GNSS slant total delays in the ALADIN NWP system

Phasing of the source code from cy40h1 to cy43t2

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Introduction

The Global Navigation Satellite System (GNSS) tropospheric products are becoming an important source of information of the water vapour distribution in the atmosphere. Nowadays various meteorological institutes utilize zenith total delay assimilation in their numerical weather prediction models. Next step is to utilize slant total delay data in assimilation as valuable source of information, which provides details about spatial distribution of water vapour in atmosphere. My stay at Koninklijk Nederlands Meteorologisch Instituut (KNMI) was focused on the implementation of the observation operator developed by Siebren de Haan from **cycle 40h1** to **cycle 43t2 bf10**. The main development was done in BATOR, SCREENING and MINIMISATION steps.

The Slant Total Delay (STD) is one of many derived products of the GNSS processing. The STD is an integral delay caused by refraction of the GNSS signal in atmosphere transmitted from satellite to receiver on the Earth. The schematic picture of slant total delays (denoted as SD) is displayed in Fig. 1.

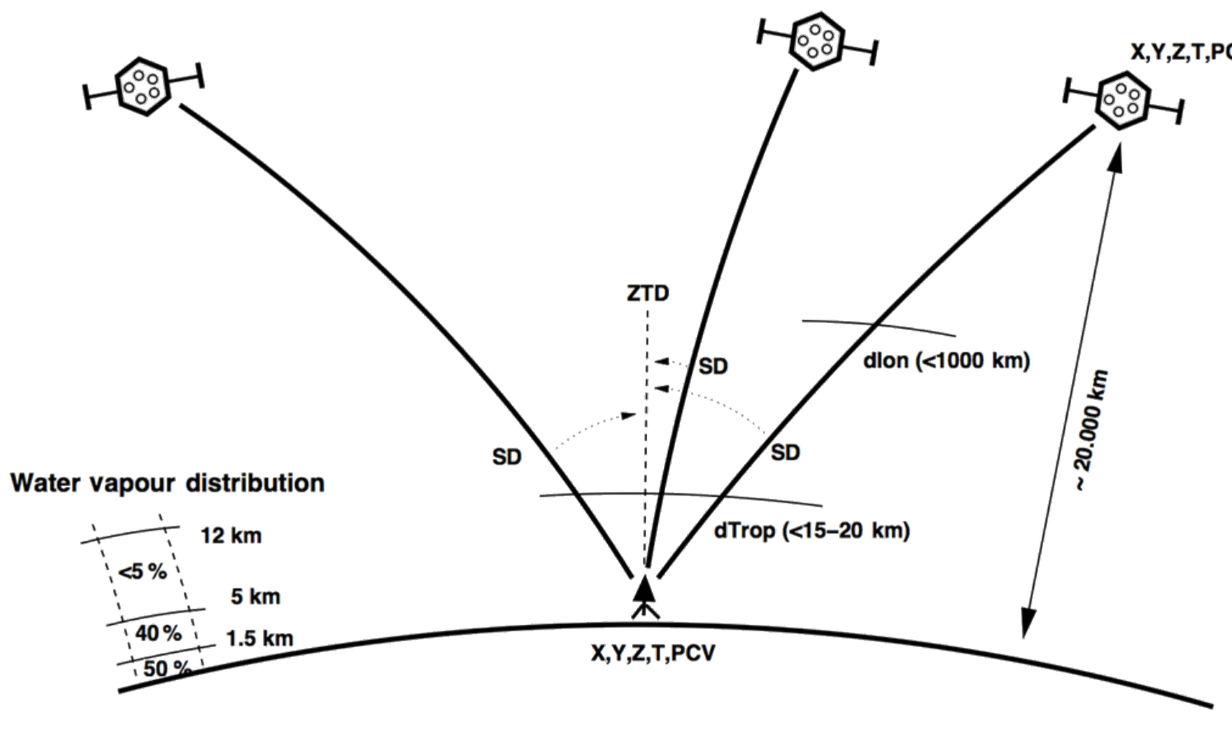

Figure 1: Schematic picture of slant total delays from Guerova *et al.* (2016).

