Validation of Slovenian GPS ZTD observations from SIGNAL network: refined observations

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7 May 2020

Introduction

GPS Zenith Total Delay observations from Slovenian Geodetic network have been provided by Geodetic Institute of Slovenia (GIS) over the last few years, with the aim to assimilate them to the ALADIN numerical weather prediction (NWP) model. However, earlier studies showed detrimental impact on the model forecast due to excessive biases in the observations. This report provides evaluation of the latest upgrade of the observation data set, where the computation method was upgraded. ALADIN has capabilities to assimilate GNSS ZTD observations. Observations from several European geodetic institutes are available to meteorological services, for instance within the EUMETNET's E-GVAP programme (http://egvap.dmi.dk/). Those or locally received observations are already operationally assimilated in several countries (e.g. France, the UK, Germany or Hungary). At the same time, efforts to assimilate other GNSS-derived product such as Slant Total Delay (STD) are also ongoing (e.g. Imrišek, 2019).

The current sample observation dataset contains measurements from Slovenian geodetic network SIGNAL, operated by GIS, plus some data from international exchange (hereby also referred to as SIGNAL2). This evaluation is performed over 1 month of data, from 1 September to 1 October 2019.

ALADIN model configuration

Most recent operational version of Model ALADIN/SI was used for this evaluation. Details about the ALADIN model and the related long-term collaboration can be found in Termonia (2018) and Wang (2018). The model setup includes:

- ALADIN model cycle cy43t1 (ALARO-v1b package of physical parametrizations),
- 432 x 432 grid points, 4.4 km horizontal resolution,
- 87 vertical levels,
- three-dimensional variational assimilation (3D-Var) for upper-air observations, optimal interpolation (OI) for soil assimilation,
- B-matrix for assimilation based on ECMWF ensemble data assimilation (and model version cy40),
- 3-hourly assimilation cycle,
- lateral boundary conditions from ECMWF,

- conventional and satellite observations: SYNOP, AMDAR, AMV, HR-AMV, TEMP, AMSU&MHS, SEVIRI, IASI, ASCAT, Mode-S MRAR/EHS, ZTD (subject of experimentation).

The model domain and SIGNAL2 observation locations are shown in Figure 1. The observations are located mostly in or around Slovenia, with 3 additional stations in Switzerland, Germany and Slovakia.

