Exploitation of Ground-Based GNSS for Meteorology and Climate Studies in Bulgaria/South-Eastern Europe

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SUMMARY

The Global Navigation Satellite Systems (GNSS), a new technology that revolutionised the navigation, is also proved to be an accurate atmospheric sensor of the most abundant greenhouse gas namely atmospheric water vapour. Application of GNSS in Meteorology is a well established research field in Europe and GNSS data from 1,800 stations are available for model validation and assimilation in the state-of-art models used for operational weather prediction by the National Meteorologic Services. Advances in GNSS data processing is making possible to also use the GNSS data for climatic trend analysis, an emerging new area of research both attractive and important.

As a first step towards the application of GNSS for Meteorology and Climatic studies in Bulgaria/South-Eastern Europe the Sofia University Atmospheric Data Archive (SUADA) is developed. SUADA is a user friendly database and includes GNSS tropospheric products like Zenith Total Delay (ZTD) and derivatives like vertically Integrated Water Vapour (IWV) as well as observations from Radiosonde and surface atmospheric data. Archived in SUADA are: (1) GNSS tropospheric products (over 30 000 000 individual observations) and derivatives (over 245 100) from five GNSS processing strategies and 107 stations for the period 1997–2014 with temporal resolution from 1 min to 6 h, (2) Radiosonde IWV data (over 6 000 observations) for station Sofia (1999–2012), (3) Numerical Weather Prediction model (175 000) and climate model (23 352) data and (4) observations of PBL height from ceilometer instrument (over 200 000). In this work are presented two applications of the SUADA data for study of long and short term variation of water vapour in Bulgaria/South-Eastern Europe.

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1. INTRODUCTION

Atmospheric water vapour is the most abundant greenhouse gas, accounting for 60-70 % of atmospheric warming. Atmospheric water vapour is one of the most variable and important parameters for forecasting extreme weather events and monitoring climate change, but is under-sampled in current operational meteorological and climate observing systems. As the GNSS signal travels trough the atmosphere its propagation is affected by atmospheric gases and in particular by water vapour, which has high temporal variation up to 20-30 % within a day.

Developed largely by the geodetic community remote sensing of the atmospheric water vapour with GNSS is today an established atmospheric monitoring technique GNSS-Meteorology (Bevis 1992, Guerova et al., 2015). GNSS signal propagation delay in the lower atmosphere-troposphere provides information of atmospheric water vapour. GNSS derived Integrated Water Vapour (IWV) has been proved to be a valuable data source for high resolution limited area Numerical Weather Prediction (NWP) models (Guerova et al. 2004, Vedel et al., 2004). Today in Europe, an operational service (E-GVAP, http://egvap.dmi.dk) provides GNSS tropospheric products for assimilation in NWP models and impact studies by the National Meteorological Services. In addition, GNSS-IWV is identified as a priority one measurement of the Global Climate Observing System Reference Upper Air Network (Seidel et al., 2009) of the World Meteorological Organization. Ongoing is development of the advanced GNSS tropospheric products for severe weather and climate monitoring as a part of the EU COST Action ES1206 "Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate” (GNSS4SWEC, 2013-2017, http://gnss4swec.knmi.nl).

In Bulgaria development of GNSS-Meteorology was initiated in 2011 within a Marie Curie project aimed at: (1) development a water vapour database and (2) use the data for meteorologic and climatic studies in Bulgaria/South-Eastern Europe. In this paper are presented the results of the project.

2. SUADA

The Sofia University Atmospheric Data Archive (SUADA, http://suada.phys.uni-sofia.bg) was developed in collaboration with the Institute of Applied Physics of University of Bern. The SUADA is hosted by the Faculty of Physics Linux Cluster Physon (http://physon.phys.uni-sofia.bg/). Archived in SUADA are : (1) data from ground-based GNSS networks in South-Eastern Europe, (2) regional NWP and Climate model data and (3) ground-based observations from, radiosonde and ceilometer instrument as well as in situ surface observations for the period 1997–2014 with temporal resolution from 1 min to 6 h. As of 1.1.2015 recorded in SUADA are: (1) over 30 000 000 GNSS Zenith Total Delay (ZTD) for 107 stations, (2) IWV derived from GNSS (245 100 for 32 stations), radiosonde (6 376 for one station), NWP (175 000 for 39 grid points) and Climate model (23 352 for two grid points) and (3) PBL height observations from ceilometer instrument in Sofia (over 200 000 individual observations). In Figure 1 is presented a map of the stations from which data is archived in SUADA.

The SUADA date is accessible via a web portal (http://suada.phys.uni-sofia.bg/?page_id=964) with 15 registered users, from which 9 are from Bulgaria and 6 international from Algeria, Germany, Poland (2), Romania and Turkey.

Figure 1. Map with location of the archived in SUADA: (1) GNSS stations in Bulgaria (yellow pointers), Greece (blue pointers) and South-Eastern Europe (green pointers), (2) radiosonde (red pointer) and (3) ceilometer instrument (gray pointer).

