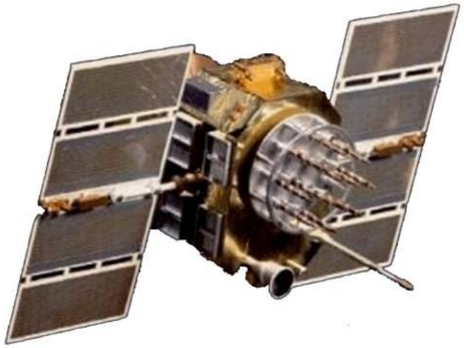
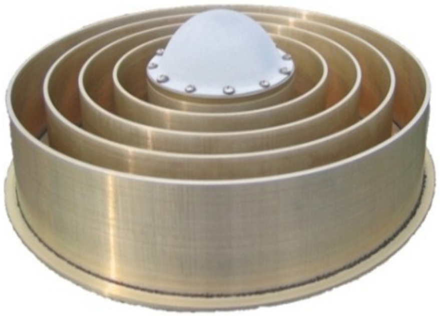


Status & developments at GFZ Potsdam

Florian Zus, Galina Dick and Jens Wickert
(zusflo@gfz-potsdam.de)

GFZ
Helmholtz Centre
Potsdam

E-GVAP expert team and plenary meeting
November 15-16, 2012, Madrid, Spain



Outline

(1) Processing & Validation:

Transition from EPOS6 to EPOS8.

(2) ZTD & STD data monitoring:

Comparison with NWM (GFS) short range (6h) forecasts.

(3) Vertical profiling of radio-refractivity:

Simulation studies & real data application.

(4) Summary

Processing & Validation

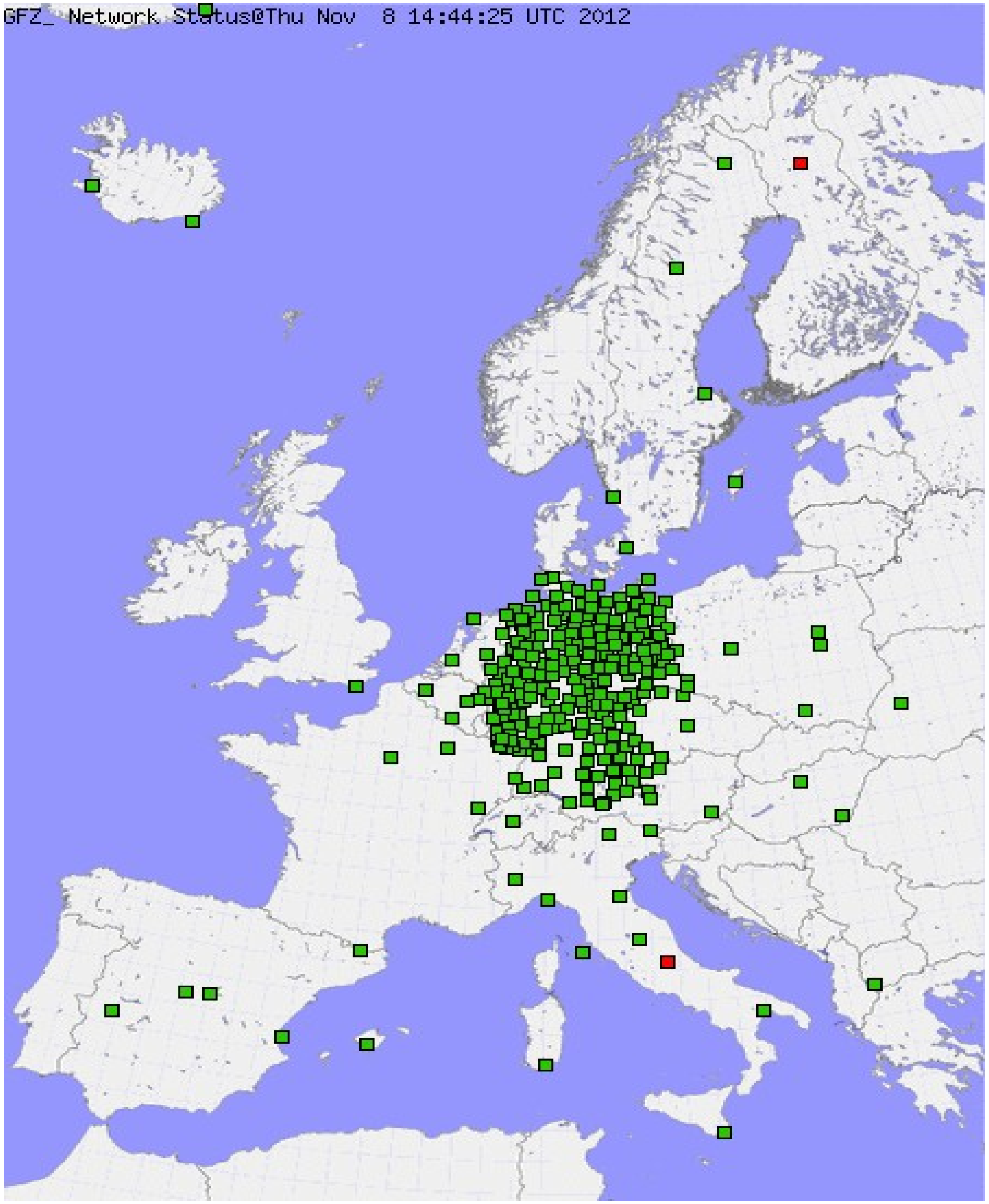
GPS ground station network

GFZs software EPOS6:

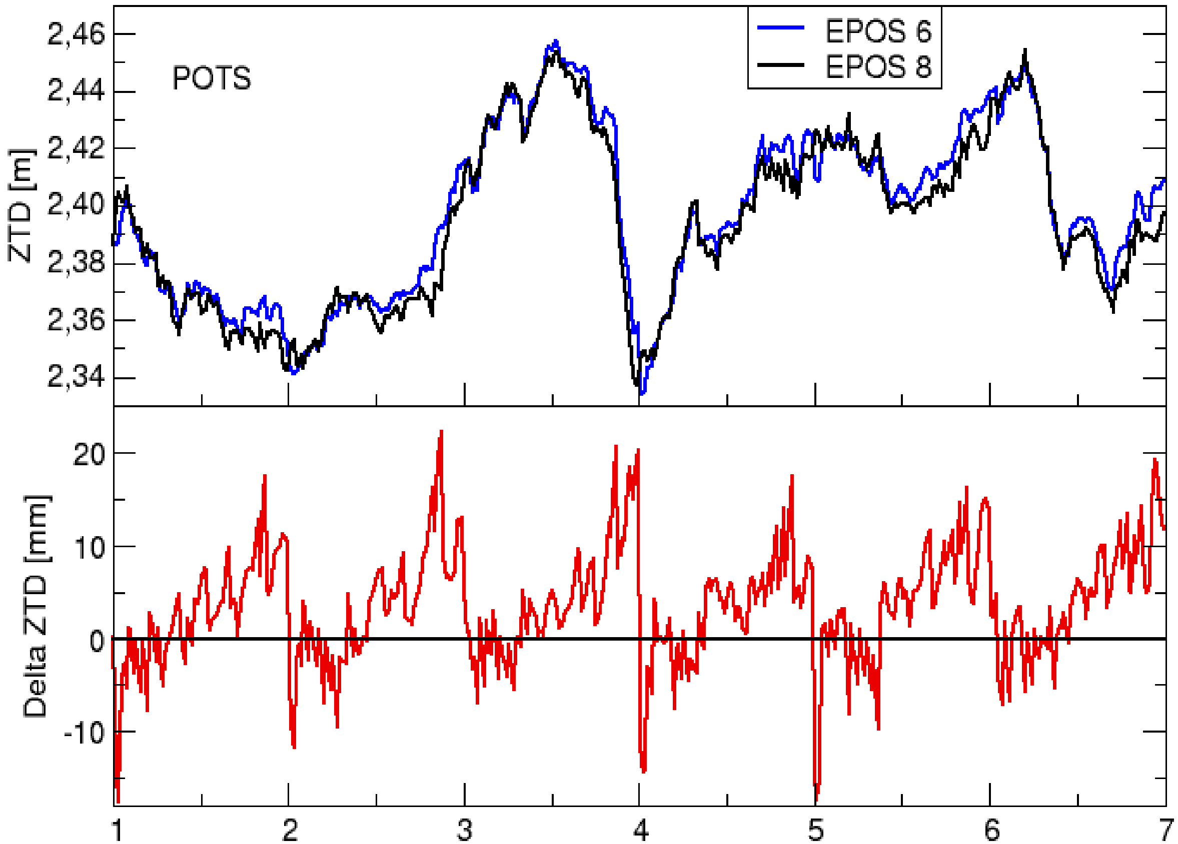
- NRT data from 300 stations (PPP).
- ZTDs available every 15 min; operational & used by NWP (e.g. Bennitt et al. 2012, MWR).
- STDs available every 2.5 min; operational & field of research (water vapour tomography Bender et al. 2011, ASR).

