Sofia University GNSS Analysis Center (SUGAC)

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SUMMARY

The Sofia University GNSS Analysis Centre (SUGAC, suada.phys.uni-sofia.bg) is a new analysis centre established via collaboration between the Department of Meteorology and Geophysics of Sofia University, the IPOS - BuliPOS GNSS network in Bulgaria, the University of Luxembourg and the Space Research and Technology Institute at the Bulgarian Academy of Sciences. In April 2014, the first processing campaign took place. One year of GNSS data from 7 stations of the BuliPOS network were processed in collaboration with the University of Luxembourg. Tropospheric products (Zenith Total Delay and gradients) with 5 min temporal resolution were obtained using the NAPEOS software, developed by ESA. The tropospheric products from this campaign were then used for validation of the Weather Research and Forecasting (WRF) model as well as for case studies during intense precipitation events and fog. In this work the WRF model validation for Bulgaria will be presented. Future work will be the establishment of autonomous near real-time processing of the regional ground-based GNSS network in Southeast Europe in support of the EUMETNET E-GVAP and COST ES1206 ”Advanced Global Navigation Satellite Systems for Severe Weather Events and Climate” projects.

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1. INTRODUCTION

Application of GNSS for atmospheric remote sensing is a well established research field in Europe. As a part of the EUMETNET program E-GVAP (http://egvap.dmi.dk) data from over 2000 ground-based GNSS stations, are provided to the National Meteorological Services. The data is collected and processed by 17 GNSS Analysis Centers and tropospheric products are provided within 90 minutes after the observation and used for monitoring the state of the atmosphere. None of the Analysis Centres delivering tropospheric products for E-GVAP services is from South East Europe. In 2014, after signature of a national agreement for data exchange between Sofia University and the Bulgarian BuliPOS GNSS network the Sofia University GNSS Analysis Centre (SUGAC) was established. SUGAC is the first GNSS Analysis Centre in South East Europe targeting atmospheric monitoring with the tropospheric products from the ground-based GNSS networks in the region. In collaboration with the University of Luxembourg and with support from COST Action ES1206 "Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate" (GNSS4SWEC) the first processing campaign took place in 2014. This paper reports the results of the first SUGAC processing campaign for Bulgaria. Tropospheric products are used for inter-comparison with a Numerical Weather Prediction Model (NWP), presented is also comparison of IWV from GNSS and NWP.

2. METHODS

2.1 SUGAC processing strategy

The SUGAC is the first analysis center in Bulgaria and South-East Europe, focused on GNSS derived tropospheric products and NWP validation using GNSS derived tropospheric products. The center uses GNSS data, provided by the BuliPOS ground-based GNSS network in Bulgaria. GNSS station BURG, which is monitored in this work, is situated at the Black Sea coast of Bulgaria and at altitude 72 m asl.

The NAPEOS version 3.3.1 software (developed by ESA) was used for the processing of the GNSS data. The processing was performed using Global Mapping Function (GMF) *(Boehm et.al. 2006)* and 10^o elevation cut-off angle. The NAPEOS software allows multi-GNSS processing, but only GPS data were analysed in this study. The station was processed using the Precise Point Positioning (PPP) strategy, employing IGS satellite orbit and clock products and included data for 2013.

2.2 WRF processing

The Weather Research and Forecasting (WRF) *(Michaelakes et.al., 2004)* is a fully compressible, and nonhydrostatic model (with a runtime hydrostatic option). It uses a terrain-following hydrostatic pressure vertical coordinate. The model uses the Runge-Kutta 2nd and 3rd order time integration schemes, and 2nd to 6th order advection schemes in both horizontal and vertical directions. It uses a time-split small step for acoustic and gravity-wave modes. The dynamics conserves scalar variables *(Skamarock et.al. 2008)*. The model has been jointly developed by the National Center for Atmospheric Research (NCAR), the Forecast Systems Lab oratory and the National Centers for Environ-mental Prediction of the National Oceanic and Atmospheric Administration (FSL, NCEP/NOAA) and the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma. The used parametrizations are: Unified Noah land-surface model for the land surface (LS) *(Chen and Avissar, 1994)*; YSU scheme for the planetary boundary layer (PBL) (*Xiao-Ming et.al., 2010*) WSM 6-class graupel scheme for the microphysics (MP) (*Hong et.al., 2010*) RRTM/RRTMG (Rapid Radiative Transfer Model) for the long-wave/short-wave radiation. The used version of the WRF model is V3.4.1 with spatial resolution- 9km, vertical resolution- 44 levels (up to 20 km), temporal resolution- 30 min Initial and boundary condition from GFS Model for 6 hours. The processing was performed without data assimilation

The domain of the model covers the territory of Bulgaria, as well as partly Greece, Macedonia, Serbia, Romania and Turkey, as shown in figure 1.