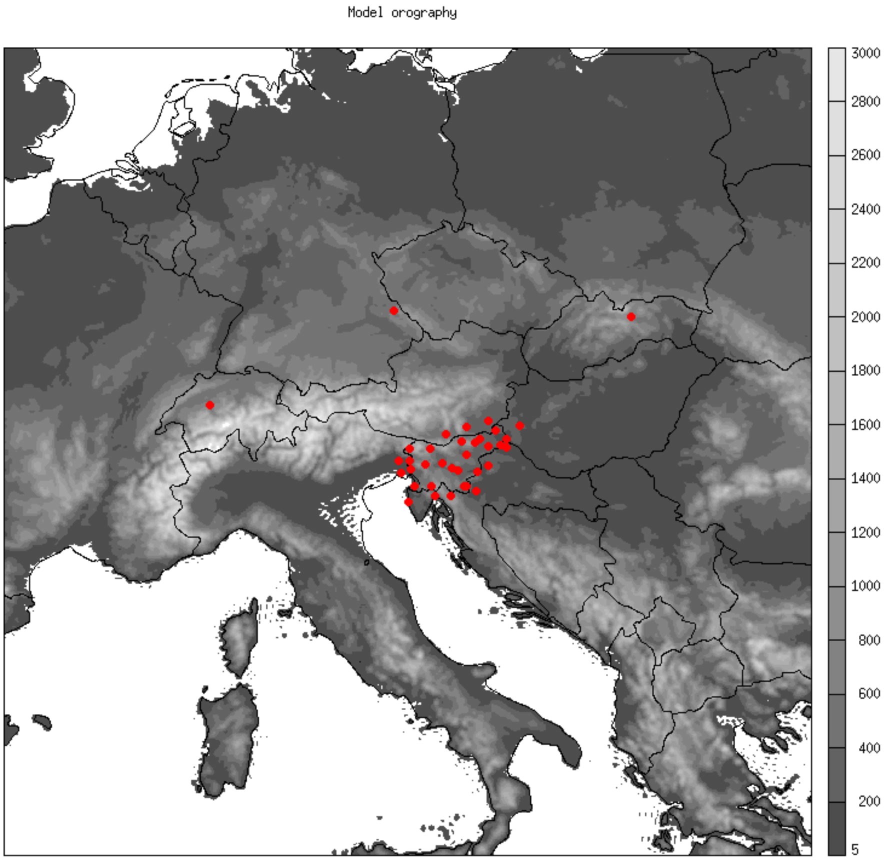

Figure 1: ALADIN/SI model domain with model orography height [m] and GNSS ZTD observations available within the SIGNAL2 dataset.

Experimental setup

The experimental setup consists of two initial experiments, an operational-like reference suite (REF) and an experimental suite (EXP) that uses SIGNAL2 data set on top of all other observations. Both experiments are initialized from operational first guess forecast valid for 1 September 2019 0 UTC. The reference experiment also includes the SIGNAL2 data set, but only in passive mode, so that the observations-minus-guess (OMG) statistics can be computed without affecting the analysis. In the EXP experiments, a variational bias correction scheme with one predictor is applied to correct for possible biases in the SIGNAL2 dataset, arising either from observations themselves or from the mismatch between the altitude of stations and the local model height. Additional experiment EXP2 repeats the EXP, except that the latest (and thus more converged) bias correction coefficients (from the end date of EXP) are applied to the initial time of EXP2 and cycled further in the assimilation process.

Results

Validation of passive assimilation

The SIGNAL observations are used passively in the EXP, so their statistics can be used for independent validation. Here we rely on the background (or obs-minus-guess, OMG) departures, i.e. the difference between 3-hour ALADIN forecast interpolated to observation location and the observed value. As OMG represents a sum of forecast error and observation error, it cannot be used as absolute measure of quality of any of those. However, by comparing OMG of different observations, one can attribute its systematic component (bias) to either model or observations. The mean OMG values in systems like ALADIN are close to zero. Figure 2 shows mean and standard deviation of OMG for all SIGNAL stations over the period of September 2019. There is a mean bias of around 0.015 m for most stations except ZALA which appears as almost bias free. The observed standard deviation is rather uniform in the interval between 0.011 and 0.015 m.

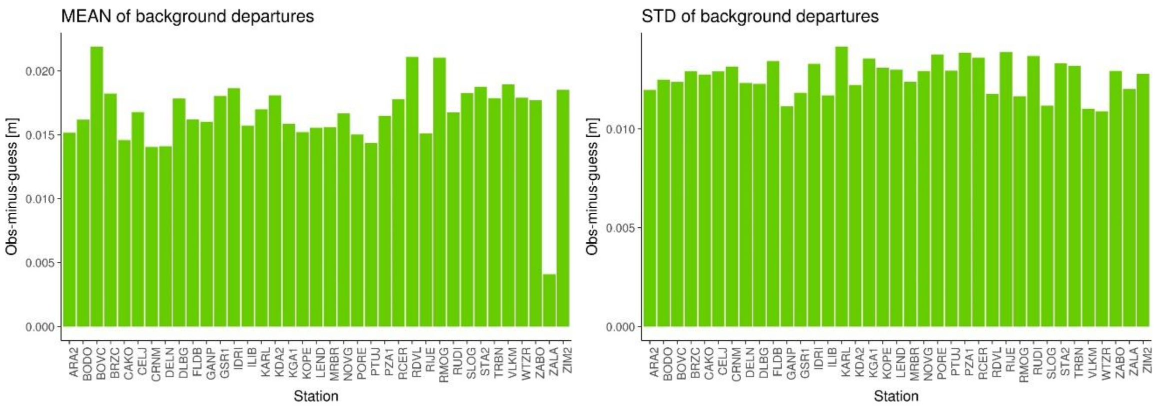

Figure 2: Mean and standard deviation of OMG for all SIGNAL stations in experiment REF (passive assimilation).