GFZs software EPOS8:

- Updated models & parameters.
- GLONASS & Galileo.



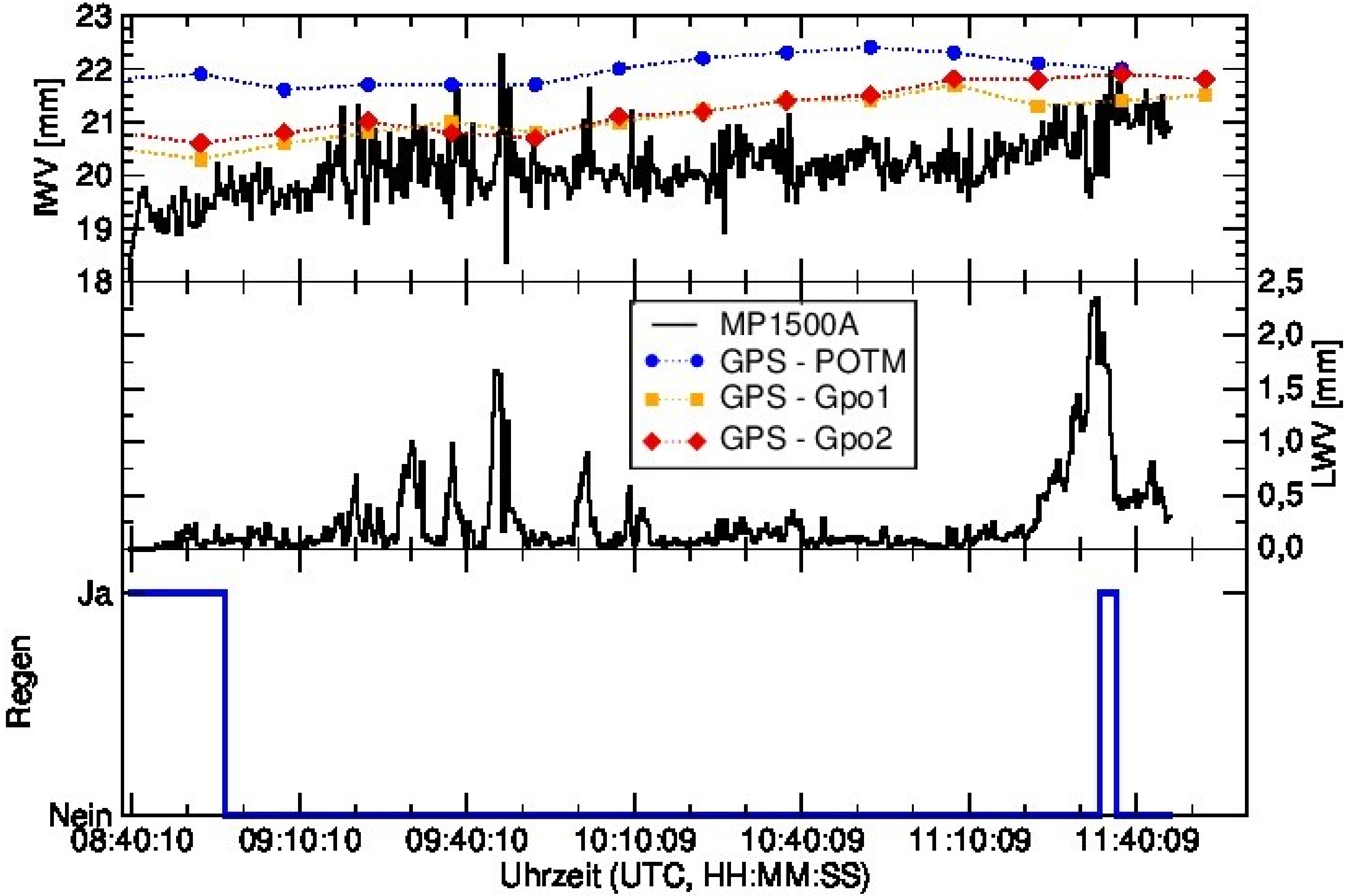
First ZTD results from EPOS8



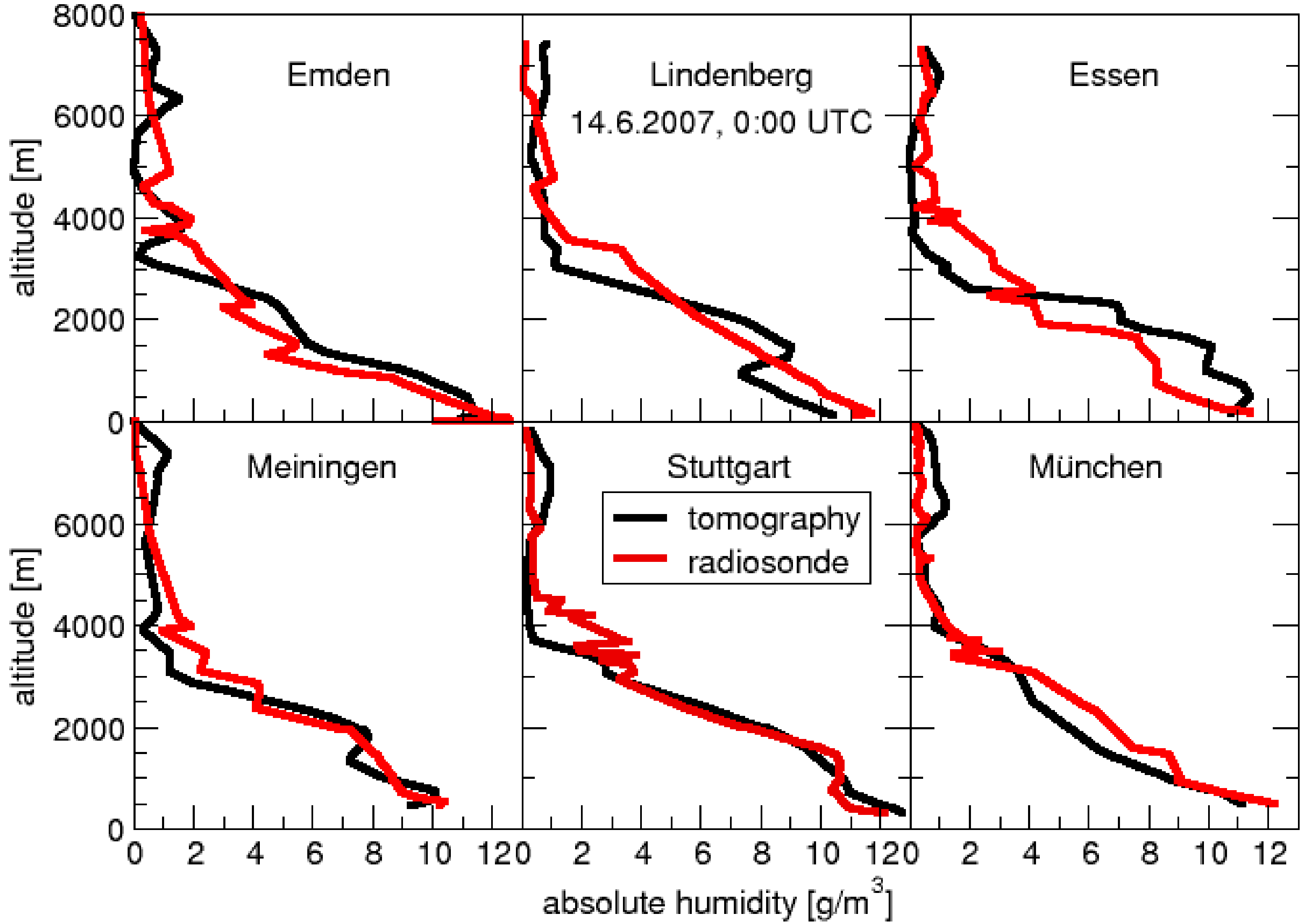
First results look reasonable, but tuning is still needed.

