GROUND-BASED GNSS METEOROLOGY: CASE STUDIES FOR BULGARIA/SOUTHEAST EUROPE

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ABSTRACT

To facilitate the use of the ground-based GNSS Meteorology method for meteorologic and climatic studies in Bulgaria/Southeast Europe the Sofia University Atmospheric Data Archive (SUADA) is developed. The SUADA database includes GNSS tropospheric product and derivatives like Integrated Water Vapour (IWV) from 37 stations in Bulgaria and Southeast Europe. The first application of the SUADA data is comparison between IWV from the radiosonde station in Sofia, Bulgaria and IGS-repor1 and CODE-repro2 from SOFI station. The second application of the SUADA data is for severe weather events associated with intense rainfall with frontal or convective origin. Selected and analyzed are 22 case for 2012 using the 2 dimensional maps of IWV field over Bulgaria, derived from the ZenitGEO network in combination with Meteosat products.

Key words: Global Navigation Satellite Systems (GNSS), ground-based atmospheric sounding, water vapour, intense precipitation.

1. INTRODUCTION

Water vapour is the most abundant greenhouse gas involved in the climate feedback loop. Due to its high mobility (residence time in the atmosphere 7-10 days) and constant phase transition it transports a large amount of latent heat, which is of significant importance for the global redistribution of energy in the atmosphere. In the last decade, atmospheric sounding using the Global Navigation Satellite Systems (GNSS) tropospheric products has become an established technique for measuring atmospheric water vapour. As a first step towards application of ground-based GNSS tropospheric products in operational meteorological and climate observing systems in Bulgaria/Southeast Europe the Sofia University Atmospheric Data Archive (SUADA) was developed. SUADA is a platform for archiving GNSS data on an ongoing basis. Currently, SUADA (http://suada.phys.uni-sofia.bg/) includes GNSS tropospheric products and derivatives like IWV from 5 processing strategies and total of 37 stations for the period 1997-2013. In addition, IWV from the Radiosonde station Sofia in Bulgaria and from Numerical Weather Prediction (NWP) model is archived. The envisaged applications include: (1) cross-validation of ground-based and satellite observations and derivation of systematic biases; (2) validation of NWP models used for research and operational forecast; (3) study of water vapour distribution in Bulgaria/Southeast Europe; (4) detection of long term water vapour trends in Bulgaria/Southeast Europe and links to heat waves, droughts and changes in the pathway of the Atlantic Cyclones; (5) study how well state-of-the-art climate models, notably the one participating in Intergovernmental Panel on Climate Change (IPCC) AR5 assessment, simulate present climate of Bulgaria/Southeast Europe. SUADA was developed in close collaboration with the Institute of Applied Physics, University of Bern (IAP-UniBe) Switzerland. Since 2001, IAP-UniBe operates the STARTWAVE (STudies in Atmospheric Radiative Transfer and Water Vapour Effects) database. STARTWAVE database Morland et al. (2006a) was used for studies covering: (1) validation of two operational NWP models used in MeteoSwiss Guerova et al. (2003), (2) comparison with the 40 year reanalysis data (ERA40) of the European Centre for Medium Range Weather Forecasting Morland et al. (2006b) and (3) evaluation of the ECHAM5 climate model. In addition, STARTWAVE was used for instrumental intercomparisons, the major result being 1) detection of day-time bias in the radiosonde observations Guerova et al. (2005) and 2) instrumental problems at the high altitude station Jungfraujoch Guerova et al. (2003). Morland & Matzler (2007) found a consistent positive IWV trend in Switzerland.

2. SUADA DATA-SETS

SUADA is developed using the Structured Query Language (SQL). Uploaded in SUADA are raw observations from Radiosonde station in Sofia, Bulgaria and GNSS tropospheric products from 37 ground-based stations in Bulgaria/Southeast Europe (figure 1). From both Radiosounde and GNSS the Integrated Water Vapour (IWV) is derived by integration of the Radiosonde profile and using surface pressure and temperature for GNSS as suggested by Bevis et al. (1992) and Emardson et al. (1998).

