Generating VRS Data Using Atmospheric Models: How Far Can We Go?

Daniele Barroca Marra Alves (PhD Student)
Adj. Prof. João Francisco Galera Monico
Luiz Fernando Antonio Dalbelo (MSc Student)
Faculty of Science and Technology (FCT) - São Paulo State University (UNESP)
FCT/UNESP – Pres. Prudente, São Paulo, Brazil

Dr. Luiz Fernando Sapucci
Center for Weather Forecasts and Climate Studies
CPTEC/INPE - São Jose dos Campos, São Paulo, Brazil
Nowadays, with the implantation of reference station networks, several positioning techniques have been developed and/or improved.

Applying multiple reference station methods one can obtain higher positioning accuracy in a larger coverage area.

In addition to gain in:
- Reliability
- Availability
- Integrity
Several methods have been developed to generate corrections from network stations data.

In this paper was decided to use the VRS concept, which may be quite useful in Brazil.

VRS data are generated using a different methodology.

In the proposed methodology ionospheric and tropospheric models developed in Brazil were used.
At UNESP, a regional ionosphere model (Mod_Ion) has been developed. This model presented good results in Point Positioning.

A NWP model was used. This kind of troposphere modeling has been very used by the scientific community. The procedure used to compute the ZTD by NWP model was jointly developed by UNESP and CPTEC/INPE.
MOD_ION – Brief Historical

Mapping Function

- Standard Geometric

Modeling Function

- Fourier Series
- Spherical Harmonic
- Taylor Series
- 4-order polynomial

Developed by Camargo (1999)

Added by Matsuoka (2003)

Sardón et al. (1994)

Komjathy (1997)

Improved by Aguiar (2005)

Kalman Filter

Fourier Modeling Function was altered

Mod_Ion_FK

Real time applications
Mod_Ion_FK has the goal of providing ionosphere corrections in real time.

The parameters of the model are estimated through the Kalman Filter and the Gauss-Markov process for prediction.

As a modeling function, a 19 coefficient Fourier series is used.
The use of ZTD prediction from NWP models is a good alternative to minimize the effects of the troposphere for real time applications.

Zenithal tropospheric delay from NWP developed at CPTEC/INPE & FCT/UNESP is available in Brazil.

It is based on the General Atmosphere Circulation Model of CPTEC/INPE.
The ZTD values are provided for all South America twice a day with predictions for a period of 66 hours.

Resolution: horizontal 100 x 100 km; vertical - 18 levels

It is under development: 20x20 km horizontal resolution; vertical - 19 levels

Available in: http://satelite.cptec.inpe.br/htmldocs/ztd/zenital.htm
ZTD FROM NWP – CPTEC/INPE

RESOLUTION
- horizontal: 20x20 km
- vertical: 19 levels
Using network RTK positioning, it is possible to model the distance dependent errors.

**Ionosphere Effect**

**Troposphere Refraction**

Several methods have been developed to formulate corrections from a network station's data:

- **PDA**
- **Interpolation**
- **Conditional Adjustment**
- **VRS**

The VRS concept is quite useful in Brazil:

**A reference station close to the user**
The VRS data are not provided by a real receiver, but its data are generated from real GPS observations collected by an active multiple reference station network.

The idea is that the VRS data resemble as much as possible a real receiver data at the same location.

The user has the possibility of using the VRS as if it were a real reference station in your proximities.

The user can accomplish the relative positioning using a single frequency receiver.

Wanninger (1999)
**METHODOLOGY**

1. **Input Data**
   - Reference Stations Coordinates
   - IGS ephemerides
   - VRS coordinates

2. Base station choice and RINEX reading

3. Computing GC

   - Yes: Computing the atmospheric effect differences between the base and VRS stations
     - Computing corrections
       - Generating the VRS file
     - End process
   - No: Generating the VRS file

4. Use atmospheric corrections?
It was used data from GPS Active Network of West of São Paulo State, and an extra station.

The data were collected in 28, 29, 30 December 2006, 24 hours a day.

The VRS was generated for one of the stations (PPTE).

The PPTE data were used just for testing.