GFZ Microwave Radiometer „Radiometrics“ MP-1500A

IWV validation with Radiometer



WV (tomography) validation with Radiosondes



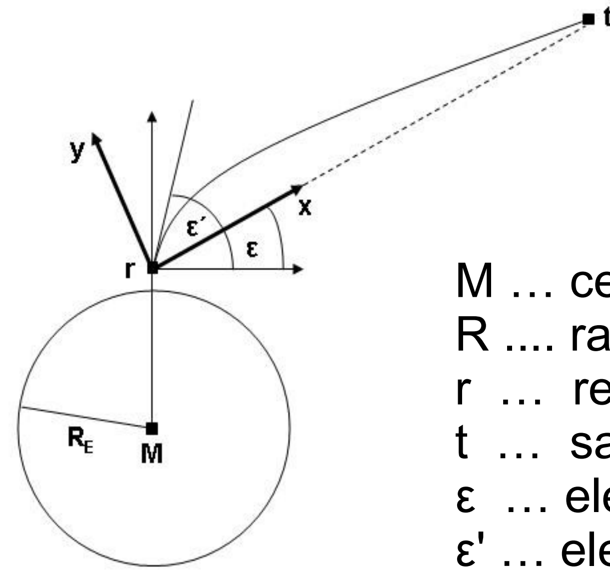
ZTD & STD data monitoring

Slant Total Delay (STD) derived from NWM

Def.: $S = \int_r^t n\,ds - \int_r^t dg$

$n = 10^{-6} N + 1$

N ... radio-refractivity
s ... signal path
g ... geometric path



M … center of Earth
R .... radius of Earth
r … receiver
t … satellite
ε … elevation geometric
ε' … elevation signal

The Euler Lagrange Equation:

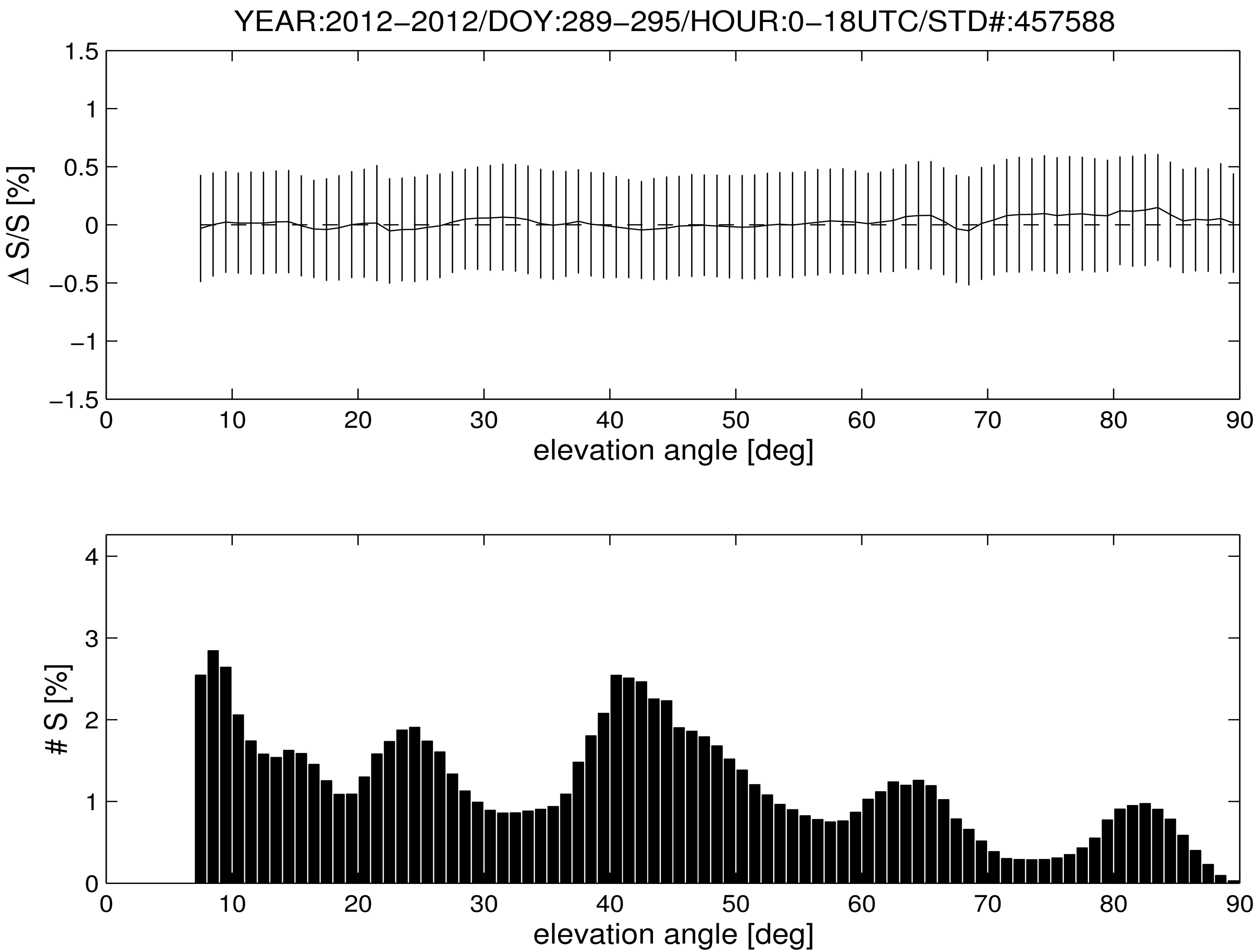
$$y'' = [\partial_y n(x,y,z) - \partial_x n(x,y,z) \cdot y'] \cdot (1 + y'^2 + z'^2) / n(x,y,z)$$
$$z'' = [\partial_z n(x,y,z) - \partial_x n(x,y,z) \cdot z'] \cdot (1 + y'^2 + z'^2) / n(x,y,z)$$