2.1 SUADA GNSS data sets

Archived in SUADA are GNSS tropospheric products from private and research GNSS networks in Bulgaria and South-Eastern Europe. The stations in these networks are permanent geodetic GNSS antennas and receivers, which are primarily used for monitoring of the movement of the Earth's crust, for ionosphere observations, as well as for observations of the state of the troposphere. The SUADA includes tropospheric products from 5 different processing namely: (1) EUREF post-processed ZTD and IWV for station Sofia (SOFI, 2001-2004), (2) IGS reprocessed ZTD and IWV for GNSS station SOFI (1997-2012), (3) CODE reprocessed ZTD and IWV for station SOFI (2001-2010), (4) ZTD and IWV from 29 stations from Zenith-geo company network in Bulgaria (since 2011) and (5) ZTD and IWV from 40 stations from GNSS network in Greece (2012).

2.2 SUADA ground based data sets

Archived in SUADA are ground based observations from: (1) in situ surface observations, (2) radiosonde and (3) ceilometer instrument.

The SUADA in situ surface observations include: 2 m surface temperature, surface pressure, relative humidity, 10 m wind direction and speed and accumulated precipitation for different time periods. The in sutu observations are sampled manually by the National Institute of Meteorology and Hydrology and are with temporal resolution 3 hours. Archived in SUADA are in situ observations from Bulgaria, Romania, Greece, Croatia, Germany and Switzerland. The data is available from OGIMET weather information server (Ogimet Weather Information Service, 2014).

The SUADA radiosonde observation record include vertical profiles of: temperature, pressure, humidity, wind speed and direction for the station Sofia, Bulgaria. The station is operated by the Central Aerological Observatory at the National Institute of Meteorology and Hydrology (NIMH) and routine daily sounding are preformed at 12 UTC. Archived in SUADA is also IWV computed for the period 1997-2012.

The SUADA ceilometer data is from an instrument CHM15k Jenoptik (1064) operated by Department of Meteorology and Geophysics of Sofia University. The ceilometrs provide observations of the height of the Planetary Boundary Layer (PBL) with temporal resolution 60 seconds. The data is used in conjunction with GNSS tropospheric products to study the PBL dynamics.

2.3 SUADA model data sets

Data from a regional NWP and Climate model are archived in SUADA. Since 2013, regular simulations with the NWP Weather Research and Forecasting (WRF) model are computed on the Physon cluster. Recorded in SUADA are one and three dimensional model output fields from 39 stations from Bulgaria for the 2010-2013 period. They are used to derive model water vapor as well as to compute water vapour from GNSS tropospheric products. In collaboration with Hungarian Meteorologic Service the regional ALADIN-Climate model simulations for the period 2000-2007 are also archived in SUADA. The model data was compared to the GNSS derived water vapour for station Sofia.

3. WATER VAPOUR STUDIES IN SOUTH-EASTERN EUROPE

3.1 Short-term variation of IWV: fog at Sofia Airport

The accurate fog forecast is of a critical importance for the operational aviation. The operational fog forecast is based on assessment of the visibility and the low level cloud height. The current operational tools at the Sofia Airport are based on the synoptic analysis and regression methods. In this study the WRF model is used in combination with GNSS derived IWV to study the fog dynamic on 5 February 2010.

Presented in figure 2a are the observed (black lines) and modeled (color lines) of: 1) relative humidity (top plot), 2) temperature (middle plot) and wind speed (bottom plot). Until 10 UTC on 5 February the observed relative humidity is above 95 % and fog is registered at the Sofia Airport. The drop of relative humidity to 75 % at 11 UTC resulted in fog dispersion. The model (blue line) do not reproduce well the observed change in the relative humidity. The model relative humidity remains above 85 % for the day. The diurnal variation of temperature is better reproduced by the model (red line) but the differences to the observed temperature (black middle line) are in average ±2° C. The observed (black line) and modeled (green line) wind speed are in agreement up to 10 UTC.

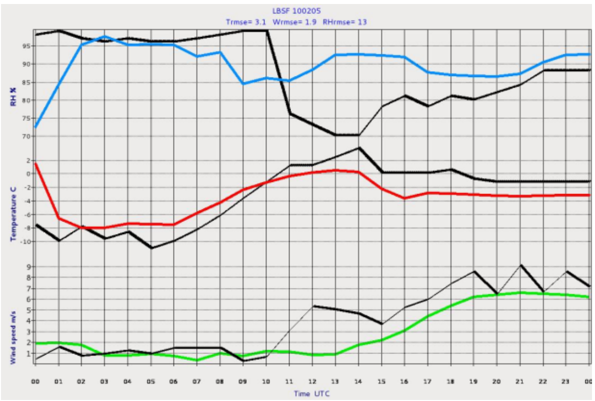

Figure 2a: Observed (black line) and modeled (color line) relative humidity (top plot), temperature (middle plot) and wind speed (bottom plot) on 5 February 2010.

