AN OBSERVATION OPERATOR FOR GPS SLANT TOTAL DELAYS

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1 Motivation

Novel Numerical Weather Prediction (NWP) systems enable direct assimilation of Slant Total Delay (STD) observations processed from the ground-based measurements with Global Positioning System (GPS). Assimilation schemes require forward modelling of the observed quantity as a function of the model variables. At FMI, an observation operator is developed for forward modelling of the STD observations with the High Resolution Limited Area Model (HIRLAM).

Assimilation of the STD observations is motivated by several aspects:

- The number of STD observations is nearly tenfold the number of Zenith Total Delay (ZTD) observations at each time instant.
- The anisotropic information, which is averaged out from the ZTD observations, can be contained in the STD observations.
- ZTD observations can be assimilated as a special case of STD thus making use of the STD observation operator.
- STD observations provide potential for water vapour tomography.

2 Algorithm

The STD observation operator consists of three main algorithms.

2.1 Determination of the signal path across the NWP model grid

The Geometrical Path (GP) as expressed by the geometrical satellite azimuth and zenith angles is used as the starting point for the signal path computation. Emphasis is put on the methods for taking into account the effects of the Earth's curvature, the refractive bending of the signal path and the complications set by the NWP model grid geometry. The signal path is a set of coordinates indicating the points of cross-over between the signal path and the model levels (intersections).

2.2 Projection of the model variables on the signal path

Bi-linear interpolation at the model levels is used for calculation of the NWP model variables at the intersections. The interpolated HIRLAM model variables are logarithm of surface pressure, temperature and specific humidity. At the receiver location, the corresponding values are calculated using applicable methods, such as hydrostatic equation and vertical extrapolation with fixed lapse rates.

Model levels	**ZTD** (cm)	**STD** (cm); ζ=80°
31	242.98	1346.64
61	242.95	1346.56
121	242.95	1346.57
481	242.95	1346.57
1921	242.95	1346.55

Table 1: ZTD and STD as a function of the number of the model levels in the experiment with the standard atmospheric data.

2.3 Numerical integration of refractivity along the signal path

STD is the integral of refractivity N as calculated over the signal path from the satellite to the receiver. The refractivities at the intersections are therefore numerically integrated. The numerical integration is done by adding the contributions from the layers between two model levels; for each layer, N is assumed to be of the form

$$N = exp(a + bz)$$

where z is geometrical height. Solving the parameters a and b allows analytical integration for each layer.

3 Validation

The STD observation operator is validated by two approaches. The first approach is tailored for checking that the modelling of the delays is independent on the number of NWP model levels. For this purpose, the standard atmospheric vertical profiles of pressure, temperature and relative humidity are applied. These profiles are interpolated to the model levels and given as an input to the observation operator. The resulting behaviour of ZTD and STD is shown in Table 1.

The second approach for the validation is to compare the geodetically processed STD observations with the corresponding meteorologically modelled values. The model counterparts are calculated for more than 360 000 STD observations from 16 receiver stations in the Western Europe. The validation scores for four individual receiver stations are shown in Figs. 1 and 2.

The conclusions from the two validation approaches are as follows:

- The delays are practically independent on the number of model levels. Therefore, the algorithm for refractivity integration is suitable for STD modelling.
- The modelled delays are systematically lower than the observed ones; this bias is about one centimeter near zenith, and increases with zenith angle.
- The standard deviation of the modelled minus observed difference is about two centimeters at zenith and about eight centimeters at the zenith angle 80°.
- Biases are specific for receiver station, but the standard deviations are not.

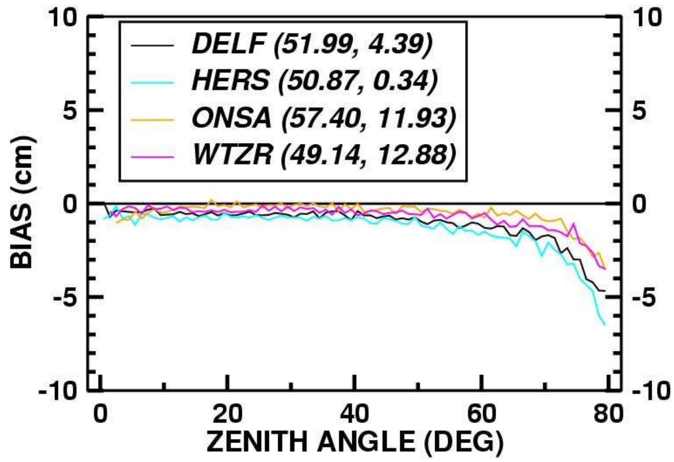

Figure 1: Mean of the difference between modelled and observed STD at some receiver stations as a function of zenith angle.

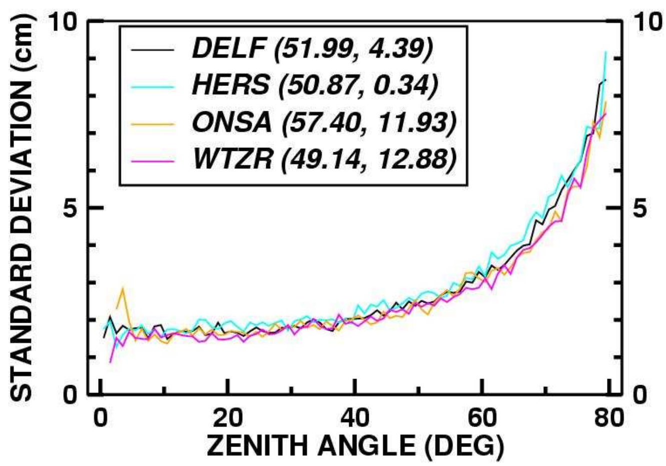

Figure 2: Standard deviation of the difference between modelled and observed STD at some receiver stations as a function of zenith angle.

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