2.1. GNSS data-set

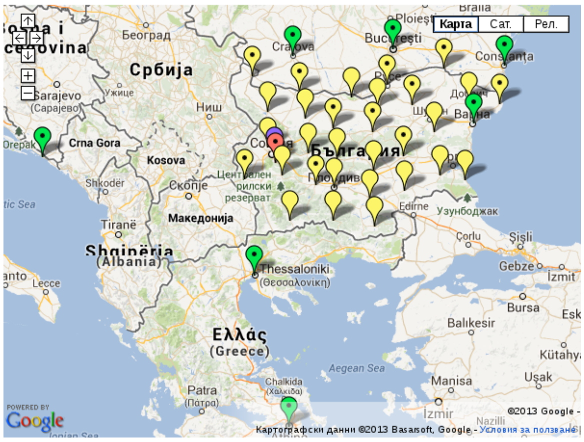


Figure 1. SUADA GNSS stations in Bulgaria/Southeast Europe.

Currently SUADA has 5 GNSS tropospheric data-sets processed with different software and strategies (table 1). As seen in table 1 the GNSS tropospheric products are with temporal resolution from 5 min to 6 hours. The SOFI IGS station in Sofia Bulgaria (red pointer in figure 1) has been processed since 1997. The first GNSS data-set is IGS-repro1 (IGS-repro1 Rebischung et al. (2012)). Archived in SUADA are IGS-repro1 tropospheric products (Zenith Total Delay - ZTD) and derivatives (Zenith Hydrostatic Delay - ZHD, Zenith Wet Delay - ZWD and IWV) for station SOFI for the period 1997-2007. The second GNSS data-set (CODE-repro2) is the contribution of the Center for Orbit Determination in Europe (CODE, http://igscb.jpl.nasa.gov/igscb/center/analysis/code.acn) for the second IGS reprocessing campaign (Meindl et al. (2012)). The tropospheric products are with 2 hour resolution for the period 2001-2010. The third GNSS data-set in SUADA is produced by European Reference Frame (EUREF). Tropospheric parameters are estimated on a weekly basis (post-processing mode EUREF-post) with 2 hourly sampling rate. In SUADA are uploaded SOFI tropospheric products from 2001 to 2004 processed by the BKG (Bundesamt fr Kartographie und Geodsie) Analysis Center in Germany. The forth GNSS data-set is provided by a private company ZenitGEO (http://www.zenitgeo.com/home_en.html). Since 2009, the company operates a GNSS network with 30 GNSS stations, evenly distributed over Bulgaria (marked by yellow pointers in figure 1). ZenitGEO tropospheric products are also with very high temporal resolution of 5 min. The fifth GNSS data-set is a targeted processing performed by Dr. Kenarka Vasilleva (Balkan) for the period 19-26 2007. Uploaded in SUADA is data from 8 stations in Southeast Europe (marked green pointers in figure 1).

2.2. 2D maps of GNSS water vapour

The dense GNSS network of ZenitGEO is used to produce 2 dimensional maps of IWV. The suggested by Morland & Matzler (2007) altitude correction is applied:

$$IWV(0.5) = a * IWV(h) * exp[\frac{h - 0.5}{H}] \quad (1)$$

where: $IWV(0.5)$ is IWV at altitude 500 m, $IWV(h)$ is the estimated IWV at altitude h, a is empirically derived coefficients and H is scale height. This correction is applied to 11 stations from the ZenitGEO network at altitude between 36 and 542 m. The 2D IWV maps are used for convection case studies in section 3.2.

3. CASE STUDIES

3.1. Comparison IGS-repro1 and CODE-repro2

The official IGS-repro1 and CODE-repro2 tropospheric products for station SOFI are compared to the RadioSonde (RS) in Sofia for the period 2001-2007 and 2001-2010 respectfully. On figure 3 are presented the IWV differences. Clearly seen in figure 2a is the period in 2004 with large spread of IWV difference between the IGS-repro1 and the radiosonde. No such spread is seen in figure 2b for the CODE-repro2 and RS derived IWV. This comparison clearly suggests the need for quality control of the IGS-repro tropospheric products. This work is on of the tasks of working group 3 of COST Action ES1206 ”Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)”.