Given the typical values of ZTD observations (0.1-0.3 m for varying wet component, useful for NWP, plus 2.3 m of mostly constant dry delay), the OMG bias is not negligible and must be corrected. In the active experiment EXP, we use variational bias correction method which is able to adaptively correct biases.

Validation of active assimilation

In the experiment EXP, SIGNAL observations are used in variational minimization which aims at finding the ALADIN model state which best fits its first guess (3-hour forecasts) and observations, based on their respective error characterizations. The VarBC scheme is part of this minimization and finds an improved estimate of bias for a given observation group, separately for each analysis time. As previous estimate, the corresponding value of previous day (not the previous analysis time) is used to account for possible diurnal changes of bias.

The temporal evolution of detected bias for each of the stations at 12 UTC is presented in Fig. 3. It can be seen that the VarBC scheme progressively identifies the (positive) biases detected in REF and adds them to observed values before analysis, thus decreasing the OMG over time (Fig. 4). Although the VarBC coefficients did not fully converge by the end of the evaluation period, the bias becomes smaller after 10 September. The diurnal variability remains, which can be explained in two possible ways: either the diurnal cycle strongly affects the ZTD observations or the bias correction scheme was not (yet) equally successful for all analysis times. The net effect on OMG bias for the whole period can be seen in a summary (Fig. 5), which can be compared to Fig. 2 of REF. The mean bias is now around 0.005 m which is roughly 30 % of initial value. In EXP2, where warmed-up bias correction from EXP was applied, the mean OMG decreases further (Fig. 6).

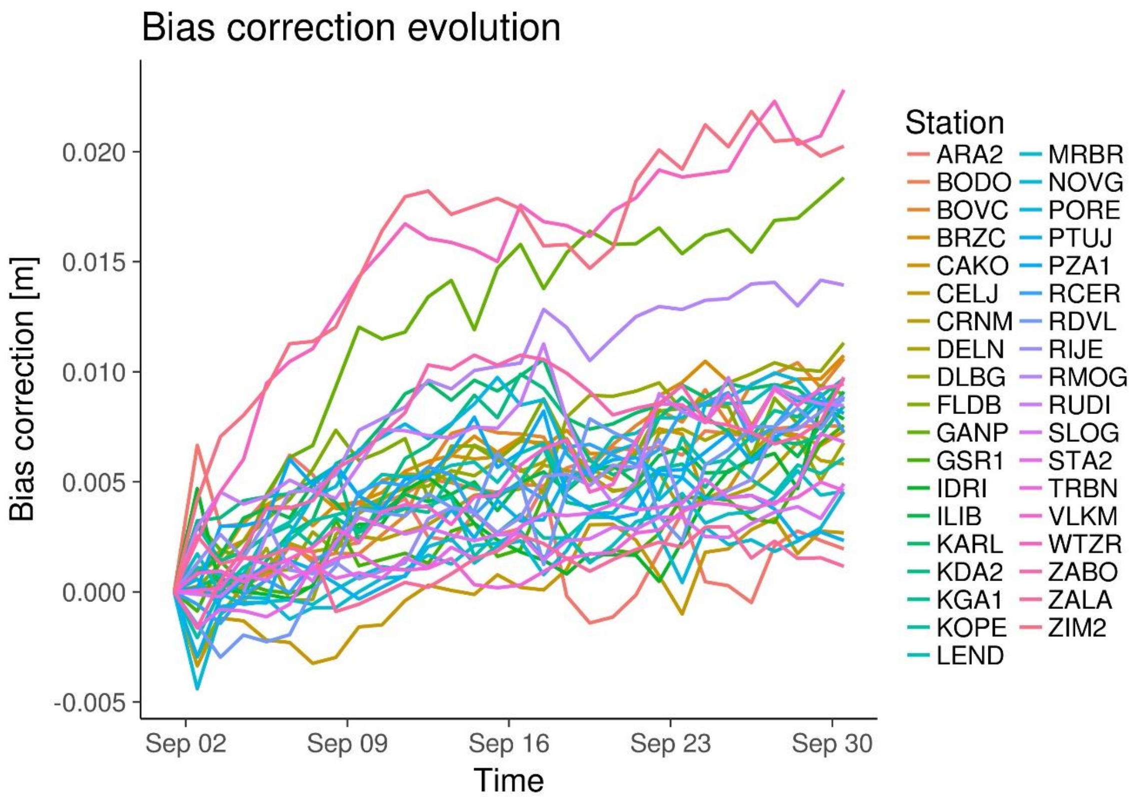

Figure 3: Evolution of bias estimate for SIGNAL observations at 12 UTC over the experimentation period. Each analysis time of day has its own bias correction.

