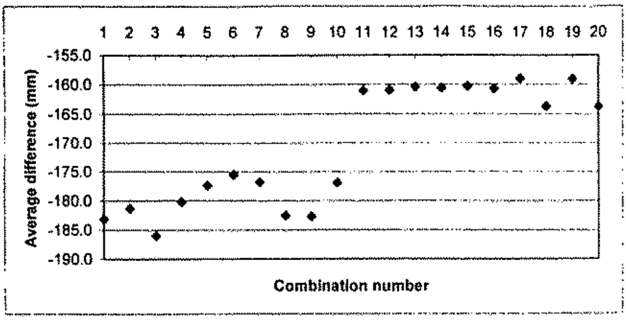

Figure 3 – Vertical component, average difference with respect to SIRGAS, elevation angle equal to 10 degrees

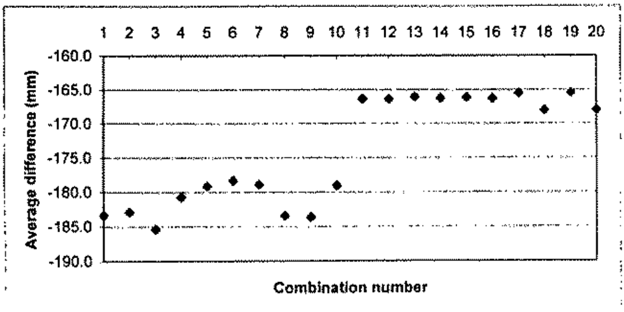

Figure 4 – Vertical component, average difference with respect to SIRGAS, elevation angle equal to 15 degrees

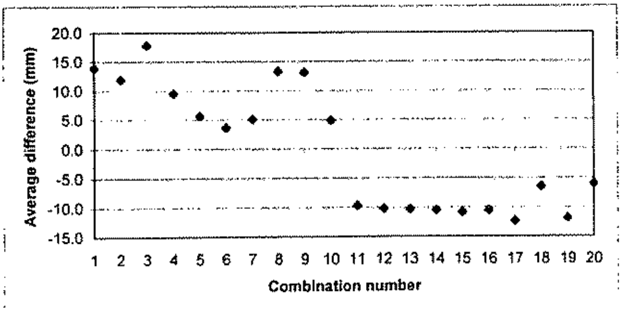

Figure 5 – Vertical component, average difference with respect to mean value, elevation angle equal to 10 degrees

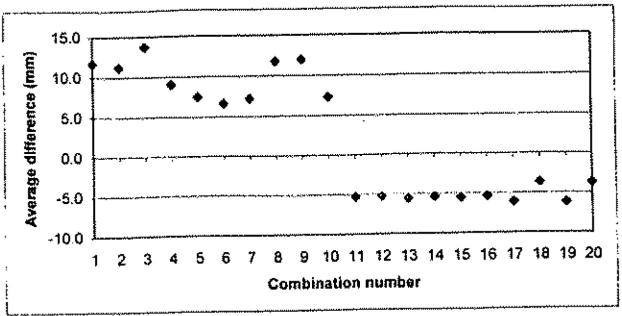

Figure 6 – Vertical component, average difference with respect to mean value, elevation angle equal to 15 degrees

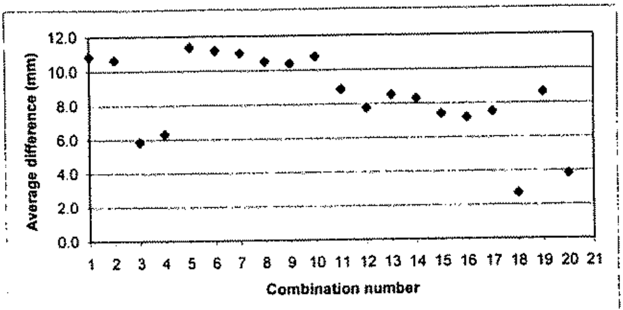

Figure 7 – Baseline length, average difference with respect to SIRGAS, elevation angle equal to 10 degrees

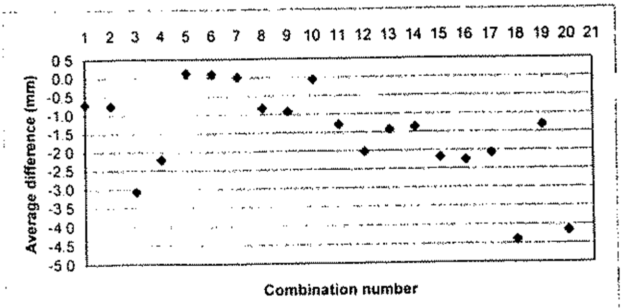

Figure 8 – Baseline length, average difference with respect to SIRGAS, elevation angle equal to 15 degrees

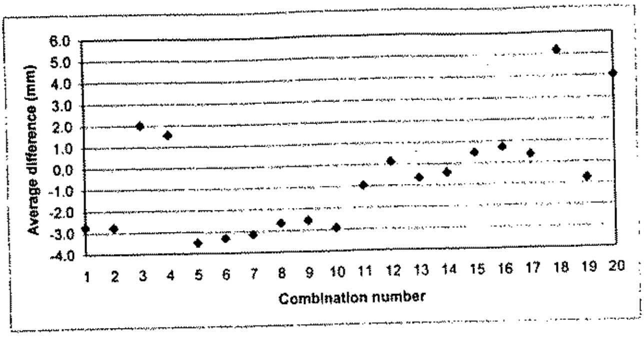

Figure 9 – Baseline length, average difference with respect to mean value, elevation angle equal to 10 degrees

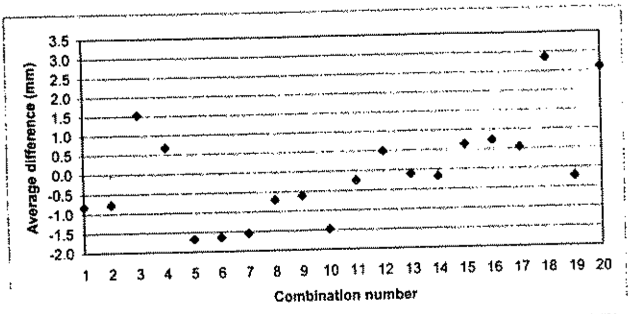

Figure 10 – Baseline length, average difference with respect to mean value, elevation angle equal to 15 degrees

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