3.2. Intense precipitation 2012

In collaboration with the operational weather prediction department of the National Institute of Meteorology and Hydrology 22 cases with intense precipitation in 2012 were selected. Presented here is the case on June 27, when precipitation of 74 l/m^2 is recorded at the Black sea region Kaliakra. In the period 24-27 June the air mass over Bulgaria is unstable. The weather is dynamic, changeable with cumulonimbus clouds development and precipitation with different range and intensity. The passage of the atmospheric fronts lead to temperature fall. On 26 June a cold front passes over Bulgaria and the temperatures on the 850 hPa drop from 18°C at 0000 UTC on 26 June 2012 to around 10°C at 0600 UTC on 27 June 2012. After the passage of the front the territory of Bulgaria is under the influence of a cyclone, which is situated far north over the Scandinavian peninsula. Both the high relative humidity a 700 hPa and warming in the upper troposphere facilitate the convection development. The 2D IWV maps capture well the advancement of cold front and the associated cold and dry air mass on 26 and 27

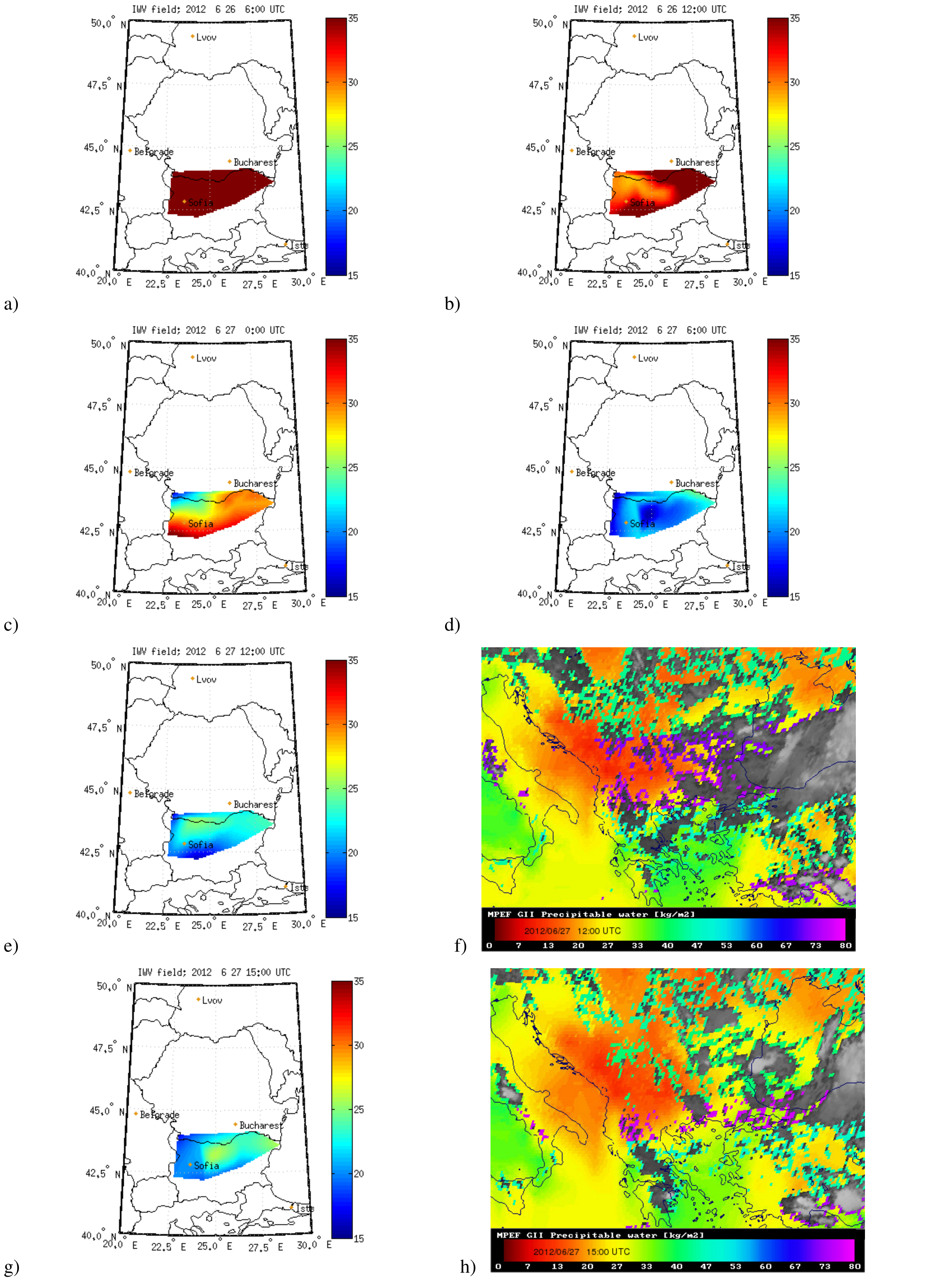
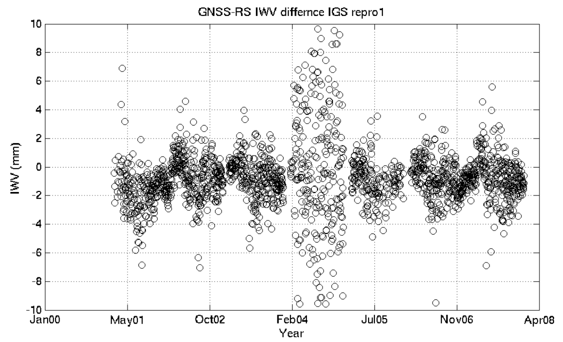


