Installation and processing of ground-based GPS stations of the Moroccan National Meteorological Service

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Abstract

Besides the GPS (Global Positioning System) traditional application for precise geodesy, the GPS system has proved to be a powerful tool in atmospheric studies, such as climatology and meteorology. In fact, the Zenith Tropospheric Delay (ZTD) of the GPS signal induced by the refraction in the troposphere is related to the atmospheric Integrated Water Vapor (IWV).

The GPS network of the Moroccan Meteorological Service, recently installed, comprises ten permanent ground-based GPS stations. Those Ashtech ProFlex receivers are designed to collect, store and transfer high-quality raw data which are concentrated in a hub server at near real time.

The present work describes the developed operational processing of GPS data based on BERNESE software. The computed stations coordinates are validated using an Australian Online GPS Processing Service (AUSPOS). The results show a difference, mostly lower than 2 cm in the horizontal direction and lower than 1 cm in the vertical.

Introduction

The atmospheric water vapor plays a crucial role in weather prediction, namely for the forecast of heavy rainfall situations (Ducroq et al. 2002). However, there is a great lack in the measurements of this key parameter. In fact, the radiosondes that allow the vertical distribution observation of humidity are very insufficient in terms of both spatial and temporal resolution (maximum 5 radiosondes in Morocco). To overcome this lack, it seems appropriate to exploit the potential of GPS data to measure tropospheric water vapor. When propagating through the atmosphere, GPS signals are slowed and bended by the troposphere. This delay is related to the atmospheric temperature, pressure and water vapor of the crossed layers and it is expressed as a total delay at the zenith (Zenith Total Delay, ZTD). ZTD is considered as a pseudo observation of integrated water vapor (IWV) and it’s more and more used by the meteorological services especially in numerical weather prediction.

The Moroccan meteorological service (DMN) has installed a network of 10 Ground-based GPS meteorology stations. The computation of the precise coordinates of the different stations is of great importance. This is the first step to perform before the computation of the tropospheric parameters used by meteorological models. To calculate those precise coordinates, a processing chain based on BERNESE software was implemented and validated.
In this paper we explain the interest of GPS observations in meteorology. The description of the Moroccan GPS meteorology is showed in section 2. In Section 3, we present the GPS data processing chain based on the Bernese software. The results of the computation of Moroccan stations coordinates and their validation by AUSPOS are discussed in section 4.

I. The interest of GPS observations in meteorology

While propagating through the atmosphere, the GPS signal is delayed due to the variation of the index of refraction in the troposphere. In order to achieve millimeter accuracy, in space geodetic methods, geodesists tend to remove these effects of atmosphere on the GPS signal propagation. However, this error is considered as a very important source of information for meteorologists, since it is directly related to the amount of precipitable water in the atmosphere.

In fact, the atmosphere affects the GPS signal in two ways: the propagation delay and the ray path bending (fig. 1). This effect of bending is very negligible, accounting for ~0.1% of the total error. The tropospheric delay (ZTD) is the most significant part of the total error and it consists of two components:

- The hydrostatic delay (dry) ZHD: it is the GPS signal delay caused by the hydrostatic component of the atmosphere. It can be modeled using pressure surface.
- The wet delay ZWD: represents 10% of ZTD and it is derived not only from surface parameters but, from water vapor distribution in the troposphere. In fact, it is the very important component in meteorology.

![Figure 1](image1.png)

**Figure 1**: The effect of the troposphere on the GPS signal propagation.

For those reasons, The GPS system is nowadays considered as a non conventional and an implicit water vapor observation. The GPS technique has a lot of advantages compared with conventional water vapor measurements methods, namely radiosondes, surface-based microwave radiometers and satellite-based microwave remote sensing: It is inexpensive, accurate, reliable and it is not affected by the rain and clouds thanks to its carefully chosen carrier wave frequency. The accuracy of GPS derived water vapor data is comparable to the accuracy of radiosondes and microwave radiometers (Emardson et al., 1998) with a precision better than 10mm.

The GPS system has a lot of meteorological applications especially in numerical weather prediction. GPS observations are used for the validation, as the radiosondes, of the model forecast data, but with higher temporal and spatial resolution. They can also be used directly to improve the model...
initial conditions by their integration in the data assimilation system. The latter was the principal motivation of having and processing a set of GPS meteorology in Morocco.

II. Description of Moroccan GPS meteorology network
Since 2012, the Moroccan meteorology service has carried out a project of acquisition and installation of 10 Ground-based GPS stations intended to meteorological use. The main phases of this project are: 1) the installation of the hardware on different sites 2), the concentration of the GPS stations measurements in the central, 3) the locally processing of raw data in order to produce ZTD and IWV.

The GPS stations are now installed in different Moroccan synoptic stations to ensure the availability of ground-based meteorological data and the monumental stability with a communication accessibility. Figure 2 shows the GPS network sites.