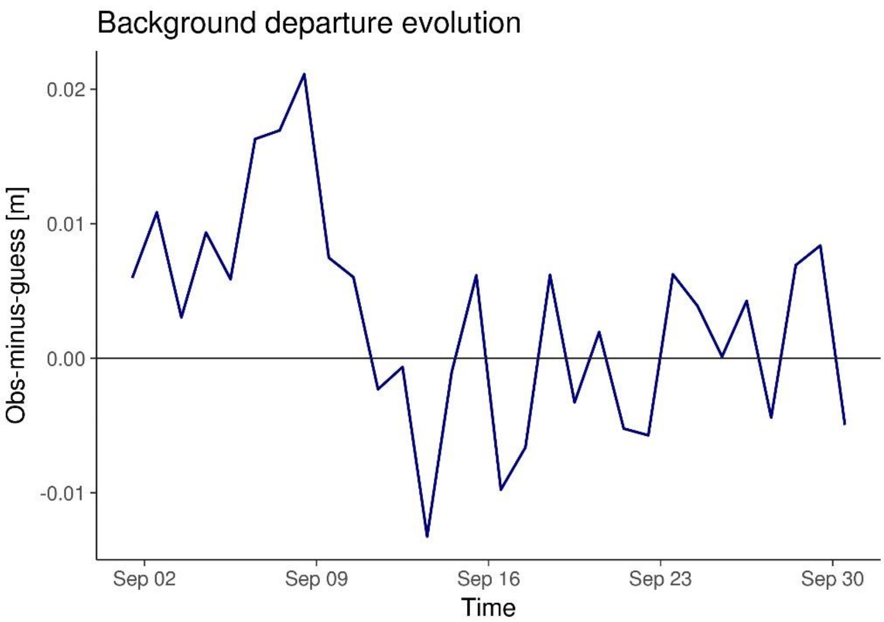

Figure 4: Evolution of OMG bias in EXP (mean over stations) estimate for SIGNAL observations at 12 UTC over the experimentation period.

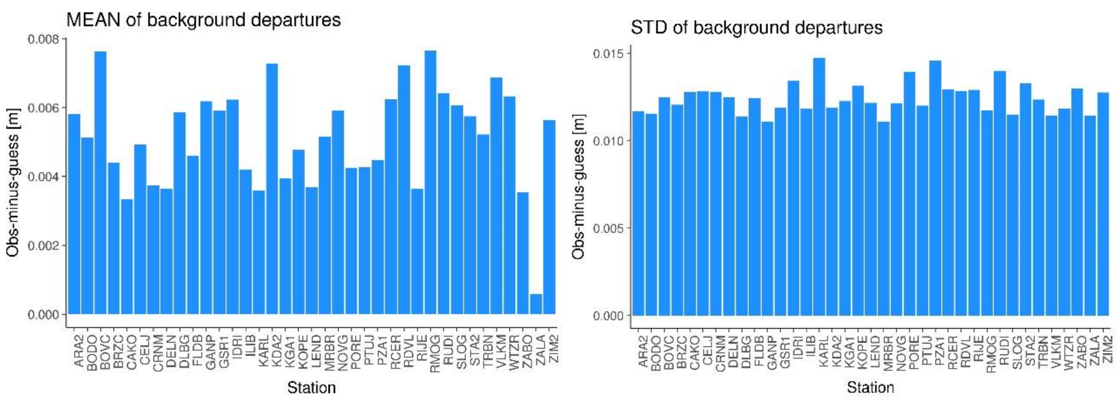

Figure 5: Mean and standard deviation of OMG for all SIGNAL stations in experiment EXP (active assimilation).

