GPS Meteorology: Concepts and possibility of application in Brazil

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Introduction

- GPS Meteorology (GPS/Met) is a very new and challenge field of research and applications;
- Promoting the use of GNSS in Meteorology may be a field of interest of OOSA.
Introduction

- GPS Meteorology;
  - Space Based; (CHAMP, COSMIC, EQUARS, ...) GPS Occultation

CHAMP: Challenging Minisatellite Payload for Geophysical Research and Application
COSMIC: Constellation Observing System for Meteorology, Ionosphere & Climate
EQUARS - Equatorial Atmosphere Research Satellite
COSMIC GPS Occultation


UN/US International Meeting on GNSS
December 2004
• **Ground Based:**
  - From GPS receiver on the ground, one can estimate the total tropospheric delay ($D_{TROP}$);
• **Ground Based:**

\[ D_{TROP} = D_{ZH} + D_{ZW} \]

- It is composed of two components: hydrostatic and wet delays ...

\[ D_{ZH} = (2,27671422 \times 10^{-3}) \frac{P_0}{(1 - 0,0026 \cos 2 \varphi - 0,00028h)} \]

- Therefore:

\[ D_{ZW} = D_{TROP} - D_{ZH} \]

- The accuracy is claimed to be of the order of 4-12 mm,
Objectives

• To present the Concepts of GPS Meteorology – Ground Based;

• To introduce the present and future situation of GPS Meteorology in Brazil and the possibilities of applications and of a Pilot Project in this area.
Basics of GPS/Met – Ground Based

- Once one obtain $D_{ZW}$, it can be converted to IWV by applying the following equation:

$$IWV = D_{ZW} \Psi$$

$$\Psi = \frac{10^6}{R_w \left[ k_2' + \frac{k_3}{Tm} \right]}$$

- $R_w = (461,5181) \text{ Jkg}^{-1}\text{K}^{-1}$ specific constant of WV

- $k_2' = 22,10 \text{ K hPa}^{-1}$ and $k_3 = 373900 \text{ K}^2 \text{ hPa}^{-1}$

- $Tm$ is the mean weighted temperature of the atmosphere along the vertical coordinate.
How to obtain $T_m$?

- $T_m$ is frequently obtained from surface temperature ($T_s$), by applying a model that relates $T_m$ and $T_s$;
  - An global example is given by Schueler et al., (2002):

$$T_m \approx 86.9 + 0.647 \, T_s + \text{corrections}$$

- Precision of about 2 to 5 K
A Tm model to be used in Brazil

- It was based on the last 30 years of historical radiosonde measurements (94800 data set).

### Independent Evaluation of the model

<table>
<thead>
<tr>
<th>Site</th>
<th>Radiosonde Numbers</th>
<th>Resulting models:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nossa Senhora</td>
<td></td>
<td>$T_m = 110.578 + 0.0105P_s + 0.558T_s$</td>
</tr>
<tr>
<td>Guajara Mirim</td>
<td></td>
<td>$T_m = 121.75 + 0.55508T_s$</td>
</tr>
<tr>
<td>Porto Velho</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Site Mean Error (K)

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean Error (K)</th>
<th>Standard Deviation (K)</th>
<th>RMS (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nossa Senhora</td>
<td>2.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guajara Mirim</td>
<td>2.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porto Velho</td>
<td>2.08</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The first successful GPS/Met Experiment in Brazil - 2001

