Assimilation of STD and ZTD Data at the German Weather Service

M. Bender, R. Potthast, A. Rhodin,
K. Stephan, Ch. Schraff

German Weather Service (DWD)

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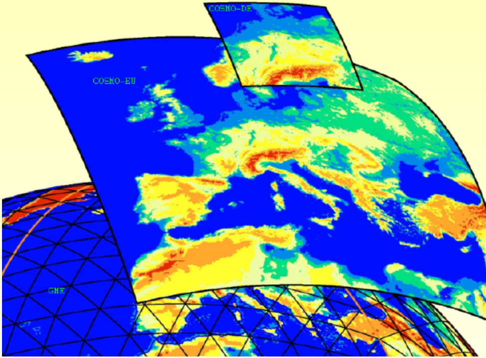
Weather Models and Assimilation Systems

Operational numerical weather models running at the DWD



Global Model: GME, ICON
Resolution 20 km,
3D-Var data assimilation

European Model: COSMO-EU
Resolution 7 km,
assimilation: nudging
will be replaced by ICON with
a local grid refinement
over EUROPE

German Local Model: COSMO-DE
Resolution 2.8 km, assimilation: nudging, will soon be replaced by
a local transform ensemble Kalman filter (LETKF)

GNSS Data Assimilation

A STD forward operator was developed at the DWD which

- has interfaces to the operational DWD models: GME/ICON, COSMO-DE,
- works with the LETKF (COSMO), i.e. provides the STD forward operator,
- works with the 3D-Var (GME/ICON), i.e. provides also the adjoint operator and
- assimilates ZTD data like STD data with elevations of 90°.

The operator needs individual interfaces to the 3D-Var system and to COSMO which handle the MPI exchange of the non local data between different processors.

STD Assimilation Operator

The STD assimilation operator H_{STD} consists of 3 parts:

1) Compute the 3D refractivity field N(r)

$$\boxed{N(\mathbf{r}) = k_1 \frac{p_d}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2}} \quad , \qquad \mathbf{r} \text{ is the position vector}$$

2) Estimate the bended signal path S – raytracing

Solve Fermat's Principle for the given atmospheric state and a given stallite-receiver geometry:

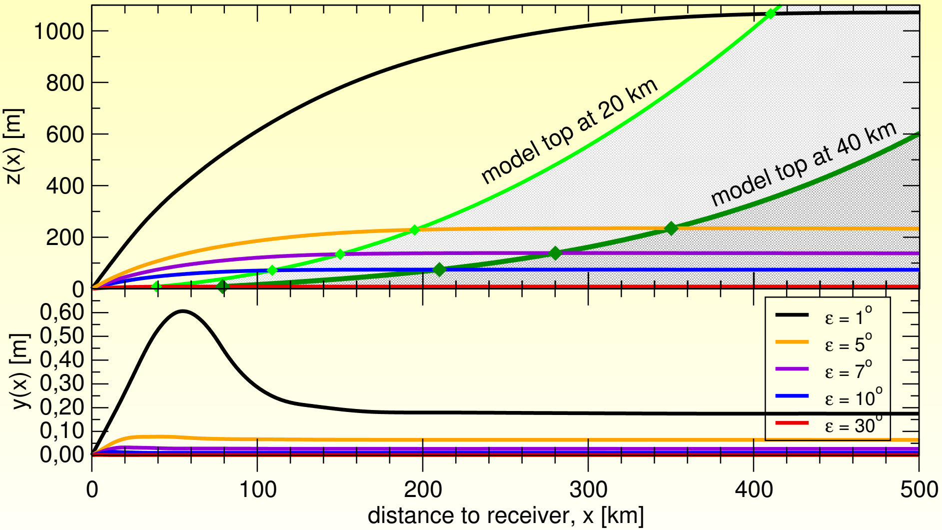
Variational problem $\boxed{\int_S n(x, y(x), z(x)) \sqrt{1 + y'^2 + z'^2}\, dx = \min.}$