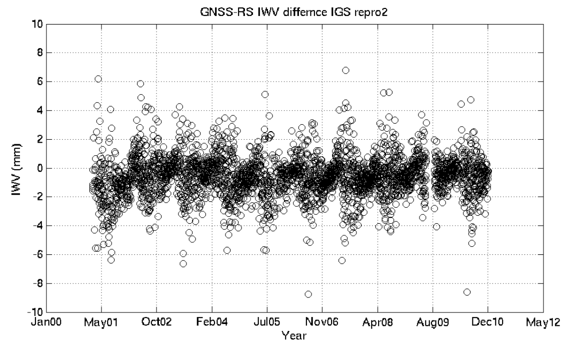
Figure 3. 2D maps of the GNSS-IWV on: a) June 26 at 0600 UTC, b) June 26 at 1200 UTC, c) June 27 at 0000 UTC, d) June 27 at 0600 UTC, e) June 27 at 1200 UTC and g) June 27 at 1500 UTC. 2D maps of the Meteosat-IWV on: f) June 27 at 1200 UTC and h) June 27 at 1500 UTC. Note the difference in the color map.

data-set name	tropospheric product	available from-to	number of stations	observation frequency
IGS-repro1	ZTD / ZHD / ZWD / IWV	07.1997-12.2007	1	5 min / 3 / 3 / 3 hours
CODE-repro2	ZTD / ZHD / ZWD / IWV	01.2001-12.2010	7	2 / 6 / 6 / 6 hours
EUREF-post	ZTD / ZHD / ZWD / IWV	04.2001-11.2004	1	1 / 3 / 3 / 3 hours
ZenitGEO	ZTD / ZHD / ZWD / IWV	11.2011- 05.2013	30 / 11 / 11 / 11	5 min / 3 / 3 / 3 hours
Balkan	ZTD / ZHD / ZWD / IWV	19-25.07.2007	8	1 / 3 / 3 / 3 hours

Table 1. SUADA GNSS data-sets as of 1.10.2013.



a)



b)

Figure 2. IWV difference between: a) IGS-repro1 and RS for 2001-2007 and b) CODE-repro2 and RS for 2001-2010.

June 2012 (figure 3). Within a day the IWV in the north Bulgaria decreased by half from above 35 mm at 0600 UTC on June 26 (figure 3a) to 15-20 mm at 0600 UTC on June 27 (figure 3d). The strong north-south gradient of IWV over the Balkan peninsula is confirmed by the Meteosat derived IWV product (figure 3f and 3h). An isolated convective cell is clearly seen at 1500 UTC in the infrared cloud cover image (figure 3h). The presented case study demonstrates the synergy between GNSS and Meteosat water vapour maps. Future work will be detailed analysis of further 20 convective situations for 2012.

4. CONCLUSION

The Sofia University Atmospheric Data Archive (SUADA) is a regional database for Bulgaria and Southeast Europe. Archived in SUADA are GNSS tropospheric products (over 12 000 000 individual observations) and derivatives (over 55 000) from five GNSS processing strategies and 37 stations in Bulgaria/Southeast Europe for the period 1997-2013. The temporal resolution of GNSS data is from 5 minutes to 6 hours. The comparison of IWV data-set from RadioSonde and IGS-repro1 shows unexpected large spread in IGS-repro1 in 2004. No such spread is observed in CODE-repro2 data-set. Using 2D water vapour maps advancement of cold front on June 26 and 27 is followed. The unstable air mass resulted in an intense precipitation of 74 l/m^2 for 6 hours at the Black sea coast of Bulgaria.

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