Boundary values: $y_r = y(x_r),\, z_r = z(x_r)$

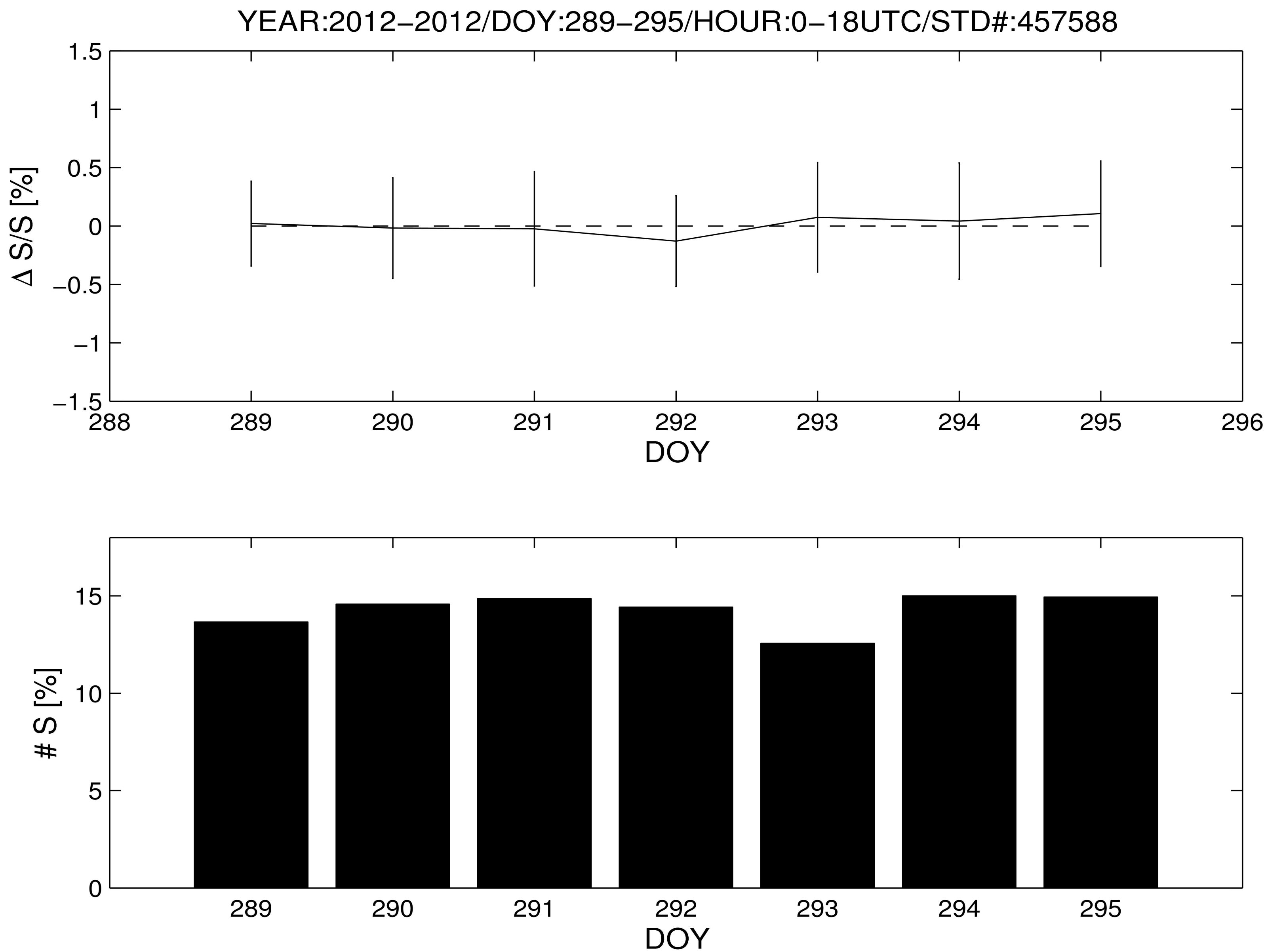
$y_t = y(x_t),\, z_t = z(x_t)$

For details see Zus et al. 2012, Radio Science

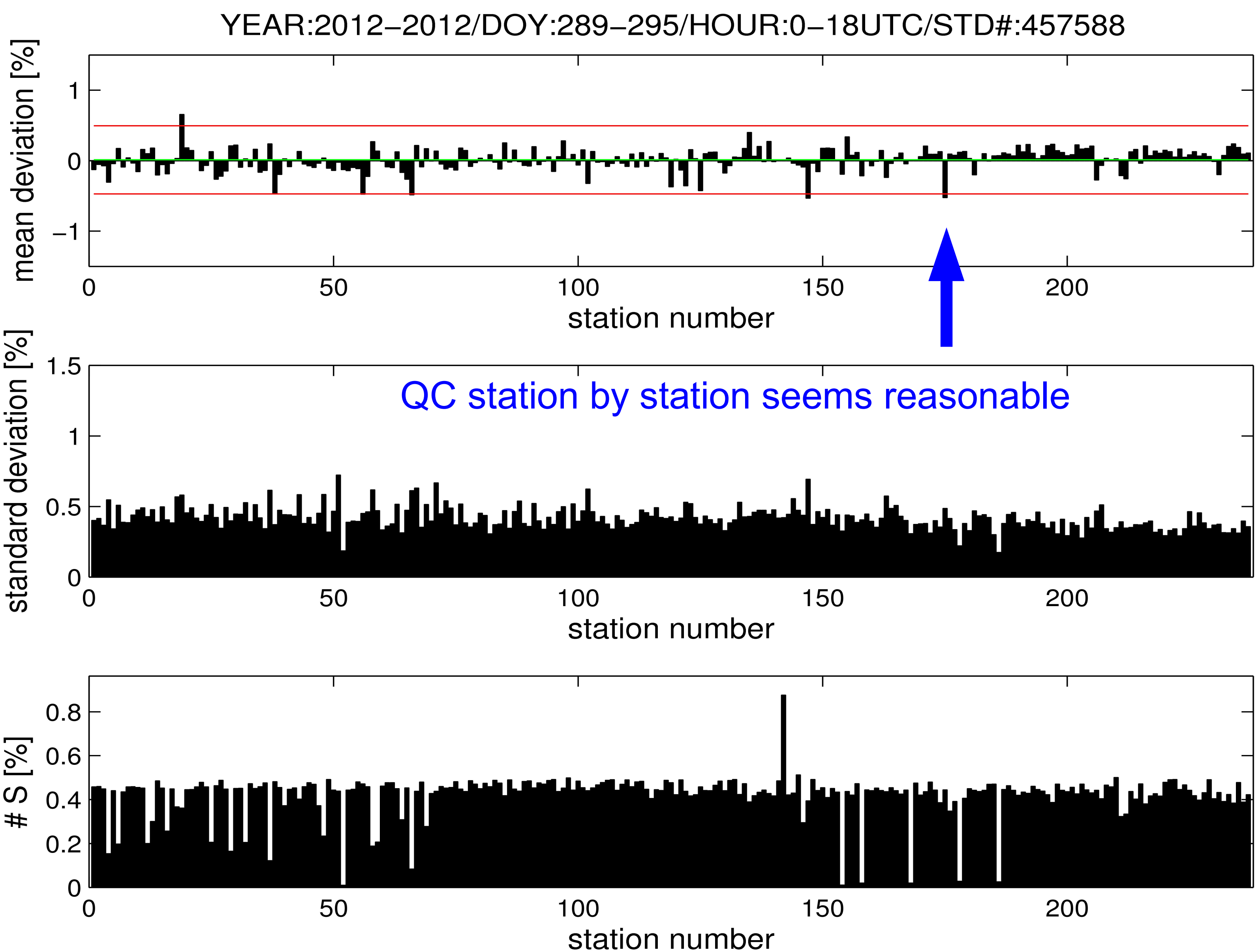
GPS minus NWM STD versus elevation angle



GPS minus NWM STD versus DOY



GPS minus NWM STD versus station



Vertical profiling of radio-refractivity using STD data from a single ground-based receiver

The forward & inverse problem

Let us introduce a refractivity profile:

$$N = B\exp[-(H-(i-1)\cdot\Theta)\cdot x_i]\prod_{k=1,i>1}^{i-1}\exp(-\Theta\cdot x_k) \qquad (i-1)\cdot\Theta \le H < i\cdot\Theta$$

B ... ground level refractivity
θ ... layer thickness
X ... inverse scale height
H ... height

Forward Problem: Suppose B and **x** is known, determine **y** (the STDs).