![Figure 2: Sites in the Moroccan GPS network.](image)

1. Characteristics of Moroccan GPS meteorology stations
The principle components of the GPS stations are the receiver and the antenna.

a) The GPS receiver
The GPS receivers of the Moroccan network are Ashtech Proflex type, which are designed to collect, store and transfer high-quality raw GPS data (fig. 3). The Ashtech receivers are a powerful positioning system that offers a lot of advanced functions. Their main characteristics are:

- The embedded BLADE technology ensures high quality measurements by using multiple GNSS constellations: GPS, GLONASS, GALILEO, COMPASS and SBAS.
- The receiver works as well as reference station or as a fixed or mobile base station for both real time and post processing applications.
- The embedded Web Server ensures a remote access via internet. The raw data can be automatically sent to an external FTP server and the authorized users can directly download the raw data files stored in the station.
- The raw data can be managed in sessions from the Web Server. We can chose up to 96 sessions per day.
- The raw data are available on RINEX (Receiver INdependent Exchange) format which is the standard format that allows management of the measurements of GPS receivers.
a) The GPS antenna

The GPS station is equipped with an antenna responsible for capturing the L-bands signals transmitted from GPS satellite. The CHOKE RING antenna used for Moroccan GPS network (fig. 4) can provide millimeter precision and is characterized by:

- The ability to receive multi-frequency and multi-constellation signals. The captured signals are:
  - GLONASS : L1 and L2 C/A.
  - GALILEO : E1 and E5.
  - SBAS (WAAS/EGNOS/MSAS/GAGAN).
  - Fully independent code and phase measurement
- The ability to reject multipath signals fading from near sources.
- The Stability of phase centre.

2. Central concentration of GPS raw data

The raw data measured by GPS station are delivered, in near real-time to a central server via the IP VPN network of DMN (fig. 5). The central sever is provided by a software ensuring the concentration, the management and the quality control of GPS data. It allows:

- The Concentration of data measured by Moroccan GPS stations on RINEX format, in addition of the navigation message files containing broadcast messages for all satellites collected during the observation time and also the meteorological data (surface pressure and temperature) needed for data processing.
- The acquisition of raw data of the IGS (International GPS Service) stations close to Moroccan domain.
• The storing and archiving as a database of GPS data and the meteorological data.
• The automatic check of data quality using TEQC (Translation, Editing and Quality Checking) software developed by UNAVCO.
• The automatic downloading of data by authorized users.
• The configuration and setting up the remote receivers by choosing the number of sessions and the cadence of observations. For the GPS meteorology network, 24 sessions per day (hourly sessions) are stored with an observation cadence of 30s.

III. Operational GPS data processing
The Moroccan network GPS data are processed with the BERNESE software. BERNESE is a scientific, high-precision, multi-GNSS data processing developed at the Astronomical Institute of the University of Bern. It is based on the least square method to estimate the unknown parameters especially, station coordinates, tropospheric zenith delay parameters, orbital parameters and Earth orientation parameters. It performs double differenced GPS observations from each site within the regional network.

The principle components of BERNESE data processing are shown in figure 6. The different programs used are:

• **POLUPD**: updates the file containing the Earth rotation parameter (EOP) information in order to obtain the most accurate EOP.
• **PRETAB**: generates the intermediate tabular orbit files and extract clock information from the precise orbit files.
• **ORBGEN**: generates a standard orbit from tabular file or directly precise orbit files.
• **RXOVB3**: converts the RINEX observation files into BERNESE observation files.
- **CODSPP**: synchronizes the receiver clock with GPS time.
- **SNGDIF**: generates the baselines.
- **MAUPRP**: preprocess the different baselines.
- **GPSQIF**: resolves ambiguities by QIF (Quasi Ionosphere-Free) algorithm.
- **GPSEST**: estimates the unknown parameters/ (coordinates, ZTD,...).
- **ADDNEQ2**: computes multi-session solutions from the combination of a set of single-sessions solutions.

To estimate the tropospheric delay, an a priori model is applied to compute its a priori value. The a priori model used is the “DRY GMF” (Global Mapping Function) model and “WET GMF” for ZHD and ZWD into the slant path directions of the GPS satellites.

Figure 6: Functional flow diagram of the operational GPS data processing.
IV. Calculation and validation of GPS stations coordinates

The first step in data processing is the georeferencing of Moroccan stations, which means the calculation of their coordinates accurately. Those fixed coordinates will be used to calculate ZTD by the BERNESE chain. The accuracy of the stations coordinates influences the quality of ZTD. The period from 19/4/2016 to 9/5/2016 is considered. The BERNESE chain was used to calculate the coordinates over daily sessions along this period. In addition to the local stations, 19 IGS stations closest to Morocco were used. Thus, IGS manages a dense network of GPS stations around the world and IGS ensures the availability of high-quality data products. The IGS stations coordinates are calculated with a high accuracy in the International Terrestrial Reference Frame (ITRF). Table 1 shows the Moroccan stations codes and their locations and the IGS station codes used in the processing.