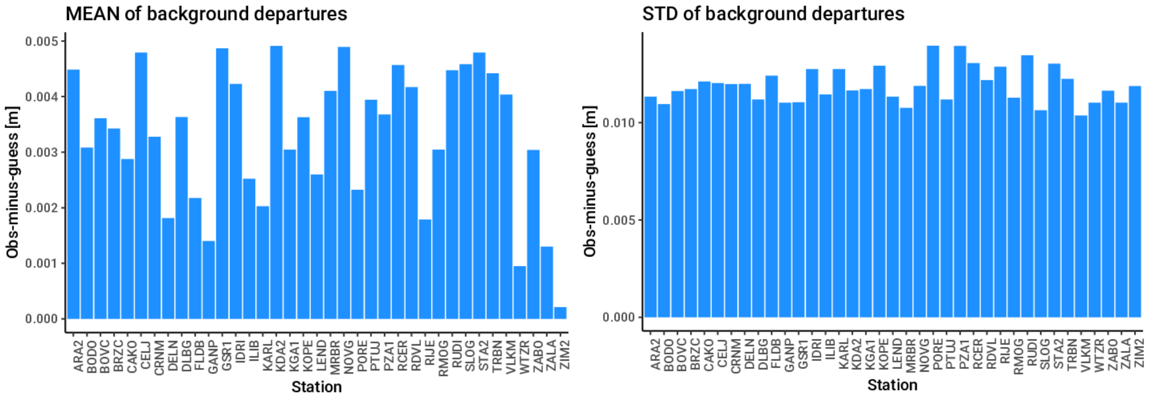

Figure 6: Mean and standard deviation of OMG for all SIGNAL stations in experiment EXP2 (active assimilation).

Impact on forecast

Impact on forecast is measured by a standard verification tool which compares forecasts of different length to surface stations and radiosonde observations. Forecasts of 24 h length are computed twice per day (0, 12 UTC) from initial conditions provided by experiments REF, EXP and EXP2. Forecast values at standard meteorological stations (SYNOP) and their profiles at locations of radiosonde measurements are computed, which finally enables computation of scores such as mean error (bias) and root mean square error (RMSE).

As impact on forecast is considered (and in fact is) small far from SIGNAL observations, only the area of Slovenia and its near surroundings is presented here (12-17°E and 44.6-47.3° N), and stations below 500 m above sea level ASL to avoid potential errors due to large model/station height mismatch.

Upper-air verification (verification is based on radiosonde measurements from Ljubljana, Zagreb, Graz, depending on time of day) suggests that assimilation of SIGNAL reduces the bias of specific humidity in the. It is important to note that EXP2 performs better then EXP, suggesting that the adaptive bias removal process did not fully converge in one month period. Vertical verification of temperature and specific humidity is shown in Fig. 7 and shows slight improvements of bias for both parameters at 850 and 925 hPa (this is approximately 1500 and 900 m ASL), while the RMSE is not significantly improved.

Surface verification (Fig. 8), on the other hand, suggests significant decrease of accuracy due to using SIGNAL2 dataset. Especially visible is systematic decrease (cold bias) of temperature and significant increase (moist) of humidity in the EXP and EXP2 compared to REF. This impacts also the RMSE, where errors of EXP, EXP2 are higher than REF for both parameters. However, EXP2 shows improvement compared to EXP. Consistent with upper-air verification, the cloudiness, which is a vertically-integrated quantity shows moderate improvement in bias during first hours of forecast.