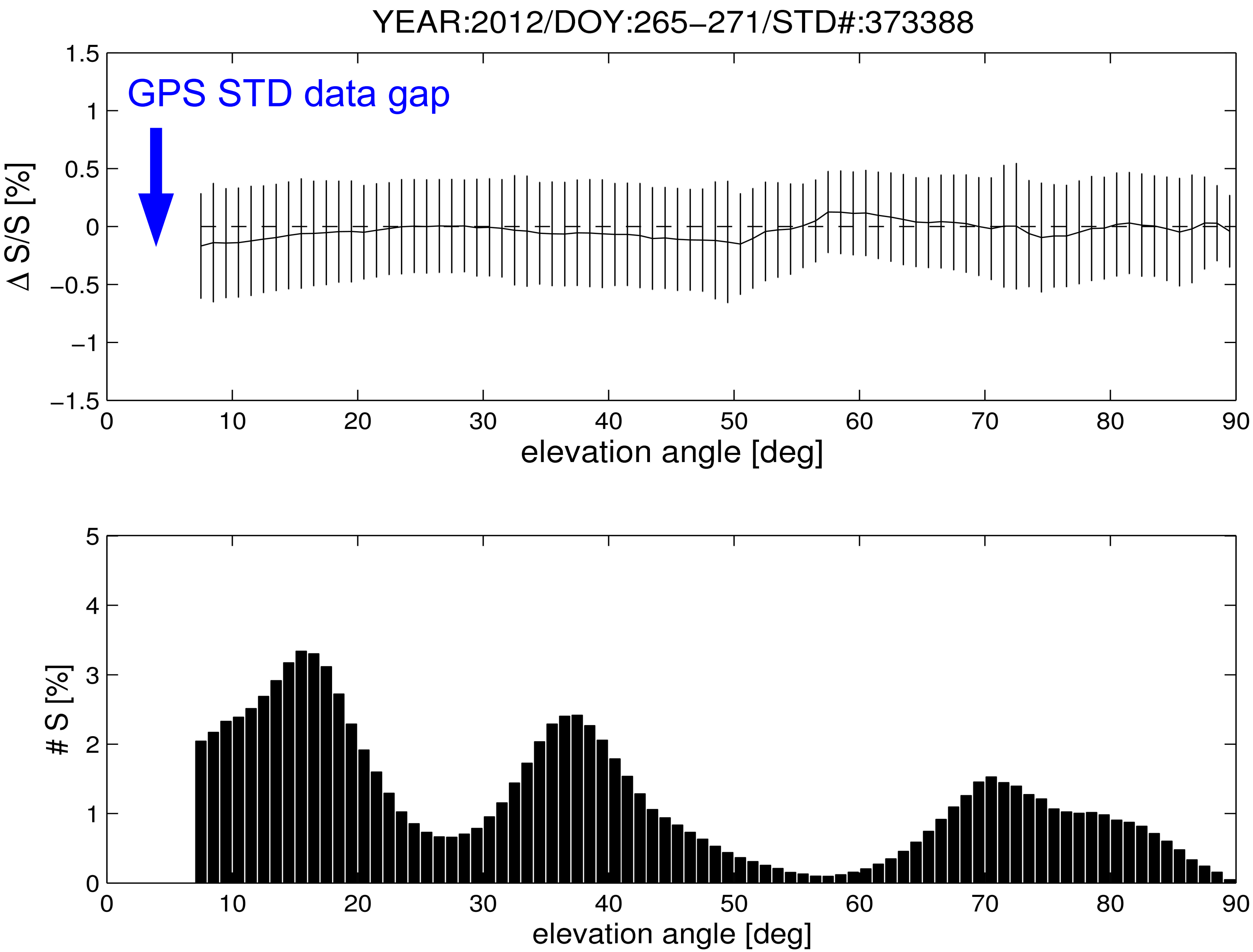
$$\boldsymbol{y} = S[\boldsymbol{x}]$$

Inverse Problem: Suppose B and **y** is known, determine **x** (the N-profile).

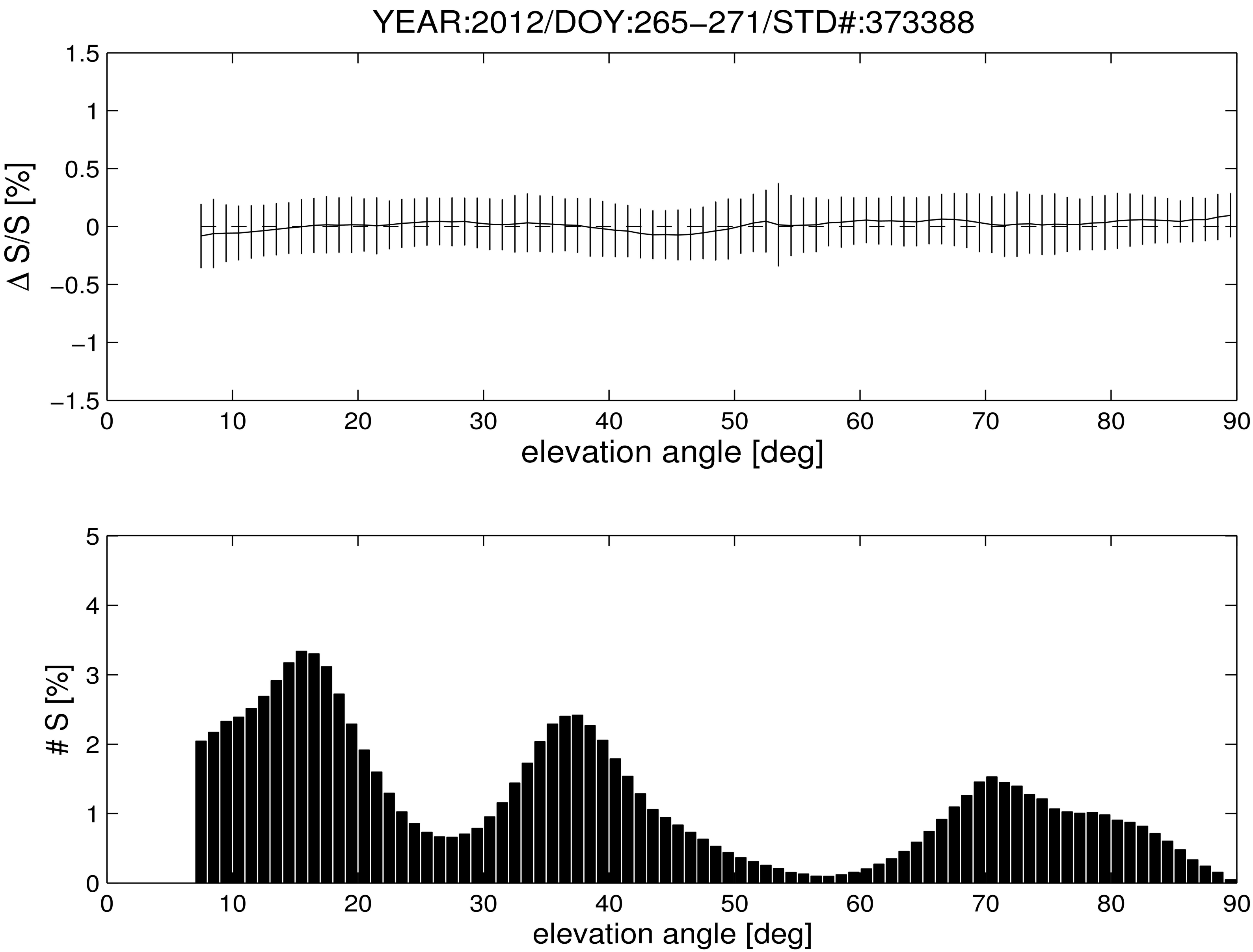
$$\boldsymbol{x} = P^{-1}[\boldsymbol{y}] \qquad \text{(Least-Square Analysis)}$$

In other words; collect GPS STDs for a single receiver (e.g. all data within 20 min) and determine a refractivity profile above the receiver such that observed STDs fit to simulated STDs.