3) Compute the line integral for a given signal path S

$$\boxed{STD = \int_S n(x, y, z) \sqrt{1 + y'^2 + z'^2}\, dx \; - \; G}$$

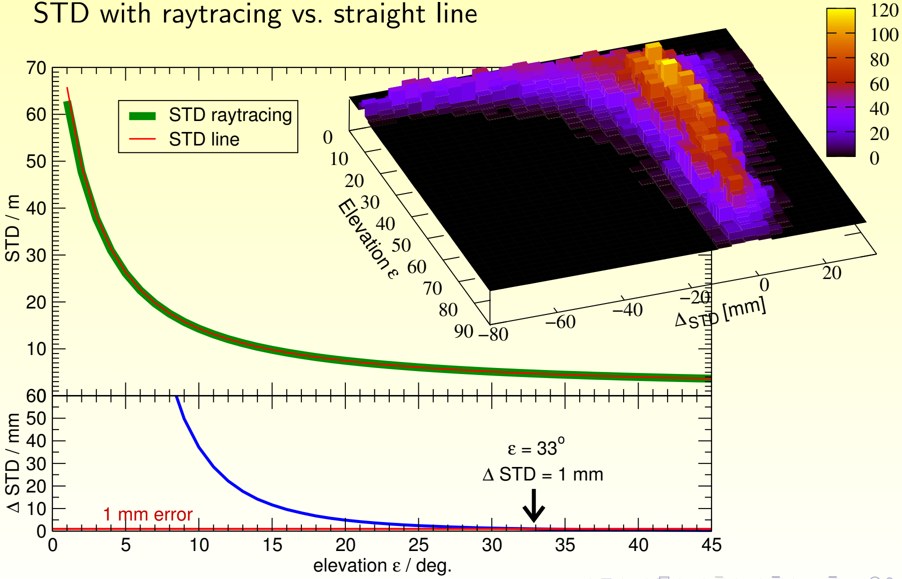
S is a parameterized curve through the scalar field N or n, G is the geometric distance between satellite and receiver.

Bended Signal Path inside the Model



Impact of the Raytracer

STD with raytracing vs. straight line



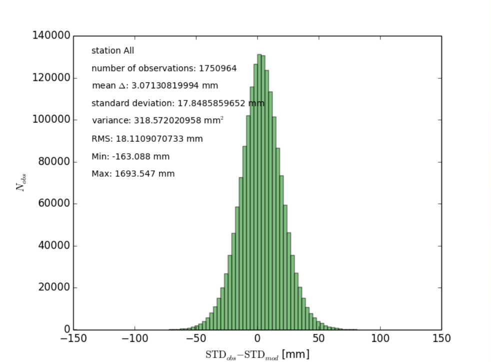
Next Steps

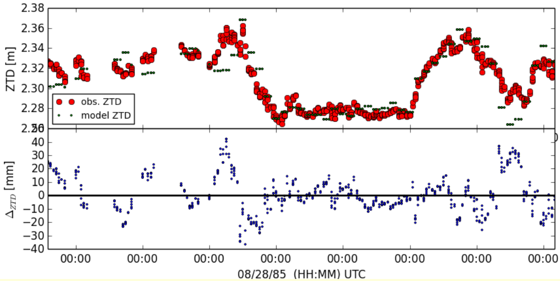
- Observation minus background monitoring; STD and ZTD data, GME and COSMO
- Optimization of the STD forward operator
- Estimation of the operator error
- Bias correction
- Assimilation experiments

GME - ZTD Monitoring

GME – ZTD minus background, 6.9. – 13.9.2014:
all E-GVAP stations, all processing centers, 1750964 observations

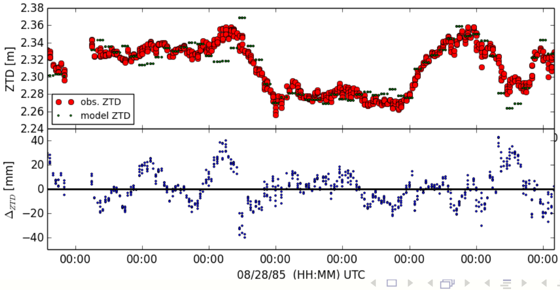
$\bar{\Delta} = 3.07$ mm	$\bar{\Delta}_{\mathrm{map}} = 3.07$ mm	$\bar{\Delta}_{\mathrm{rel}} = 0.12$ %
$\sigma = 17.84$ mm	$\sigma_{\mathrm{map}} = 17.84$ mm	$\sigma_{\mathrm{rel}} = 0.74$ %
$\sigma^2 = 318.57$ mm^2	$\sigma^2_{\mathrm{map}} = 318.57$ mm^2	$\sigma^2_{\mathrm{rel}} = 0.56$ %
RMS $= 18.11$ mm	$\mathrm{RMS}_{\mathrm{map}} = 18.11$ mm	$\mathrm{RMS}_{\mathrm{rel}} = 0.76$ %





