Near Real Time atmosphere model based on GNSS and meteorological data from ASG-EUPOS reference stations

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Motivation

- The term GNSS meteorology relates to the utilization of the Global Navigation Satellite System’s (GNSS) radio signals to derive information about the state of the troposphere - Slant Troposphere Delay (STD).

- The problem of Slant Troposphere Delay (STD) determination has been investigated by various research institutions since 1990.

- The GNSS tomography allows to resolve the spatial structure and temporal behavior of the tropospheric water vapor. The GNSS tomography is based on the signal slant delays, precisely Slant Wet Delays (SWD), result of the GNSS data processing.

- Since 2008 the new national permanent GNSS network ASG-EUPOS has been established in Poland. 17 Polish stations equipped with GNSS receivers and uniform meteorological sensors work currently in the frame of the European Permanent Network.

- The new concept of national integrated investigations based on the GNSS and meteorological observations from ASG-EUPOS stations and NWP models will be performed.
GNSS meteorology is the remote sensing of the atmosphere using GNSS. Continuous observations from GNSS receivers provide an excellent tool for studying the earth atmosphere.

There are many GNSS meteorology applications:

- Climatology - large set of uniform and well spread stations, observation time span over 15 years.

- Synoptic meteorology - Tropospheric Delay (TD) as an additional data input for NWP models.

- Nowcasting - TD alone is a standard real time product used as synthetic measure of the state of the atmosphere.

- 4D monitoring - TD is use to build the tomography model and gain spatial and temporal characteristics of the troposphere above the network of receivers.
Tropospheric Delay

Introduction
GNSS and meteorological data
4D NRT atmosphere model
Conclusions

Motivation
GNSS meteorology
Tropospheric Delay
GNSS troposphere tomography

\[ \text{ZTD} - \text{ZHD} = \text{ZWD} \]

\[ f(T,p) \]

\[ \text{Models: } \begin{align*} &\text{Saastamoinen} \\ &\text{Hopfield} \end{align*} \]

\[ \text{MF} \]

\[ \text{SWD} \]

\[ \text{4DT} \]

\[ \text{WVD} \]

\[ m(z) = \frac{1 + \frac{a}{b}}{1 + \frac{1 + c}{a}} \cos(z) + \frac{b}{\cos(z) + c} \]

\[ \text{NMF: Neill Mapping Function} \]
\[ \text{IMF: Isobaric Mapping Function} \]
\[ \text{VMF: Vienna Mapping Function} \]
\[ \text{GMF: Global Mapping Function} \]

Zenith Path Delay time series for WROC
http://www.epnecb.oma.be

10th Czech-Polish Workshop: Szklarska Porba / Poland - November 5-7, 2009
Assumption

The results of the measurements of the parameters, the a priori information on model parameters, and the information on the physical correlations between observable parameters and model parameters can all be described using probability densities.

**parameters:** temperature, pressure, local temperature and pressure gradients and Slant Tropospheric Delay (STD);

**a priori informations:** average temperature and pressure gradients, no humidity in height parts of troposphere;

**physical correlations** between tropospheric delay and distribution of meteorological parameters in troposphere.
ASG-EUPOS: GNSS infrastructure

72 Trimble NetRS, Trimble Zephyr Geodetic w/Radome (TRM41249.00 TZGD)

12 Ashtech Micro Z (ASHTECH UZ-12), Ashtech L1/L2 Choke Ring SNOW (ASH701945C_M SNOW - D/M element, REV.C, chokering with radome NGS)

8 Trimble NetR5, Trimble Zephyr GNSS Geodetic II w/Radome (TRM55971.00 TZGD)

4 Leica GRX1200 GG Pro, Leica L1/L2 Choke Ring, using DM-T style (LEIAT504GG LEIS)

1 Javad JPS E_GGD, Ashtech L1/L2 Choke Ring SNOW (ASH701945C_M SNOW - D/M element, REV.C, chokering with radome NGS)

1 Trimble NetRS, Dorne Margolin T Choke Ring (AOAD/M_T NONE)
ASG-EUPOS: meteorological infrastructure

Network

14 stations: Paroscientific, Inc. MET4A sensor

BOR1 station: NAVI Ltd. HPTL.3A and Skye Instruments Ltd. sensors
ASG-EUPOS: example of meteorological observations

WROC: daily data

BOR1: weekly data

http://www.igig.up.wroc.pl/SPGPS/

IMGW synoptic stations

Network

Sniezka

Jelenia Gora

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Microwave Radiometers (proposal)

Network

MP-3000A Microwave Radiometer (http://www.radiometrics.com)

Example: Measurement Microwave profiler vs. Radiosonde at Lindenberg Meteorological Observatory (http://www.dwd.de)
IMGW meteorological radars

**Network**

Radar Swalwin
Radar Gdańsk
Radar Legionowo
Radar Poznań
Radar Pastewnik
Radar Ramża
Radar Brzuchania

**Principle**

- Radar signal is dispersed from particles of water inside the cloud.
- The echo is proportional to the size of droplets.
- Wind speed is derived from Doppler frequency.