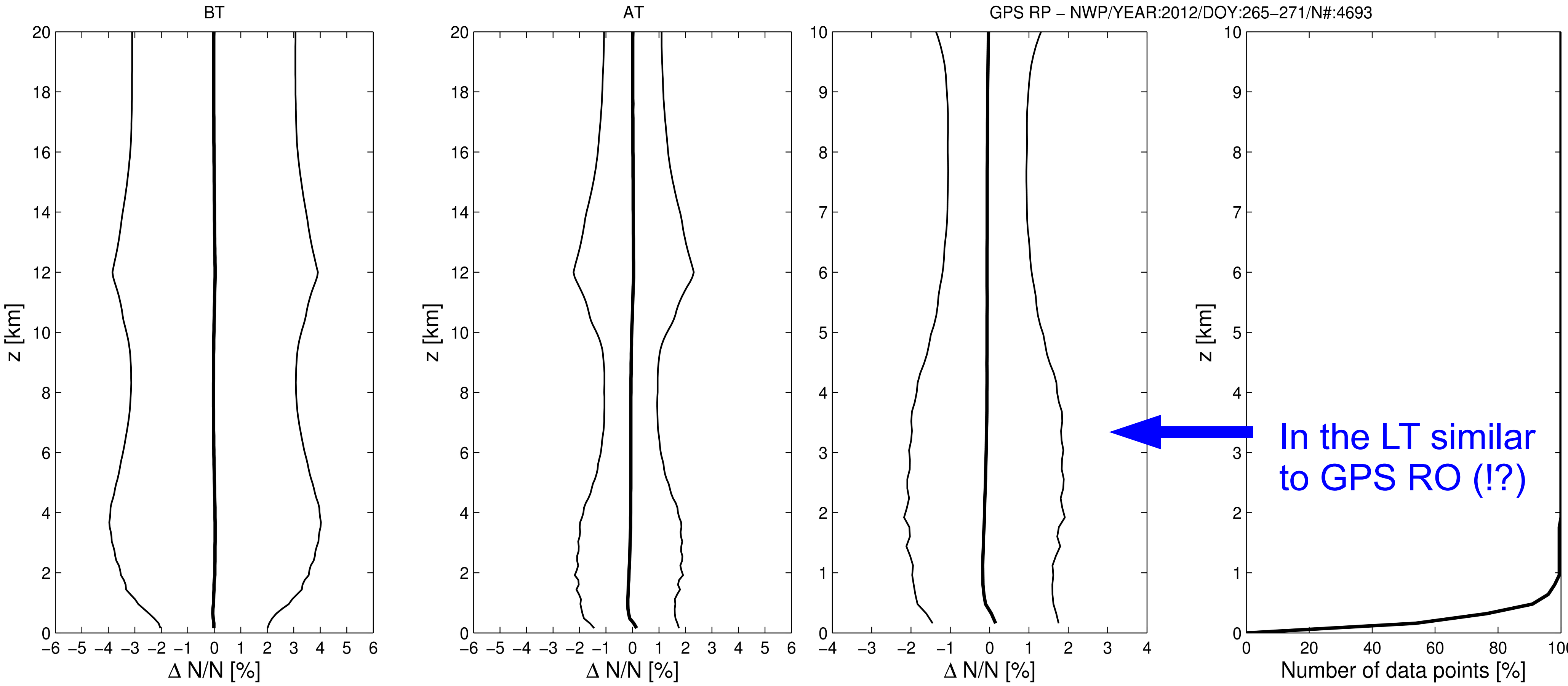
GPS minus NWM STD versus elevation angle



GPS minus Analysis STD versus elevation angle



GPS minus NWM refractivity (DOY 265-271, Y2012, ~700 profiles/day)



BT (AT) stands for the Background (Analysis) minus NWM. The right figure shows the lower troposphere for AT. The thick/thin line indicates the mean/one-sigma deviation.

Summary

(1) The transition from EPOS6 to EPOS8 is in preparation:

Fine tuning is ongoing.

(2) Monitoring of ZTD & STD data (delay 24h):

Potentially usefull as an early stage QC.

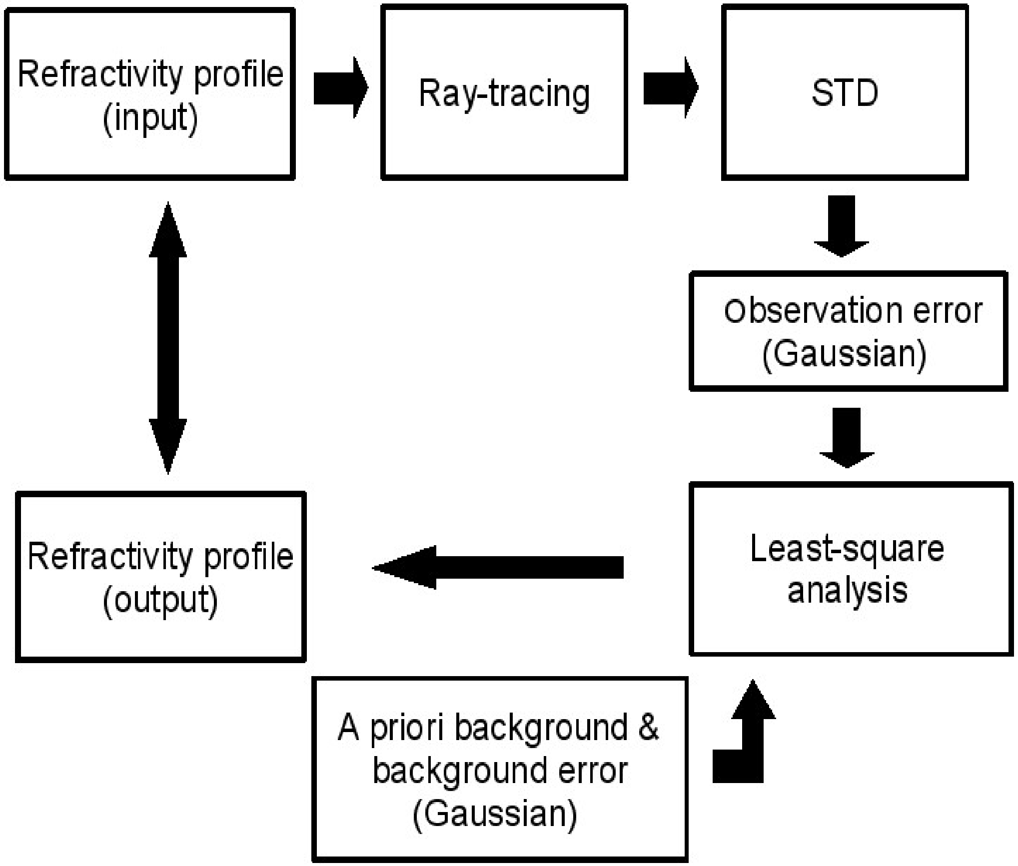
(3) Vertical profiling using STD data (delay 24h):

Low-elevation (< 10°) STDs must be available,
ideally, in the presence of spherical symmetry.

(4) Outlook: make 1-3 available in NRT.

Appendix

The simulation cycle



- N-profiles are derived from a NWM.
- Forward Problem: For each N-profile compute a sequence of STDs.
- Add STD observation errors.
- Inverse Problem: The N-profile is retrieved from STDs using Least-Square Analysis (EKF).
- Compare input & output N-profiles.