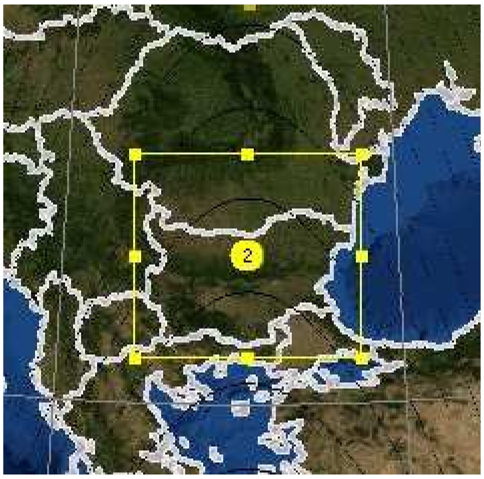

Figure 1: Domain of the WRF model, used in SUGAC. The yellow lines mark the borders of the domain

2.3 Derivation of GNSS tropospheric products

The Zenith Total Delay (ZTD) is the sum of the Zenith Hydrostatic Delay (ZHD) and the Zenith Wet Delay (ZWD). The ZHD is dependant on hydrostatic pressure and temperature, as suggested by *(Elgered et.al. 1991)*:

$$ZHD = (2.2768 + 0.0024)\frac{p_s}{f(h,\theta)}$$

$$f(h,\theta) = 1 - 0.00266cos(2\theta) - 0.00028h$$

where p_s is local surface pressure and $f(h,\theta)$ is a factor, dependent on altitude h and the latitude variation of the gravitational acceleration θ.
The pressure at the GNSS station altitude is calculated from the model pressure at the nearest model node. The pressure difference between the GNSS station altitude and the nearest NWP model node is calculated using the polytropic barometric formula *(US Standard Atmosphere, 1962)*:

$$P_g = P_m\left(\frac{T}{T - L(H_g - H_m)}\right)^{\left(\frac{g_0 M_0}{R^* L}\right)}$$

where P_g is the pressure at the GNSS station altitude, P_m is the pressure at meteorological station altitude, T is the temperature in meteorological station, $L=-6.5K/km$ is tropospheric lapse rate, H_m is the altitude of the meteorological station, H_g is the altitude of the GNSS station, $g_0=9.81m/s^2$ is the gravitational acceleration, $M_0=28.9g/mol$ is the molar mass of air and $R^*=8.31432N\cdot m/(mol\cdot K)$ is the universal gas constant.
The IWV is then calculated using the following method:

$$ZWD = ZTD - ZHD.$$

$$IWV = \frac{10^6}{(k_3/T_m + k_2')R_v}ZWD$$

where k_2, k_3 and R_v are constant and T_m is the weighted mean atmospheric temperature.

The calculation of IWV from the GNSS tropospheric products was performed in 30 minute intervals for the GNSS+WRF dataset. The resolution of the GNSS tropospheric products is 5 minutes and the resolution of the model data is 30 minutes. The calculation of IWV for the GNSS+SYNOP combination is performed with 3 hours resolution. The reduced resolution is caused by the low SYNOP time resolution.

The GNSS data in the interval [-15min;+15min] around single data point in time t was

$$ZTD^t_{avg} = \frac{1}{n}\sum_{i=1}^{n} ZTD_i\Big|_{t-15min}^{t+15min}$$

averaged for both datasets:
IWV was calculated from the averaged ZTD values.

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2.4 Derivation of IWV from WRF

The IWV calculations from the WRF datasets were performed using the relative humidity, temperature and height above the WRF node in Burgas. The data is transformed into IWV using the following formula:

$$IWV = \sum_{i=1}^{n-1} \frac{\frac{P_v^i}{R_v T^i} + \frac{P_v^{i+1}}{R_v T^{i+1}}}{2} (z_{i+1} - z_i)$$

where n is the number of layers in the model (in this case 44 layers), P_v is the water vapour pressure, T is temperature, R_v is specific gas constant for water vapour, z is the altitude of the datapoint.

