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Deutscher Wetterdienst
Wetter und Klima aus einer Hand

GPS Slant Delay Assimilation for Convective Scale NWP

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GPS Assimilation Operator

The GPS microwave signals are delayed by the Earth's atmosphere. The delay depends on the atmospheric state along the signal path and is a valuable tool for atmosphere sounding. The Slant Total Delay (STD) by the neutral atmosphere is given by

$$STD = 10^{-6}\int_S N(s)\,ds + S - G$$

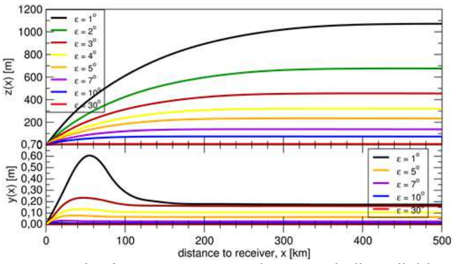
where N = 10^6 (n-1) is the refractivity, n is the refractive index, S is the curved signal path between the GPS satellite and the receiver and S-G is the difference between the geometric distance G and the length of the signal path S. The refractivity depends on the atmospheric state:

$$N = k_1\frac{p_d}{T} + k_2\frac{e}{T} + k_3\frac{e}{T^2}$$

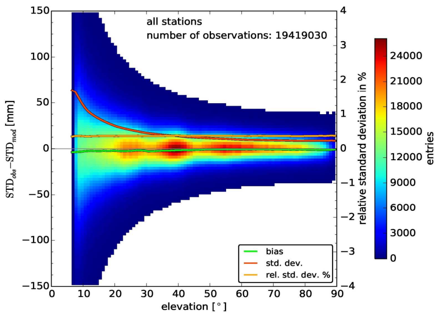
Here, p_d is the partial pressure of dry air, e is the partial pressure of water vapour, T is the temperature and $k_{1,2,3}$ are empirical constants.
The GPS assimilation operator needs to estimate the STD from the model fields p, T, and rh. This is done in three steps:

1) Interpolation of the model fields on the signal path S
2) Estimating the curved signal path in the atmosphere using a raytracer
3) Integration along the signal path to obtain the STD

The raytracing is an important part of the operator as the signal path is always above the connecting line G between satellite and receiver and integrating along G would systematically overestimate the STD. Using G as the x-axis of the signal propagation system, the deviations from G can be described as y(x) and z(x) and are shown for different elevations :



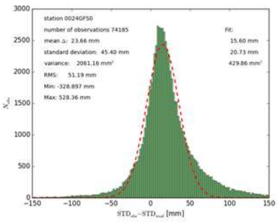
One month of COSMO-DE analyses and all available STD data were used to monitor the quality of the STD operator:



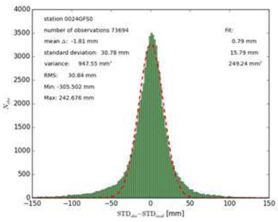
The differences STD_{obs}-STD_{mod} increase from zenith (~10 mm) to lower elevations (~60 mm at 7°) but the relative error is almost constant. The mean bias of all GNSS stations is rather small.

Assimilation Experiments

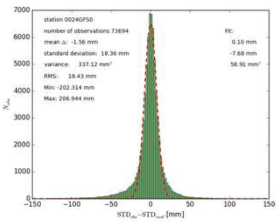
A pre-operational version of the *ensemble Kalman filter for convective scale data assimilation* (KENDA) was used to run the COSMO-DE local model together with the STD assimilation operator. Hourly COSMO-DE forecasts of 40 ensemble members were processed by the *local ensemble transform Kalman filter* (LETKF) to obtain the analyses and 24-hour forecasts were started every 6 hours. The assimilation experiment was running for two weeks beginning at 16.5.2014. About 20•10^6 STDs were assimilated together with conventional observations..
The standard deviation of the first guess departures is considerably reduced as compared to the control experiment. In the analyses the standard deviation further decreases.