Wet delay below 19 cm

- Mean Error: 0.49
- $\sigma$: 1.81
- RMS: 1.88 mm
- $9.4\%$

How good are the radiosondes results?
### Integrated Water Vapor

#### RS90 vs. Other Radiosondes

<table>
<thead>
<tr>
<th>Radiosonde</th>
<th>Flight Numbers</th>
<th>Layer 0-3 (kg/m²)</th>
<th>Layer 3-8 (kg/m²)</th>
<th>Layer 8-15 (kg/m²)</th>
<th>Layer 15-30 (kg/m²)</th>
<th>Total Content (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS90</td>
<td>18</td>
<td>1.124</td>
<td>0.387</td>
<td>0.041</td>
<td>0.005</td>
<td>1.271</td>
</tr>
<tr>
<td>MKII</td>
<td>33</td>
<td>4.158</td>
<td>1.972</td>
<td>0.218</td>
<td>0.007</td>
<td>4.605</td>
</tr>
<tr>
<td>GL-98</td>
<td>20</td>
<td>1.696</td>
<td>0.542</td>
<td>0.073</td>
<td>0.006</td>
<td>2.202</td>
</tr>
<tr>
<td>DFM-97</td>
<td>16</td>
<td>2.198</td>
<td>0.547</td>
<td>0.029</td>
<td>0.112</td>
<td>2.565</td>
</tr>
<tr>
<td>SW</td>
<td>16</td>
<td>2.186</td>
<td>0.594</td>
<td>0.080</td>
<td>0.047</td>
<td>2.413</td>
</tr>
</tbody>
</table>

**Graph:**
- Integrated Water Vapor vs. RS90
- x-axis: Integrated Water Vapor RS90 (kg/m²)
- y-axis: Total Content (kg/m²)

**Equation:**
- RS90: $y = 0.17x$
GPS intercomparison campaign

Aim:
- To compare the IWV values obtained from different receivers collocated at the same (meteorological) site.

Site: Laboratory of Spatial Geodesy – FCT/UNESP
- Lat: 21° 10' 0"

Period of data collection:
- 11 to 25 November 2002

Receivers:
- Ashtech ZXII
- Topcon/Legacy
- Trimble 4000 SSI
**Results of the GPS Intercomparison**

<table>
<thead>
<tr>
<th>Compared Receivers</th>
<th>Estimate Numbers</th>
<th>(Dzw) (mm) BIAS</th>
<th>(Dzw) RMS</th>
<th>(IWV) (kg/m²) BIAS</th>
<th>(IWV) RMS</th>
<th>(IWV) RMS(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trimble-ZXII</td>
<td>2676</td>
<td>-2.50</td>
<td>6.60</td>
<td>-0.39</td>
<td>1.04</td>
<td>2.5%</td>
</tr>
<tr>
<td>Legacy1-ZXII</td>
<td>3167</td>
<td>-7.80</td>
<td>9.10</td>
<td>-1.23</td>
<td>1.43</td>
<td>3.5%</td>
</tr>
<tr>
<td>Legacy2-ZXII</td>
<td>3199</td>
<td>-9.80</td>
<td>11.20</td>
<td>-1.54</td>
<td>1.76</td>
<td>4.3%</td>
</tr>
<tr>
<td>Legacy1-Trimble</td>
<td>3269</td>
<td>-5.20</td>
<td>6.90</td>
<td>-0.82</td>
<td>1.09</td>
<td>2.7%</td>
</tr>
<tr>
<td>Legacy2-Trimble</td>
<td>3302</td>
<td>-7.50</td>
<td>8.80</td>
<td>-1.18</td>
<td>1.39</td>
<td>3.4%</td>
</tr>
<tr>
<td>Legacy2-Legacy1</td>
<td>3794</td>
<td>-2.20</td>
<td>3.80</td>
<td>-0.35</td>
<td>0.60</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

![Graph showing zenithal wet delay from different receivers](image-url)
Accuracy of \((IWV_{GPS} - IWV_{RS})\)?

\[
\sqrt{1.1^2 + 1.2^2} \approx 1.6 \text{kg} / \text{m}^2
\]
GPS Campaign within the context of LBA

- LBA is an international research initiative leaded by Brazil.
- In order to obtain a knowledge base to help with the sustainable development of the Amazon region.
LBA Study areas and the GPS stations

- GPS Stations
- 6 radiosondes launches per day
- Other meteorological sensors
  - Aeronet (Aerosol Robotic Network)
  - Sun-sky radiometer (Brent Holben - NASA)