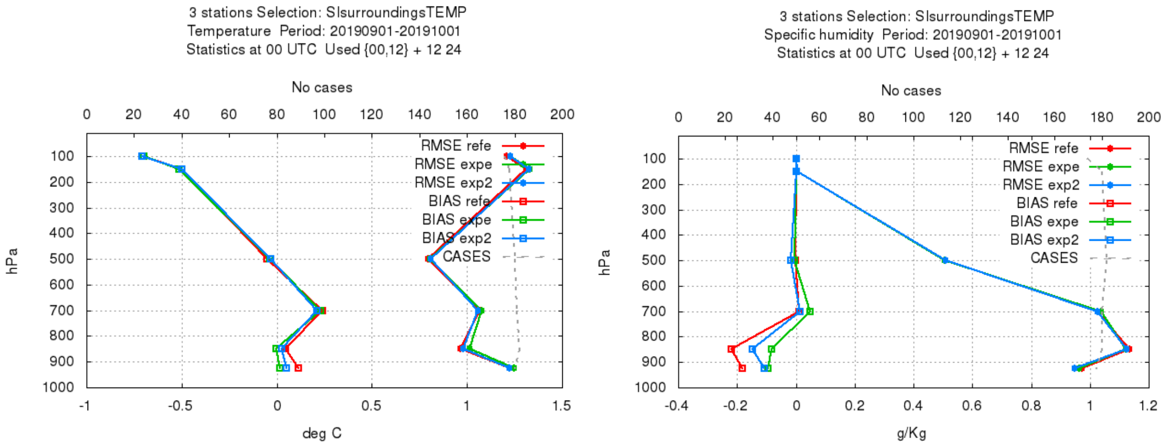

Figure 7: Verification of temperature and specific humidity profile (+12 h and +24 h forecast) against radiosonde observations: mean and RMS error for experiments REF, EXP and EXP2 (refe, expe, exp2, respectively).