Control experiment	
Station Eberswalde	
N_{obs}	74185
bias	23.7 mm
σ	45.4 mm
all stations	
N_{obs}	20178949
σ	41.6 mm
σ_{map}	13.6 mm

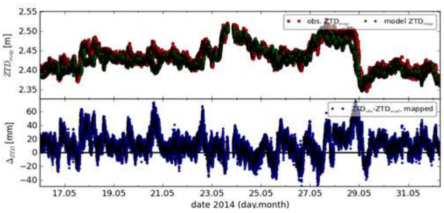


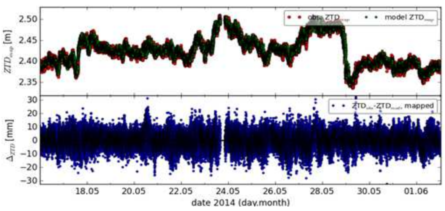
Observation–first guess	
Station Eberswalde	
N_{obs}	73694
bias	-1.8 mm
σ	30.8 mm
all stations	
N_{obs}	19966361
σ	27.9 mm
σ_{map}	9.2 mm



Analysis – first guess	
Station Eberswalde	
N_{obs}	73694
bias	-1.8 mm
σ	30.8 mm
all stations	
N_{obs}	19966361
σ	17.3 mm
σ_{map}	5.4 mm

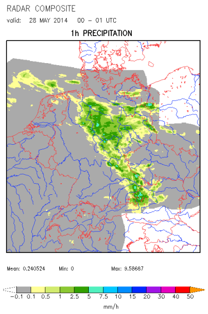
The time series of the control experiment (top) and the analysis (bottom) show that the analysis state is much closer to the GPS observations:





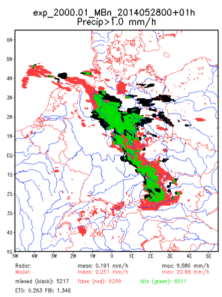
Forecast Verification

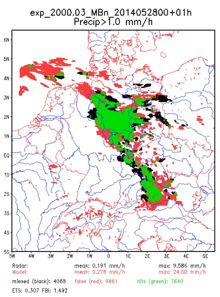
For two weeks in May 2014 two sets of 24 h forecasts were started at 0, 6 , 12, 18 UTC. The first set is the control run without GPS data, the second set was taken from the GPS assimilation experiment. Both sets were verfied using radar precipitation observations.



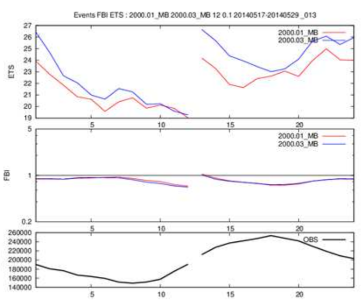
Precipitation at the 28.5.2015, accumulated from 0 to 1 UTC. The GPS forecast (bottom, right) shows a better correlation with the radar observations (left) than the control forecast (bottom, left). The number of cells with correct forcasts (hit) could be increased while the cells with missing rain decreased. The cells with incorrect forecasts (false) increased but the eqitable threat score of this event could be improved by assimilating GPS STD data.

	hit	miss	false	ETS
control	6511	5217	9299	0.283
GPS	7640	4088	9861	0.307





Several scores were derived for the full period of two weeks. The 6 and 12 UTC forecasts show a considerably improved ETS for 18 – 24 hours, the last hours are almost neutral. For 18 and 0 UTC a better ETS was found for the first 12 hours, the remaining period is neutral or slightly negative. The improvements are largest for moderate rain rates and decrease with increasing rain rates. The fraction scill score (FSS) shows a comparable behaviour with the largest improvemnts at short scales and moderate rain rates.



The precipitation forecast could be improved for the first 18 hours, within the last 6 hours the impact was almost neutral. Further improvements can be expected when the GPS quality control is active and the GPS specific LETKF parameters are better tuned.

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