The slant total delays for assimilation experiments were computed from GNSS near real time processing system of Department of Theoretical Geodesy at Slovak University of Technology in Bratislava. Various GNSS products are available at page space.vm.stuba.sk/pwvgraph/.

Code development in Bator, Screening and Minimisation

The latest version of source code is available at ECMWF HPC */home/ms/sk/skj/pack/-source/cy43/SlantYYYYMMDD.tar*.

The STD data are read in *bator_lectures_mod.F90* without any modification as conventional data *OBSOUL.conv*. Then the data are separated and stored to Observational DataBase (ODB) in *bator_ecritures_mod.F90*. The new observation type GNSS (19) and new observation STD (129) were added. One can follow this development by searching for variables NGNSS and NSTD in the source code.

The discretization in model space along the signal is necessary before the computation of the first guess value by observation operator H. The *mkglobstab_obs.F90* and *mkglobstab_model.F90* routines provide the discretization based on variable NOBSPROF. The default value of NOBSPROFS variable for any observation type is 1, however this value is not permitted for slant total delay observation operator. It is mandatory to introduce this variable to SCREENING and MINIMISATION namelists, the value can differ in these configurations. The computation of the slant total delay first guess value is done in the observation operator routine *gnss_slant_delay.F90*. The model (real) elevation angle from GNSS station to satellite is computed from the model state and the Snell's law. Model elevation angle is compared to geometric (true) elevation angle until the difference or number of iterations is satisfied. The iterations of ray tracing of signal path are displayed in Fig. 2. After the real elevation angle is obtained the slant total can be estimated.

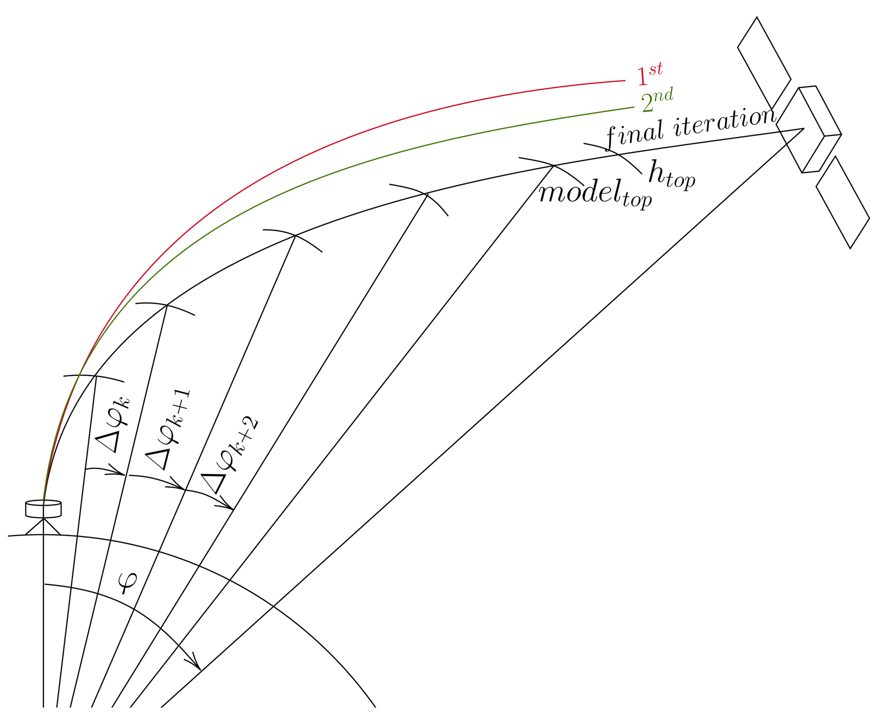

Figure 2: GNSS signal path.