ZTD [m]
2.38
2.36
2.34
2.32
2.30
2.28
2.26
obs. ZTD
model ZTD
Δ_{ZTD} [mm]
40
30
20
10
0
−10
−20
−30
−40
00:00
08/28/85 (HH:MM) UTC

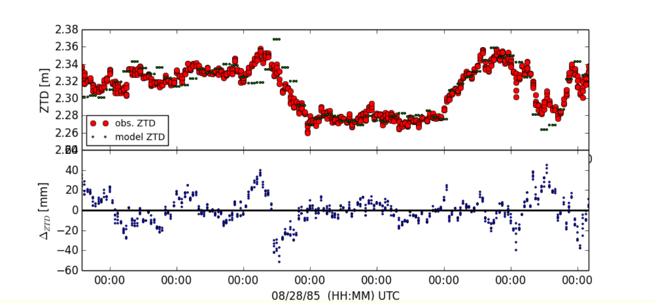
MET



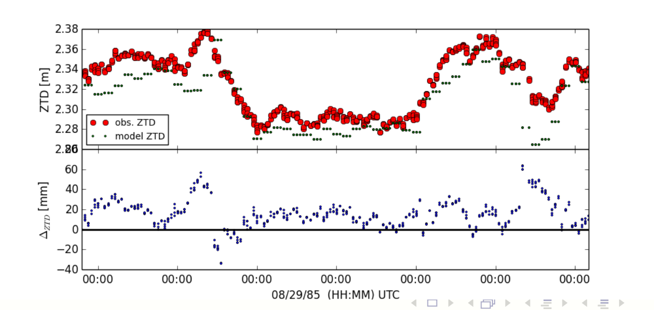
ZTD [m]
2.38
2.36
2.34
2.32
2.30
2.28
2.26
2.24
obs. ZTD
model ZTD
Δ_{ZTD} [mm]
40
20
0
−20
−40
00:00
08/28/85 (HH:MM) UTC

ROB

GME - ZTD Monitoring, Station GOPE



KNM

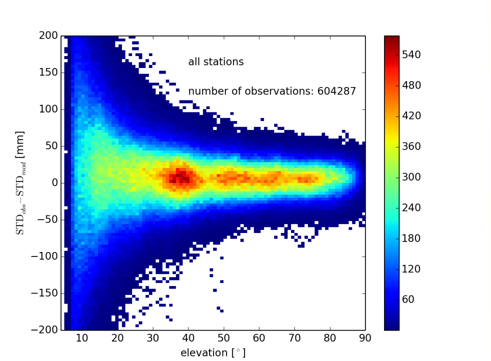


GFZ

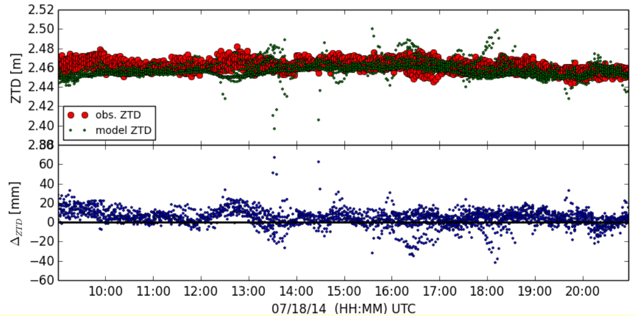
COSMO - STD Monitoring

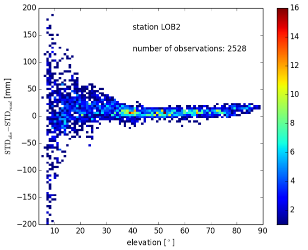
COSMO – STD minus background, 18.7.2014, 9:00 – 21:00 UTC :
GFZ STD data, 604287 observations