**Results:** map of radar reflectivity in the center of Poland thick cloud layer.
Scheme of model constriction

- IGS/EPN NRT products
- ASG-EUPOS GNSS observations
- ASG-EUPOS station meteo observations $p, T, h$

- NRT ZTD estimation system
- NRT IPWV determination system
- NRT ZWD
Integration and validation of meteorological data procedure

Methodology

- Pressure and temperature at the reference stations
  - Estimate long term linear trend
  - Pressure and temperature reference differences
- Coefficient to multiple reference random error
  - Compare in wavelet domain cmor 1-1
  - Bias
- Pressure and temperature at all investigated stations
  - Estimate long term linear trend
  - Shift between investigated and reference with the use of standard pressure and temperature gradients
  - Pressure and temperature at the investigated differences

Network

Results: bias and correlation

Investigated station: KPN

Investigated station: 559Kark

Investigated station: IV3W_JG

Investigated station: 559Kark

W = 1.0146

W = 3.7919
The COAMPS model operated on computer cluster FENIX in Applied Geomatics Section of Military University of Technology in Warsaw. The model structure is based on 30 terrain following layers calculation layers. In our case the domain has been limited to 133 x 169 nods with horizontal resolution of 1.44 km. The target time step is 1 hour.
Verification and integration of COAMPS model

Methodology

\begin{align*}
\sum_{i=1}^{n} s_i W_i & = \overline{s} \\
\text{Temperature:} & \hspace{1cm} s \leftarrow T \\
& \hspace{1cm} w_i = (h - h_i)^{-4}
\end{align*}

\begin{align*}
\text{Humidity:} & \hspace{1cm} s \leftarrow H \\
& \hspace{1cm} w_i = [(x - x_i)^2 + (y - y_i)^2 + (h - h_i)]^{-2}
\end{align*}

\begin{align*}
\text{Pressure:} & \hspace{1cm} s \leftarrow P \\
& \hspace{1cm} w_i = [(x - x_i)^2 + (y - y_i)^2]^{-1} \\
\log P_i &= \log P_{COA_i} + \frac{h_i - h}{18400(1 + \frac{T_i + T_i}{546})}
\end{align*}

Results

\begin{align*}
\text{mean} = -0.25; \quad \sigma = 2.12
\end{align*}

\begin{align*}
\text{mean} = 0.01; \quad \sigma = 0.68
\end{align*}

\begin{align*}
\text{mean} = 2.85; \quad \sigma = 0.5
\end{align*}
Model construction

Methodology

- Voxel model construction
- GPS observations on the Karkonosze Network
- On-site meteorological measurements
- ZTD estimation
- ZTD determination
- SWD = m*(ZTD-ZHD)
- The scanning rays retrieval
- Refraction Nw determination from SWD = A*Nw equation
- Inverse solution
- Gradient calculation
- Recalculation from refraction to humidity
- COAMPS model output
- The tomography model output
- Verification

Conditions

- GNSS and meteorological data acquisition
- Tropospheric delay estimation
- Scanning rays retrieval
- Inverse solution
- Verification with the use of COAMPS data

Results:

The tomographic solution from GNSS derived SWD (green), against reference wet refractivity from COAMPS at the center points of tomographic model (blue), epoch:38
Conclusions 1

**Introduction**

**GNSS and meteorological data**

**4D NRT atmosphere model model**

**Conclusions**
Conclusions 2

1. Integration and validation of different types of meteorological, GNSS data, atmosphere models guarantee the complete supply of NWP models.

2. Different ways to estimate Zenith Tropospheric Delay lead to similar results, which shows that the GPS system may be used as a meteorological data source.

3. GNSS tomography is the way for description of the state of troposphere. The proposed model based on the minimum constraints solution and the results are validated with the help of simulated weather conditions.

4. Future works will utilize the integrated meteorological and GNSS data to obtain the real 4D structure of troposphere.
Thanks for your attention

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