In order to analyze the VRS performance it was accomplished the PPP, DGPS and relative positioning with VRS data.
## PPP – COORDINATES ANALYSES

### Static Mode

<table>
<thead>
<tr>
<th>Day</th>
<th>PPTE</th>
<th>GC</th>
<th>GC+T+I</th>
</tr>
</thead>
<tbody>
<tr>
<td>362</td>
<td>2.77</td>
<td>20.11</td>
<td>2.20</td>
</tr>
<tr>
<td>363</td>
<td>3.24</td>
<td>19.48</td>
<td>2.38</td>
</tr>
<tr>
<td>364</td>
<td>2.51</td>
<td>21.09</td>
<td>2.20</td>
</tr>
<tr>
<td>002</td>
<td>2.69</td>
<td>20.78</td>
<td>3.28</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>2.80</strong></td>
<td><strong>20.37</strong></td>
<td><strong>2.51</strong></td>
</tr>
</tbody>
</table>

### Kinematic Mode

<table>
<thead>
<tr>
<th>Day</th>
<th>PPTE</th>
<th>GC</th>
<th>GC+T+I</th>
</tr>
</thead>
<tbody>
<tr>
<td>362</td>
<td>9.40</td>
<td>36.16</td>
<td>10.54</td>
</tr>
<tr>
<td>363</td>
<td>10.01</td>
<td>34.52</td>
<td>10.56</td>
</tr>
<tr>
<td>364</td>
<td>10.51</td>
<td>37.92</td>
<td>13.27</td>
</tr>
<tr>
<td>002</td>
<td>10.19</td>
<td>48.44</td>
<td>9.44</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>10.03</strong></td>
<td><strong>39.26</strong></td>
<td><strong>10.95</strong></td>
</tr>
</tbody>
</table>

NRCan software
DGPS

<table>
<thead>
<tr>
<th>Day</th>
<th>PPTE</th>
<th>GC</th>
<th>GC+T+I</th>
</tr>
</thead>
<tbody>
<tr>
<td>362</td>
<td>142.90</td>
<td>156.02</td>
<td>162.08</td>
</tr>
<tr>
<td>363</td>
<td>149.69</td>
<td>161.88</td>
<td>167.43</td>
</tr>
<tr>
<td>364</td>
<td>156.23</td>
<td>165.25</td>
<td>169.77</td>
</tr>
<tr>
<td>Average</td>
<td>149.60</td>
<td>161.05</td>
<td>166.43</td>
</tr>
</tbody>
</table>

RMS (cm)

VRS generated by GC and CG+T+I

Day 362

PPTE versus VRS

## RELATIVE POSITIONING

### Static Mode

<table>
<thead>
<tr>
<th>Day</th>
<th>PPTE</th>
<th>GC</th>
<th>GC+T+I</th>
</tr>
</thead>
<tbody>
<tr>
<td>362</td>
<td>1.51</td>
<td>9.28</td>
<td>1.28</td>
</tr>
<tr>
<td>363</td>
<td>1.46</td>
<td>9.89</td>
<td>1.60</td>
</tr>
<tr>
<td>364</td>
<td>1.96</td>
<td>10.82</td>
<td>2.01</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>1.64</strong></td>
<td><strong>10.00</strong></td>
<td><strong>1.63</strong></td>
</tr>
</tbody>
</table>

### Kinematic Mode

<table>
<thead>
<tr>
<th>Day</th>
<th>PPTE</th>
<th>GC</th>
<th>GC+T+I</th>
</tr>
</thead>
<tbody>
<tr>
<td>362</td>
<td>5.96</td>
<td>21.36</td>
<td>6.05</td>
</tr>
<tr>
<td>363</td>
<td>5.64</td>
<td>21.48</td>
<td>5.93</td>
</tr>
<tr>
<td>364</td>
<td>6.99</td>
<td>26.70</td>
<td>6.25</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>6.20</strong></td>
<td><strong>23.18</strong></td>
<td><strong>6.08</strong></td>
</tr>
</tbody>
</table>

RMS (cm) for **TGO software**
RELATIVE POSITIONING - Kinematic mode

Day 362

VRS generated by GC and CG+T+I

PPTE versus VRS

TGO software
In this presentation it was showed the performance obtained by a VRS generated using atmospheric models

IONOSPHERE – Mod_Ion_FK

TROPOSPHERE – NWP model

Developed by UNESP and CPTEC/INPE

The results obtained present evidences that the proposed methodology may be quite efficient

The results provided by VRS are similar of those obtained by real data (PPTE)
This methodology was tested using other troposphere models (Hopfield for example) – NWP provided the best results.

It has been developed a version concerning the ambiguity resolution.
Spatial Geodesy Study Group

The Spatial Geodesy Study Group (GEGE - Grupo de Estudos em Geodésia Espacial) started its activities in 1997.

This group has as goal to discuss topics related to the researches developed at Faculty of Sciences and Technology - UNESP in Spatial Geodesy and correlated fields.

Researchers from the Department of Cartography, involved in this area, together with theirs PhD, MSc, Scientific Initiation (IC - Iniciação Científica) students are member of GEGE.

http://gege.prudente.unesp.br/