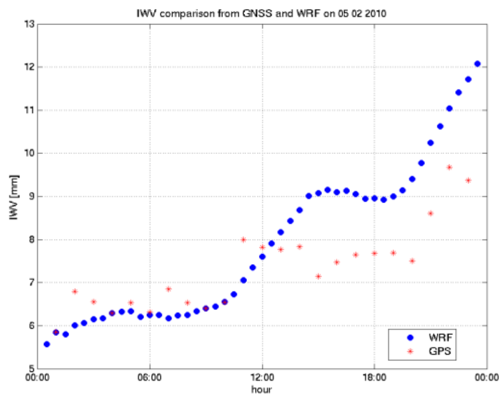

Figure 2b: GNSS IWV (red points) and model IWV (blue points) on 5 February 2010.

On Figure 2b are presented the IWV from GNSS and WRF model. Up to 10 UTC the IWV is below 7 mm. At 11 UTC and a clear increase to 8 mm is seen in GNSS-IWV (red points). The GNSS-IWV remains about 8 mm up to 14 UTC. It is to be noted that relative humidity remains below 75 % in the same period (11-14 UTC, Figure 2a). The timing between relative humidity drop and IWV jump shows clear relationship. This can be expected as the fog dispersion resulted in evaporation of water droplets thus in higher water vapour content. After 14 UTC increase of relative humidity resulted in small decrease of IWV.

3.2 Long-term variation of IWV: 2007 heat wave

Comparison between the GNSS-IWV and the regional ALADIN-Climate IWV is presented in Figure 3. During the 2000-2007 period the IWV has well pronounced seasonal cycle with high values in summer and low in winter (Figure 3a). The model (black line) and the observations (red line) capture well the seasonal cycle. However, during the summer period bigger differences can occur (Figure 3b). During the heatwave from 19 to 25 July 2007, modeled IWV values at two model grid points (black and green line) overestimate by 10-15 mm the observed IWV (red line). The 45 day average difference is 2.5 mm and 0.7 mm against the observed 20.3 mm absolute values. Regional climate models with the boundary conditions from reanalyses cannot capture all weather patterns at all points and timesteps, but they supposed to capture these synoptic-scale events better.

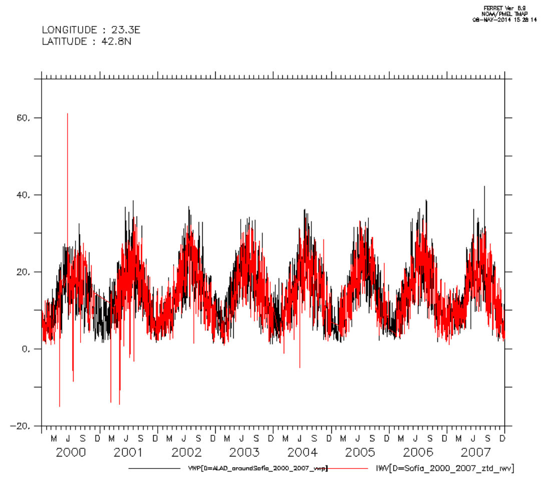

Figure 3a: Modelled (black line) and observed (red line) IWV during 2000-2007 period.

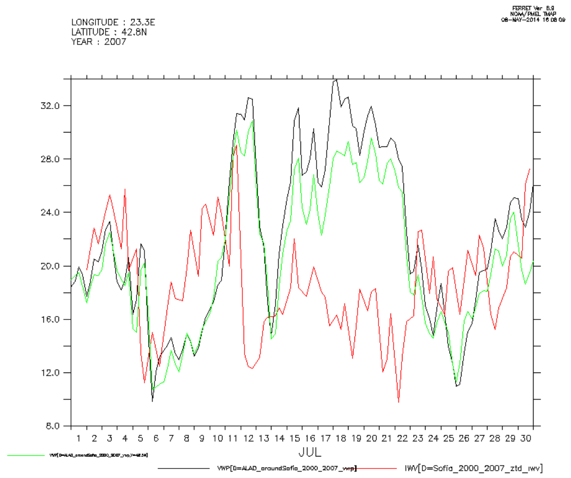

Figure 3b: Modelled (black and green lines) and observed (red line) IWV in July 2007.

4. SUMMARY

Since 2011, application of GNSS tropospheric products for meteorology and climate studies in Bulgaria/South-Eastern Europe is under development at Department of Meteorology and Geophysics of Sofia University. The work is conducted in close collaboration with the University of Bern, the University of Luxembourg and national partners. A user friendly regional water vapour database the Sofia University Atmospheric Data Archive (SUADA, http://suada.phys.uni-sofia.bg) was developed in collaboration with the Institute of Applied Physics of University of Bern. Recorded in SUADA are: 1) GNSS tropospheric products from 5 different processing, 2) Radiosonde profiles for station Sofia, 3) in situ observations, 4) ceilometer data and 5) regional NWP and Climate model data. The SUADA data is accessible via web portal.

The SUADA data is used for meteorology and climatology studies of the short- and the long-term variation of IWV derived from GNSS. The short-term variation cover application of GNSS-IWV for fog diagnosis on 5 February 2010. The fog dissipation is well captured by the decrease of relative humidity and increase of GNSS-IWV. A 8-year comparison between IWV from GNSS and ALADIN-Climate model shows well pronounced seasonal cycle. During the July 2007 heat wave the model tends to overestimate the observed IWV.

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BIOGRAPHICAL NOTES

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).

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