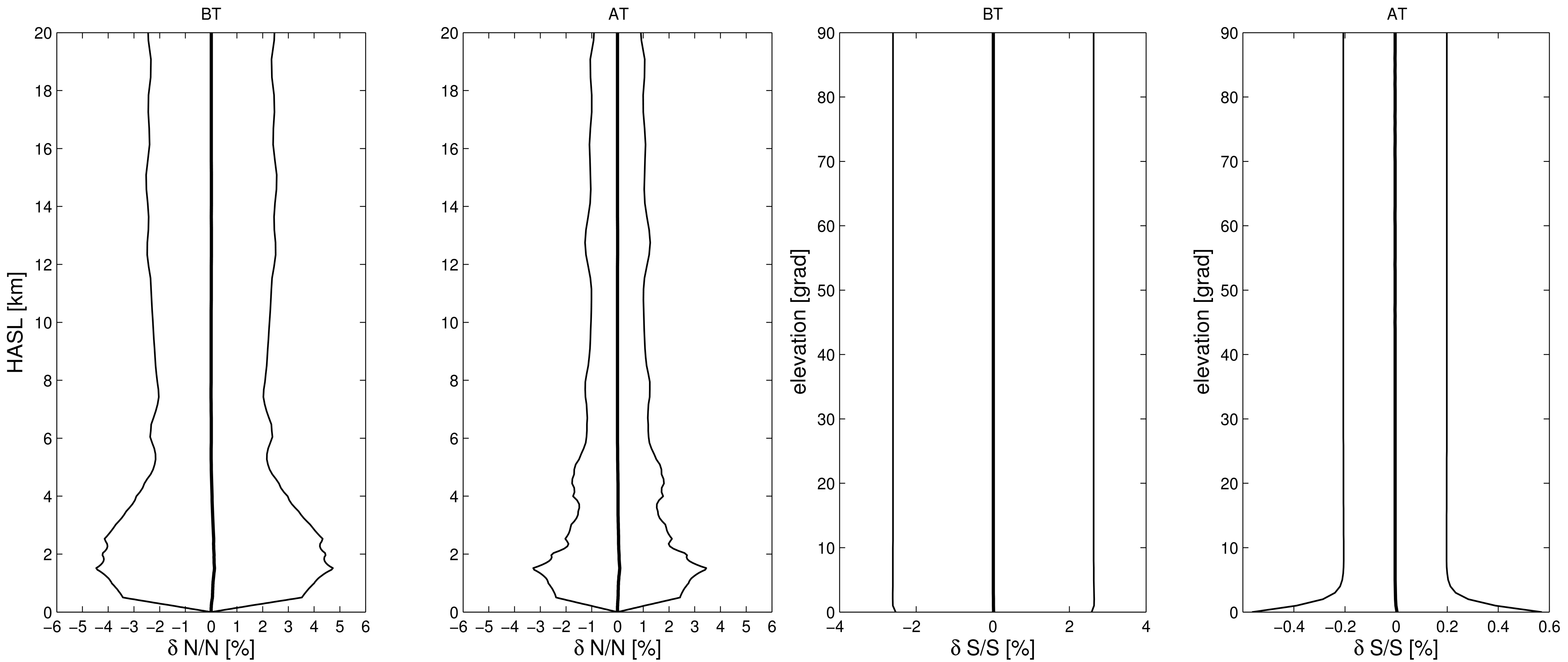
Extended Kalman Filter:

$$\delta \boldsymbol{x}_n = \boldsymbol{K}[\boldsymbol{x}_n]^{-1}[\boldsymbol{S}[\boldsymbol{x}_n]^T \boldsymbol{R}^{-1}(\boldsymbol{y} - S[\boldsymbol{x}_n]) - \boldsymbol{B}^{-1}(\boldsymbol{x}_n - \boldsymbol{x}_b)]$$

$$\boldsymbol{K}[\boldsymbol{x}_n] = \boldsymbol{B}^{-1} + \boldsymbol{S}[\boldsymbol{x}_n]^T \boldsymbol{R}^{-1} \boldsymbol{S}[\boldsymbol{x}_n]$$

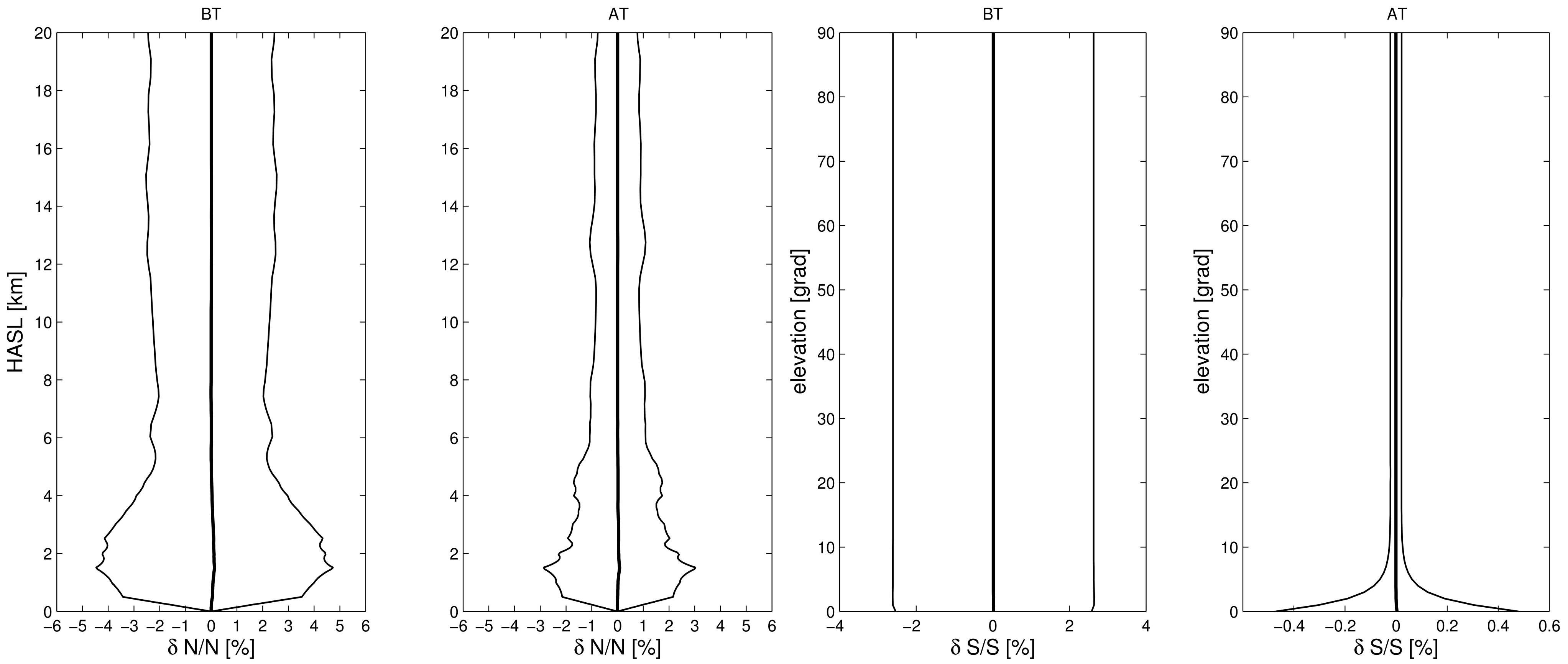
R … observation error
B … background error
$\mathbf{x}_b/\mathbf{x}_n$ … background/analysis
y … observation