<table>
<thead>
<tr>
<th>Station code</th>
<th>Station location</th>
<th>IGS stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGAD</td>
<td>Agadir</td>
<td>ALAC</td>
</tr>
<tr>
<td>BEME</td>
<td>Béni-Mellal</td>
<td>BJCO</td>
</tr>
<tr>
<td>CASA</td>
<td>Casablanca</td>
<td>CASC</td>
</tr>
<tr>
<td>DAKH</td>
<td>Dakhla</td>
<td>CEU1</td>
</tr>
<tr>
<td>FES1</td>
<td>Fes</td>
<td>MALL</td>
</tr>
<tr>
<td>OUAR</td>
<td>Ouarzazate</td>
<td>MAS1</td>
</tr>
<tr>
<td>OUJD</td>
<td>Oujda</td>
<td>MELI</td>
</tr>
<tr>
<td>SALE</td>
<td>Rabat-Salé</td>
<td>COBA</td>
</tr>
<tr>
<td>TANG</td>
<td>Tanger</td>
<td>NOT1</td>
</tr>
</tbody>
</table>

Table 1: The Moroccan GPS stations and the IGS stations used in BERNESE processing.

Table 2 shows the results of the Moroccan stations coordinates computation over three weeks by BERNESE software.

<table>
<thead>
<tr>
<th>Station code</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGAD</td>
<td>30.3266707</td>
<td>-9.3978024</td>
<td>129.05729</td>
</tr>
<tr>
<td>BEME</td>
<td>32.3666507</td>
<td>-6.3971701</td>
<td>527.70564</td>
</tr>
<tr>
<td>CASA</td>
<td>33.3684031</td>
<td>-7.5797333</td>
<td>268.42766</td>
</tr>
<tr>
<td>DAKH</td>
<td>23.7038164</td>
<td>-15.9296633</td>
<td>49.80969</td>
</tr>
<tr>
<td>FES1</td>
<td>33.9301155</td>
<td>-4.9734749</td>
<td>629.03641</td>
</tr>
<tr>
<td>OUAR</td>
<td>30.9283310</td>
<td>-6.9128590</td>
<td>1200.27219</td>
</tr>
<tr>
<td>OUJD</td>
<td>34.7893947</td>
<td>-1.9378347</td>
<td>519.81105</td>
</tr>
<tr>
<td>SALE</td>
<td>34.0454987</td>
<td>-6.7585294</td>
<td>126.92897</td>
</tr>
<tr>
<td>TANG</td>
<td>35.7258905</td>
<td>-5.9126580</td>
<td>79.39468</td>
</tr>
</tbody>
</table>

Table 2: The Moroccan GPS stations coordinates.

Furthermore, in order to control the quality of the Moroccan station coordinates computed locally, those coordinates are compared to the ones computed by AUSPOS for the day 29/4/2016. In fact, AUSPOS is a free online GPS data processing facility allowing the computation of the coordinates of any GPS station in the world taking advantages of the IGS stations Network.

The difference between the coordinates calculated locally and by the AUSPOS Center for the stations DAKH and TANG is showed in Table 3. The difference concerns the three coordinates components in
the international terrestrial reference frame IGB08. We note that the difference is lower than 1 mm; therefore the locally computed coordinates has millimeter accuracy.

<table>
<thead>
<tr>
<th>Nom de la station</th>
<th>ΔX (m)</th>
<th>ΔY (m)</th>
<th>ΔZ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAKH</td>
<td>0.00701</td>
<td>0.00381</td>
<td>0.00088</td>
</tr>
<tr>
<td>TANG</td>
<td>0.00989</td>
<td>0.00268</td>
<td>0.00177</td>
</tr>
</tbody>
</table>

Table 3: The difference between the coordinates calculated locally and by AUSPOS for DAKH and TANG stations.

Conclusion

The present work describes: firstly, the Moroccan GPS meteorology network with its technical characteristics and secondly, the implementation of a complete framework based on BERNESE software that performs the coordinates calculation in addition to the tropospheric parameters derived from GPS data. The first step of the processing chain is the georeferencing according to the standards to have precise GPS stations coordinates. The chosen period is about 3 weeks from 19/4/2016 to 9/5/2016. Besides the Moroccan stations, 19 IGS stations closest to the Moroccan domain were used to ensure the high quality processing. The computed coordinates are then compared with independent calculation performed by the online GPS processing service AUSPOS. The results show a difference, mostly lower than 1 cm in both the horizontal and vertical direction.

The georeferencing was an important step to achieve before the calculation of the tropospheric parameters ZTD and IWV. The produced ZTD and IWV must be evaluated by comparing them with the radiosonde observations and with numerical weather forecast models especially ECMWF model. After this step of assessment of the produced ZTD quality, the next step is its direct assimilation in the mesoscale model AROME-Maroc using 3D-Var technique.

References