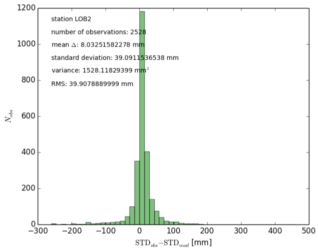
$\bar{\Delta} = 7.93$ mm	$\bar{\Delta}_{map} = 3.43$ mm	$\bar{\Delta}_{rel} = 0.14$ %
$\sigma = 62.95$ mm	$\sigma_{map} = 18.16$ mm	$\sigma_{rel} = 0.75$ %
$\sigma^2 = 3963.43$ mm^2	$\sigma^2_{map} = 330.13$ mm^2	$\sigma^2_{rel} = 0.57$ %
RMS $= 63.45$ mm	$\mathrm{RMS}_{map} = 18.49$ mm	$\mathrm{RMS}_{rel} = 0.76$ %



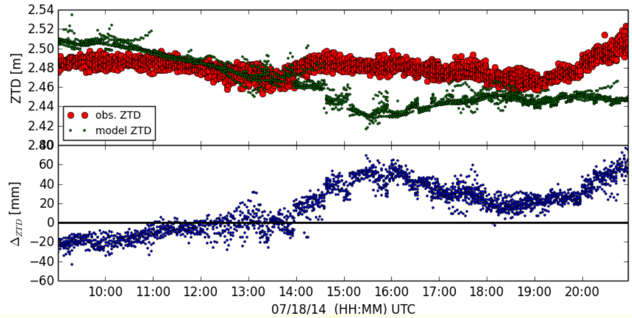
COSMO - STD Monitoring, Station LOB2

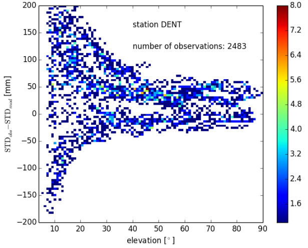


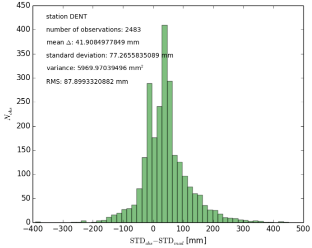




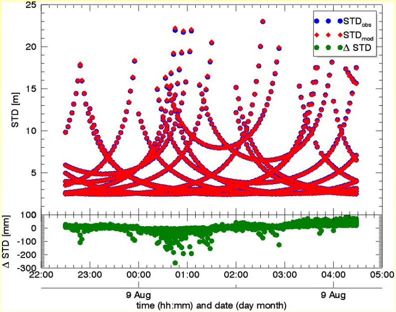
COSMO - STD Monitoring, Station DENT



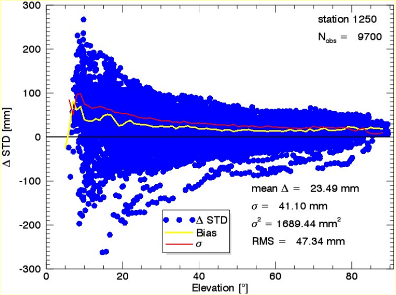




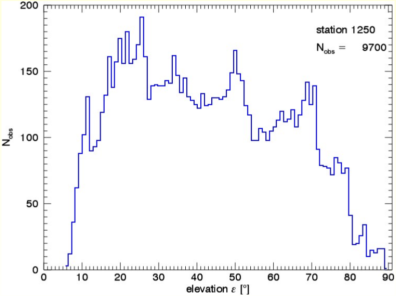
Monitoring



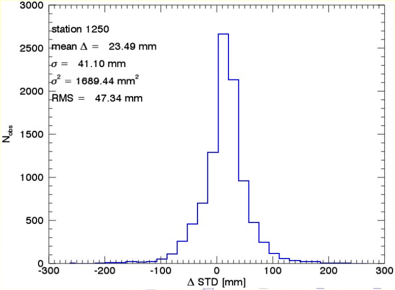
STD_obs
STD_mod
Δ STD
STD [m]
Δ STD [mm]
22:00 23:00 00:00 01:00 02:00 03:00 04:00 05:00
9 Aug
9 Aug
time (hh:mm) and date (day month)



station 1250
N_obs = 9700
mean Δ = 23.49 mm
σ = 41.10 mm
σ² = 1689.44 mm²
RMS = 47.34 mm
Δ STD
Bias
σ
Δ STD [mm]
Elevation [°]



station 1250
N_obs = 9700
N_obs
elevation ε [°]



station 1250
mean Δ = 23.49 mm
σ = 41.10 mm
σ² = 1689.44 mm²
RMS = 47.34 mm
N_obs
Δ STD [mm]