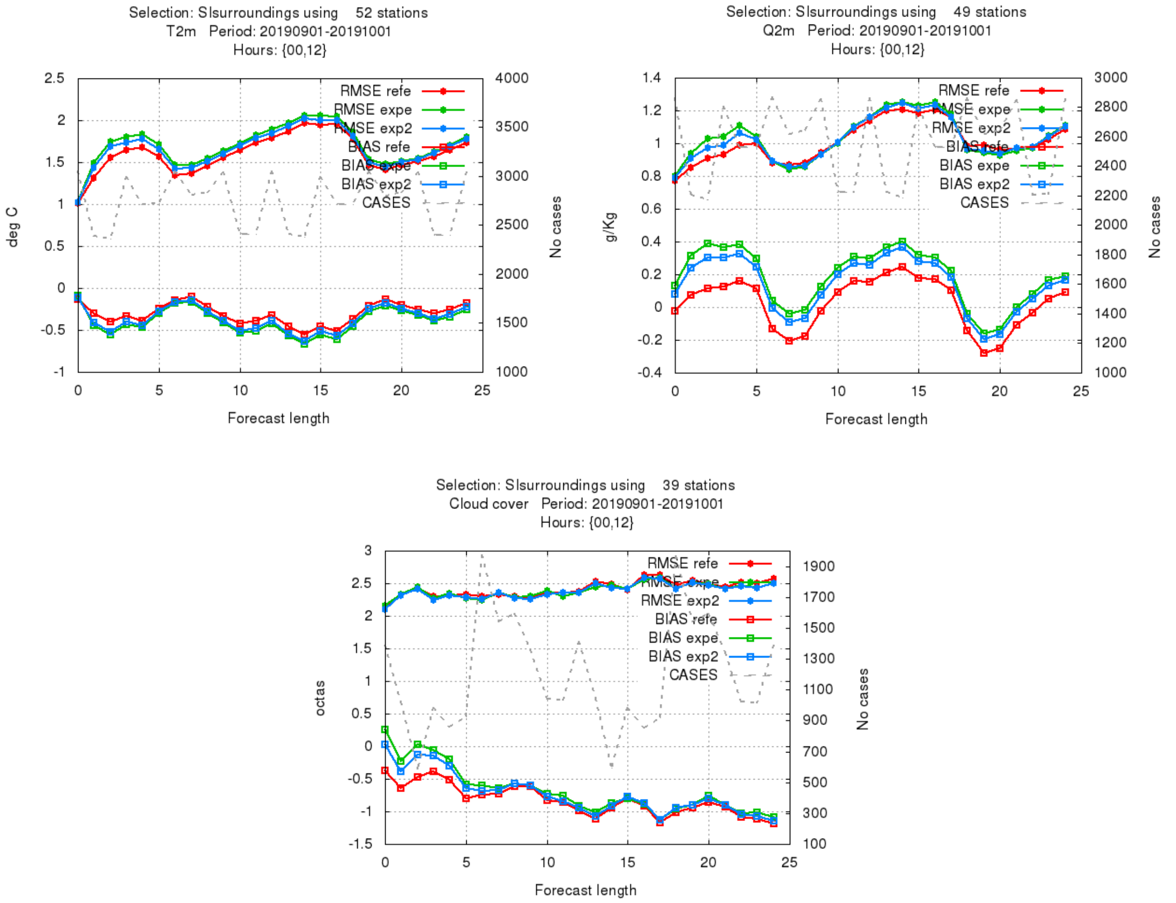

Figure 8: Verification of temperature (upper left), specific humidity (upper right) and cloudiness (bottom) against surface stations: mean and RMS error for experiments REF, EXP and EXP2 (refe, expe, exp2, respectively).

Summary and conclusions

Performance of improved SIGNAL2 ZTD observations in data assimilation system for ALADIN/SI NWP model was checked over a period of one month. In the first place, comparison of observation and the model, which is the best available proxy of the true state of the atmosphere, reveals systematic biases between SIGNAL2 and ALADIN. These can originate both from the model deficiencies or observations, and a common source of such bias is a mismatch between station height and the model terrain height. This is clearly visible for stations located in narrow valleys like BOVC (Bovec, northwest Slovenia) which also gets one of the highest bias correction in the described experiments. This issue would decrease once finer resolution NWP model is used (ARSO plans to upgrade its suite to 1.3 km horizontal resolution in the near future). However, the fact that most of the stations are biased in the same direction also suggest a remaining systematic error in calculation of ZTD.

The bias correction procedure proved to be able to detect and remove the observation-minus-model biases: mean initial ZTD bias was 0.015 m in REF and decreased to 0.005 in active assimilation (EXP) and finally to 0.003 in repeated experiment with updated bias coefficients (EXP2). The final verification suggests the process is not finished yet: the bias warming-up period should thus be extended to 3-6 months before another evaluation. The current results however suggest it is possible improve scores with longer bias spin-up. One of the main drawbacks of the current study is the lack of precipitation verification analysis, which will have to be done later.

Even though the results with ZTD assimilation are not yet fully satisfactory, the new SIGNAL2 dataset performed clearly better than the previously used dataset. The bias correction investigation suggests that a longer data set will be needed to reach optimal observation values for ALADIN/SI, and this is expected to be progressively available over time. The easiest way to achieve this is to include the SIGNAL2 dataset in operational analysis as passive observation for 3-6 months before conduction any further impact experiments.

References

Termonia, P., Fischer, C., Bazile, E., Bouyssel, F., Brožková, R., Bénard, P., Bochenek, B., Degrauwe, D., Derková, M., El Khatib, R., Hamdi, R., Mašek, J., Pottier, P., Pristov, N., Seity, Y., Smolíková, P., Španiel, O., Tudor, M., Wang, Y., Wittmann, C., and Joly, A.: The ALADIN System and its canonical model configurations AROME CY41T1 and ALARO CY40T1, Geosci. Model Dev., 11, 257–281, https://doi.org/10.5194/gmd-11-257-2018, 2018.

Wang, Y., M. Belluš, A. Ehrlich, M. Mile, N. Pristov, P. Smolíková, O. Španiel, A. Trojáková, R. Brožková, J. Cedilnik, D. Klarić, T. Kovačić, J. Mašek, F. Meier, B. Szintai, S. Tascu, J. Vivoda, C. Wastl, and C. Wittmann, 2018: 27 Years of Regional Cooperation for Limited Area Modelling in Central Europe. *Bull. Amer. Meteor. Soc.*, **99**, 1415–1432, https://doi.org/10.1175/BAMS-D-16-0321.1

Martin Imrišek, 2019: RC LACE stay report, KNMI. Available online: GNSS slant total delays in the ALADIN NWP system: Phasing of the source code from cy40h1 to cy43t2