3. RESULTS

3.1 Pressure comparison between WRF and measurements

In figure 2 the WRF modeled and SYNOP observed pressure is presented. Very good agreement is seen between the two datasets. The correlation between the datasets is 0.995 with mean difference 0.9 hPa, which is more than expected.

3.2 IWV comparison

Three IWV datasets are compared in this section. The Modeled IWV dataset uses only computations performed with the WRF. The Observed dataset uses data from GNSS and meteorological stations near Burgas. The Hybrid IWV dataset is calculated by using data from GNSS station Burgas and pressure and temperature from the WRF model.

In the analysis of the year 2013 the correlation between the Hybrid and the Model datasets is very high, 0.956. The seasonal cycle of IWV is well presented with minimum in the winter months and maximum during summer. The difference between the datasets is 1.7mm. (shown in figure 3, bottom). Most of the points, where large differences between the Model and Hybrid are observed, are outliers. These outliers are due to lack of data during the GNSS processing campaign. The NAPEOS software uses the previous coordinate estimation for station Burgas as apriori information for the next period of time. When data is missing, the lack of apriori data causes the solution to be inaccurate. The comparison between the Observed and Modeled datasets show small difference in IWV – 0.3mm.

The diurnal IWV cycle reveals the difference in water vapour characteristics for 2013. A noticeable difference in the beginning of each day is observed between Hybrid and Observed IWV on one hand and the Model on the other (shown in figure 4). This could be caused by either the high influence of the initial conditions in the beginning of each day for the model water cycle, or by the instability of the GNSS solution at the day boundary. This difference in the behaviour of the datasets will be further investigated.

4. CONCLUSION

The GNSS processing in SUGAC was performed using NAPEOS software from ESA with PPP strategy in 365 individual day procesings. The generated data were used for validation of the WRF NWP model. Analysis of three different datasets has been performed: Modeled from WRF, Observed (combination of SYNOP and GNSS) and Hybrid (Combination of WRF and GNSS)

The analysis of the pressure, computed by WRF shows very high correlation (above 0.99) with the measurements. The difference in the pressure mean values between the two datasets is 0.2 hPa.

The WRF model simulations of IWV over station Burgas for 2013 show very good agreement with the measurements. The correlation between the compared datasets is high and approximately 0.95. A significant difference in the mean values of the datasets was observed (approximately 7%).