Where

- φ is the geocentric angle from GNSS station to satellite,
- $\Delta\varphi_k$ is the difference of geocentric angles between two intersections of GNSS signal and model levels,
- h_{top} is the level closest to satellite where the signal is bent for the last time. It is set to 75 km.

In Three–Dimensional Variational analysis (3D–Var) a cost function J is minimized. Therefore the tangent linear (cost function) and adjoint version (gradient) of STD observation operator is necessary. The tangent linear version of the observation operator is developed in the *gnss_slant_delaytl.F90* routine, while the adjoint observation operator is developed in the *gnss_slant_delayad.F90*. The slant total delay τ depends on model state $\mathbf{x}$ at k and $k-1$ levels and refractivity constant C. Multiple functions $\mathbf{f}$ are used to estimate slant total delay

$$\tau = \sum_k f^k(\mathbf{x}_k, \mathbf{x}_{k-1}, C). \quad (1)$$

The considered levels k are: interpolated model state at GNSS station, model levels above the station, atmospheric state at h_{top}.

Experiments

Results of experiments are preliminary and they can change with the further development of the code. The assimilation experiments were done on the old operational ALARO/CHMI NWP setup (4.7 km/L87). As the first experiment the assimilation of only one randomly chosen STD from GNSS station BASV (Banská Štiavnica) was performed. The analysis departure was one order of magnitude smaller compared to the first guess departure (not shown). The assimilation of all available STDs from GNSS station BASV was performed, the increments of specific humidity are displayed in Fig. 3. The positive increments (more specific humidity in analysis) are located mainly on east of the station. Actually, some negative increments were noticed on west of the station. Asymmetrical increments at GNSS station are expected feature of assimilation of all available slant total delays at GNSS station.

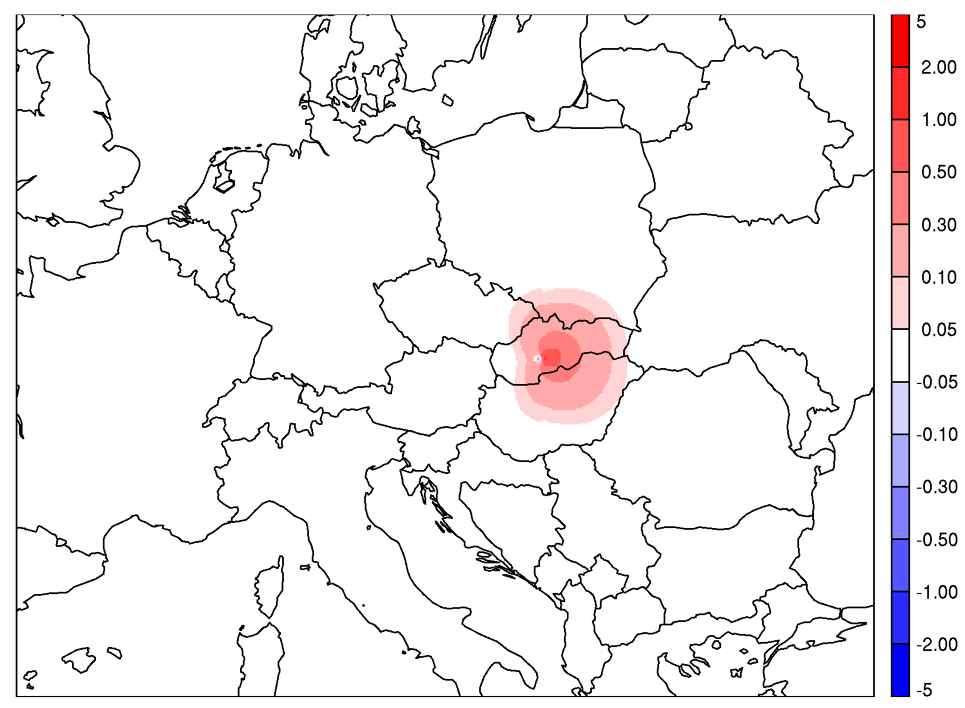

Figure 3: Increments of specific humidity $[0.1\,\mathrm{g\,kg^{-1}}]$ at model level 60 of all STDs assimilation at station BASV at 00 UTC on 7 January 2019.

