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Atmospheric Measurement Techniques Discussions

Interactive comment on "Evaluation of IWV from the numerical weather prediction WRF model with PPP GNSS processing for Bulgaria" *by* Tzvetan Simeonov et al.

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Dear reviewer,

Thank you for the time invested in helping us improve the presentation of our work! Please find below our response to the your recommendations (underlined text).

1.) The paper contains interesting comparisons of data. The new idea and proposal of new method or methodology have not been articulated enough AMT journal's requirement. The chapter "methodology" should be separated and included new products.

The new product, discussed in this paper is not the method, but the implementation of a combination of known methods for a new geographical area. However, we note that

this is maybe not sufficiently well articulated. Thus in the introduction is included the following text: Use of GNSS derived Water Vapour (WV) in Europe is a well established techniques but there exist a large difference on regional level (Guerova et al., 2016). While in West and central Europe the topic has reached maturity in South and particularly South-east Europe it is currently under development. Regarding the derivation of IWV we use NWP atmospheric parameters in combination with the GNSS tropospheric products, which is not widely used. Thus we include a validation of the NWP model parameters (surface pressure and temperature) in order to evaluate their accuracy and precision. In addition, a use of PPP derived tropospheric products is gaining interest among the atmospheric community, as it provides high temporal and spatial resolution for nowcasting applications (intense precipitation, hail and thunderstorms). The PPP products can be also used for evaluation of the NWP models. To the best of our knowledge, this is a first attempt to use them for NWP evaluation. Computed is also the Precipitation Efficiency, which reflects the water availability in the model and the atmosphere and even more importantly combines two components of the hydrologic cycle the IWV and precipitation.

2) The description of GNSS processing strategy is too detailed and refers to a known standard processing of GNSS data in PPP mode.

In our opinion, the PPP processing part of section 2 is balanced and gives the necessary details so thus the processing strategy is sufficiently well documented. As the Napeos software is not widely used for derivation of tropospheric products we took extra care to provide the processing parameters used.

3) The paper requires significant changes for showing the integration model not only comparisons of data from different sources.

This manuscript does not attempt to develop integration model as the number of GNSS stations is very limited (only 7) and sparsely distributed. In addition, the processing was conducted for limited time (2 weeks) which restricted the possible outcome. Evaluation of WRF model with GNSS-IWV was not done for South-east Europe. In South-east Europe the hydrologic regime is driven by Mediterranean cyclones and evaluation of model performance is further challenged by the topography of the region. This study is unlikely to be repeated in near real future or turned into a real/near real-time operational service due to lack of assessable real time data from the GNSS stations in Bulgaria.

4.) The WRF model needs reference: Skamarock WC, Klemp JB, Dudhia J, Gill DO, Barker DM, Duda MG, Huang XY, Wang W, Powers JG (2008) A Description of the Advanced Research WRF Version 3. NCAR Tech. Note NCAR/TN-475+STR, doi:10.5065/D68S4MVH;

Thank you this suggestion! The reference is included in the manuscript:

In this work the WRF v3.4.1 (NCAR, 2016; Skamarock et al, 2008) computed is computed for a domain covering Bulgaria with a horizontal resolution of 9 km and a vertical resolution of 44 levels.

5.) The same ideas integration of GNSS processing data and WRF model outputs are presented in the paper: Wilgan K., Hurter F., Geiger A., Rohm W., Bosy J. (2016) Tropospheric refractivity and zenith path delays from least-squares collocation of meteorological and GNSS data. Journal of Geodesy, DOI: 10.1007/s00190-016-0942-5, URL: http://link.springer.com/article/10.1007/s00190-016-0942-5

Thank you pointing to the paper by Wilgan et al. (2016)! The paper is recently published and we had not had the chance to study it before preparing the manuscript. In Wilgan et al. (2016) the refractivity of the atmosphere is calculated from the available meteorological and model data in order to compare ZTD values from GNSS and from the WRF model. In our study we are focused on comparing the IWV data, obtained from both the WRF model and the GNSS/WRF as we only have sparsely distributed stations as explained in our reply to question 3. However, Wilgan et al. (2016) is added in the introduction of the revised manuscript: For Poland, Wilgan et al. (2016) developed an integration model for estimating ZTD using WRF and reports good agreement

between the ZTD estimation of WRF, compared to both GNSS and radiosonde measurements.

6) The conclusions should show more progress than confirm already known from literature results. I cannot accept this publication in this form in AMT journal and major revision is required.

In the conclusion section of the revised manuscript is included new paragraph as below: The diurnal IWV cycle is investigated for Bulgaria for 2013. The diurnal variations of atmospheric water vapour affect long wave radiation, absorption of solar radiation and is related to processes such as atmospheric stability, diurnal variation of moist convection and precipitation, surface wind convergence and evapotranspiration. Thus it is important to evaluate the IWV cycle of the WRF model for Bulgaria. At all stations the models has a dry bias in the range 0.5-1.5 mm. Studies with other models show a link between IWV underestimation and overestimation of light precipitation. Such study could not be performed for Bulgaria as the precipitation observations are only available as accumulated 6 hourly values.

In order to link the IWV and precipitation the precipitation efficiency coefficient is computed at two stations. Precipitation efficiency gives the percentage of IWV converted in precipitation. The precipitation efficiency from GNSS and WRF show very good agreement on monthly bases with a maximum in May-June and minimum in August-September. The annual precipitation efficiency in 2013 at Lovech and Burgas is about 6 %, which is within the typical values range for low elevation stations in moderate and continental climates. It will be interesting to investigate the precipitation efficiency at the mountainous stations but co-location of GNSS and reliable surface observations is a limiting factor for such analysis.

Between 00 and 01 UTC the GNSS IWV tends to be underestimated, which is likely due to the processing time window used. In the beginning of each processing the GNSS solution is unstable due to lack of initial conditions. The PPP processing uses daily

IGS orbits files with jumps in the orbits on the day boundaries. These jumps influence the IWV values.

With kind regards, Tzvetan Simeonov on behalf of co-authors

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/amt-2016-152/amt-2016-152-AC2-supplement.pdf

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