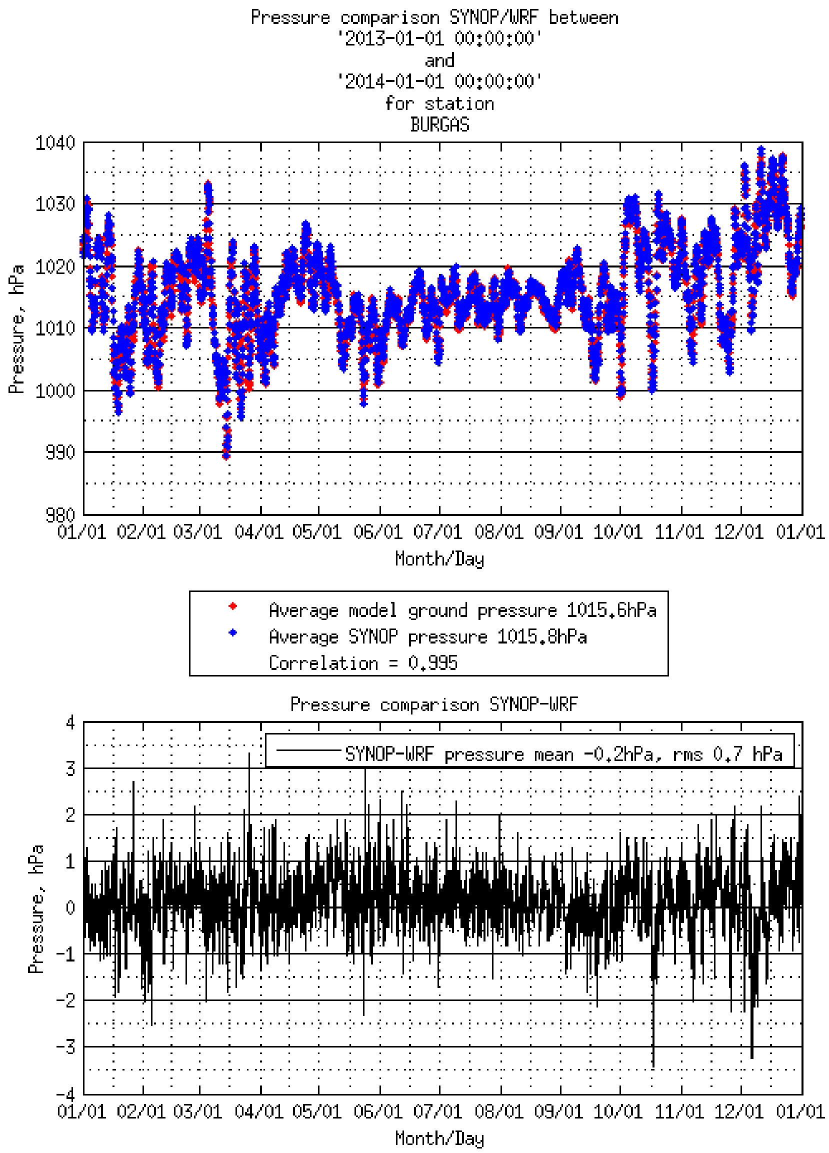

Figure 2: Pressure comparison. On the top figure (in red) - observed in meteo station Burgas, (in blue) - computed by WRF. In the lower figure - difference between the two datasets. The average differance is 0.2 hPa

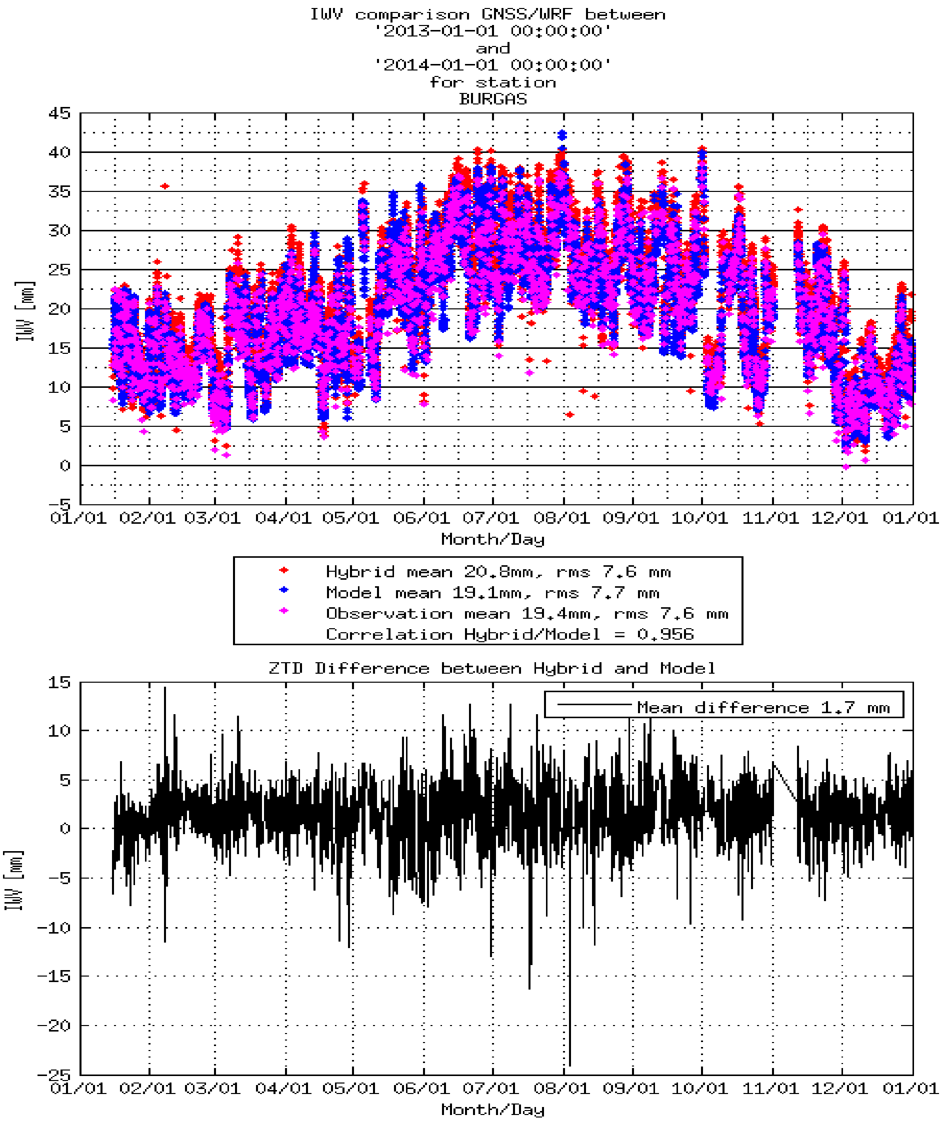

Figure 3: Top figure presents comparison of IWV computations between Hybrid in red, Model in blue and Observation in magenta. The correlation between Hybrid and Model IWVs is 0.956. The bottom figure shows the offset of the Hybrid dataset compared to the Model