After that, the assimilation of all available STDs from 7 January 2019 00 UTC was done. Overall 714 STDs from 22 GNSS permanent stations were assimilated. The increments of specific humidity are displayed in Fig. 4.

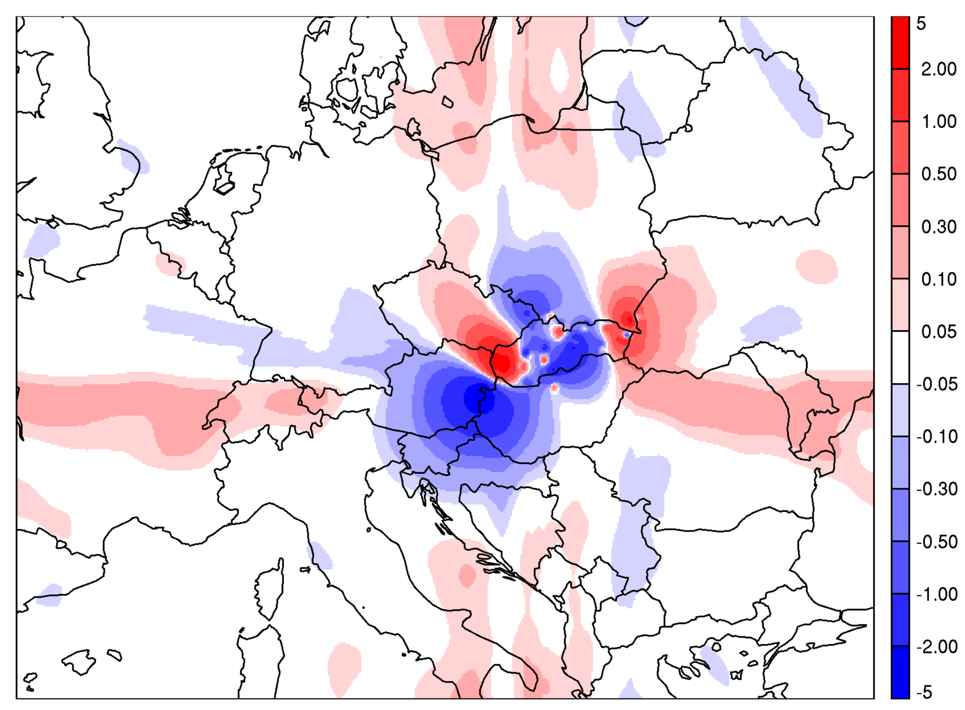

Figure 4: Increments of specific humidity $[0.1\,\mathrm{g\,kg^{-1}}]$ of STD's assimilation at model level 60 at all stations at 00 UTC on 7 January 2019.

Conclusion

The Siebren de Haan's development in utilization of STD in NWP system ALADIN was introduced to the cycle 43t2 bf10 after one month stay at KNMI and consequential work. The development was technically tested with minor success. The increments in specific humidity from assimilation of STDs are looking promising. Nevertheless, further development and testing are necessary. More detailed information can be found in the report on Regional Cooperation for Limited Area modeling in Central Europe (RC LACE) page in Data assimilation section.

Outlook

The work on this topic will be ongoing in the future. These improvements, tests of code and validations are proposed:

- To perform the tangent linear and adjoint tests.
- To study the long term impact of assimilation of STDs on NWP forecast.
- Implementation of development to the latest possible export cycle, once the STD development will be validated.

Bibliography

Guerova, G., Jones, J., Dousa, J., Dick, G., de Haan, S., Pottiaux, E., Bock, O., Pacione, R., Elgered, G., Vedel, H., & Bender, M. 2016. Review of the state-of-the-art and future prospects of the ground-based GNSS meteorology in Europe. *Atmospheric Measurement Techniques*, **9**, 5385–5406.

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