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Details of the Stations

Radiosondes and GPS data collections

Aeronet

Abracos

Antena GPS

GPS Antenna

Radiosonde Launches
Station
GPS data available and methodology

### UN/US International Meeting on GNSS
December 2004

**GIPSY OASIS II SOFTWARE**
- PPP
- ION FREE OBSERVABLES
- CUT-OFF ELEVATION ANGLE OF 10°
- PRECISE EPHEMERIS, CLOCKS AND EOPs FROM JPL
- TROPOSPHERIC DELAY AS RANDOM WALK (2CM)  📏
- NIELL MAPPING FUNCTION
- STATIONS COORDINATES CONSTRAINED TO 2CM (FROM A PREVIOUS OCCUPATION).
Preliminary Results

**Site: Fazenda Nossa Senhora**

- **GPSxWVR** \( r^2 = 0.959 \)
- **GPSxRS** \( r^2 = 0.864 \)

**Table: Compared Techniques**

<table>
<thead>
<tr>
<th>Compared Techniques</th>
<th>GPS Station</th>
<th>Comparison number</th>
<th>Bias ((kg/m^2))</th>
<th>Standard deviation ((kg/m^2))</th>
<th>RMS ((kg/m^2))</th>
<th>RMS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS – WVR</td>
<td>ABRA</td>
<td>304</td>
<td>-2.151</td>
<td>1.664</td>
<td>2.719</td>
<td>5.44</td>
</tr>
<tr>
<td>GPS – RS</td>
<td>ABRA</td>
<td>133</td>
<td>2.511</td>
<td>2.517</td>
<td>3.555</td>
<td>7.11</td>
</tr>
<tr>
<td>GPS – RS</td>
<td>GJMI</td>
<td>105</td>
<td>2.327</td>
<td>2.281</td>
<td>3.258</td>
<td>6.52</td>
</tr>
<tr>
<td>GPS – RS</td>
<td>PTVE</td>
<td>96</td>
<td>0.965</td>
<td>2.212</td>
<td>2.414</td>
<td>4.82</td>
</tr>
</tbody>
</table>

**Equation:**

\[ 1.6kg / m^2 \] Expected accuracy \( \approx 9\% \)
Perspectives of Applications of GPS/Met in Brazil

- **Brazilian GPS Network (IBGE)**
  - Data collected every 15 seconds;
  - Available to the users once a day.

- **Short period Perspectives (one/two years)**
  - Data available at least every other 1.5 hours;
  - To make the delays available within two hours to be assimilated in the CPTEC weather forecasting model;
  - To expand the number of GPS stations.

- **Activities being performed**
  - A controlled experiment to analyze the impact of assimilating GPS IWV estimates in the CPTEC model;
  - Near Real time ZTD (one hour latency) for one station.

Accuracy of 10-12 mm using a window of 3 hours of GPS data (need improvement)
Previsões do Atraso Zenital Troposférico para sistemas de posicionamento por satélites (GPS ou GLONASS)

A model to predict the zenithal delay is available at CPTEC; it was based on the CPTEC NWP (Numerical Weather Model) and can be used over all South America.
Comments and Conclusions

• The basic fundamentals of GPS Met was presented;
• A Tm model was developed for Brazil;
• Intercomparison of IWV was performed:
  – From radiosondes,
  – From GPS,

• IWV RMS absolute values from comparison of radiosondes and GPS are higher in the Amazonian region than the other tests performed;
  – but considering the high delays in that region, the percentage values are smaller (more research is needed),
Comments and Conclusions

• Perspectives of Applications of GPS/Met in Brazil was presented;

• Tests of assimilation of IWV are being performed using the CPTEC numerical model –
  - It can be easily expanded to South America, since GPS IWV values are available;
  - It can be integrated within other projects, expanding the objectives….
  - And maybe, it can be a start point of a Pilot Project for South America in this field of GNSS application.