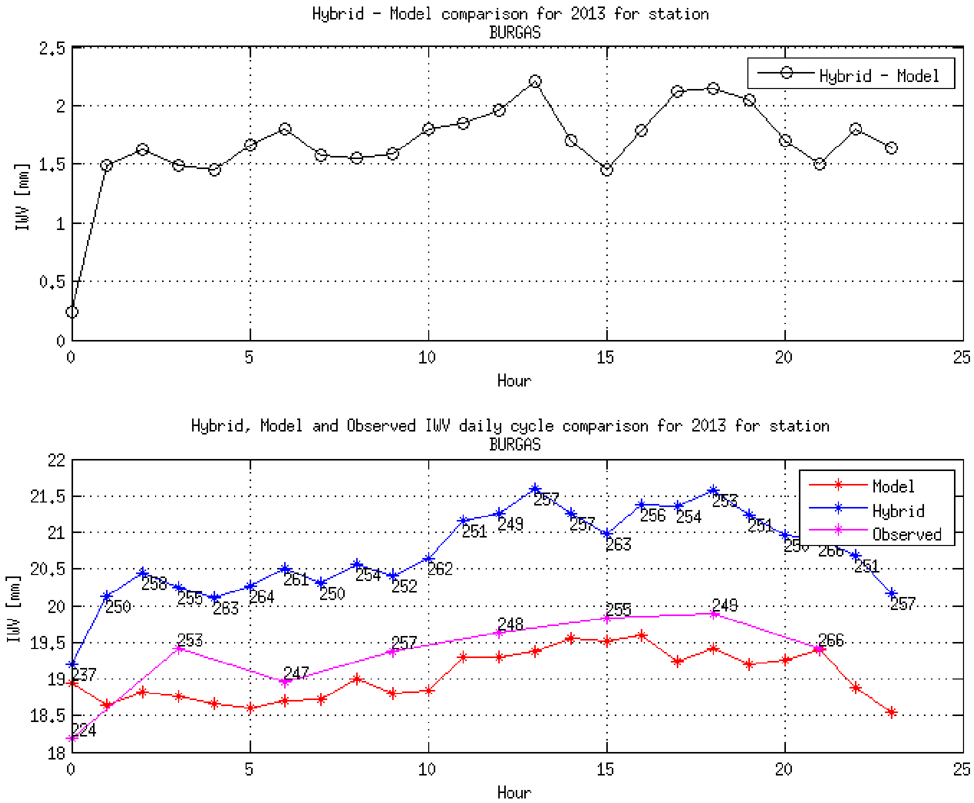

Figure 4: Daily cycle. Top - difference in IWV cycle between Model and Hybrid. Bottom - daily IWV cycle. The number of days, for which the points have been averaged is displayed around the data points. The Hybrid and Model datasets are balanced.

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BIOGRAPHICAL NOTES

Tzvetan Simeonov is a PhD student at Department of Meteorology and Geophysics of the Sofia University, Sofia, Bulgaria. He received his MSc degree in physics with honours in 2013 from Sofia University. His PhD thesis is on analysis of GNSS tropospheric product for Bulgaria. He is active science communicator and has participated and produced a number of tv reports and articles.

Guergana Guerova is an associate professor at the Department of Meteorology and Geophysics of the Sofia University, Sofia, Bulgaria. She received a MSc degree in meteorology from Sofia University and PhD in applied physics from University of Bern. Her research interest cover monitoring short and long-term variation of GNSS derived water vapour in particular for studying fog, intense precipitation, hail storm and heat waves. She is Marie Curie IRG Fellow (2011-2014) and vice chair of COST Action ES1206 GNSS4SWEC (2013-2017).

Felix Norman Teferle is Professor of Geodesy at the University of Luxembourg, Luxembourg. His research focuses on improving GNSS processing strategies and bias models for high-precision positioning while applying the technique to a range of geodetic and geophysical problems. Particular areas of interest are the monitoring of land movements in relation to sea level studies, the estimation of atmospheric water vapour and the stochastic modelling of time series.

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