e = [90°-90°], Δe = 1°, σ = 0.2%   ZTDs

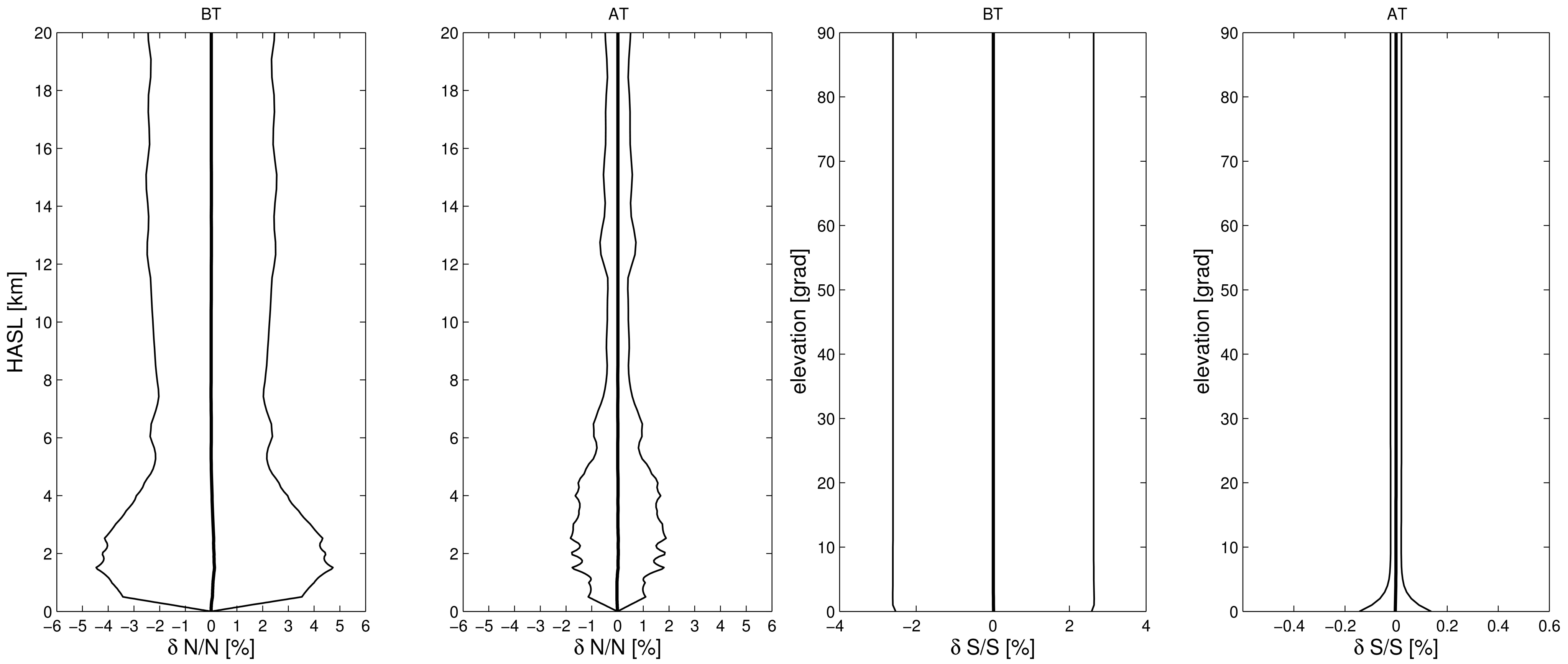


BT (AT) stands for the Background (Analysis) minus Truth. The left (right) figure corresponds to refractivity (STD). The thick/thin line indicates the mean/one-sigma deviation.
Note: An error of ± 0.2% in the ZTD is about ± 6 mm.

e = [5°-90°], Δe = 1°, σ = 0.2%   STDs



e = [0°-90°], Δe = 1°, σ = 0.2%   STDs



The lower the elevation angle the better the refractivity retrieval.

Recipe based on simulation studies

(1) Process data down to (beyond) the horizon.

(2) Estimate errors (including representative errors).

(3) Handover data & error estimates to Kalman Filter.

(4) Construct the tangent-linear & adjoint code according to the forward code.

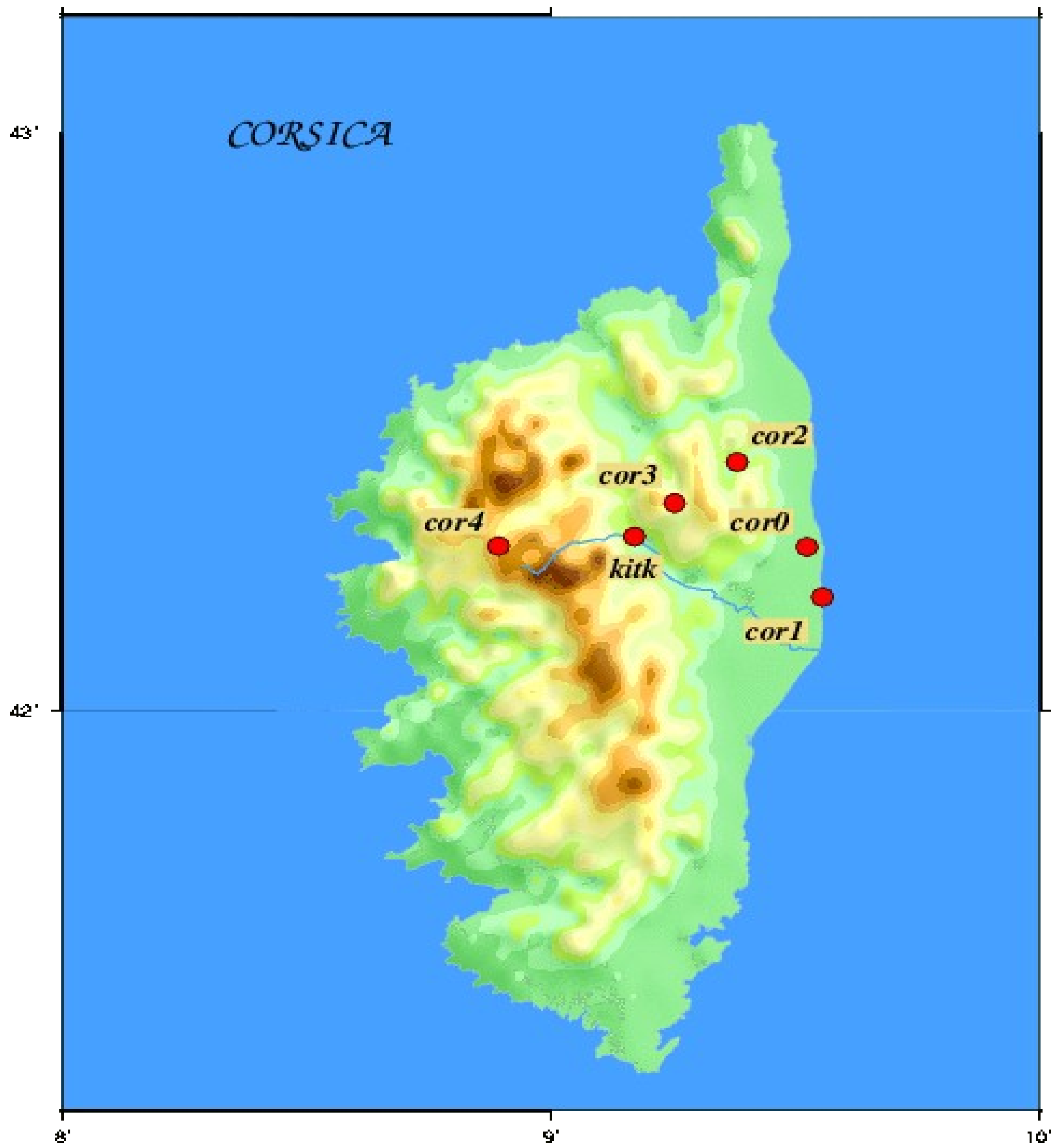
(5) Use STDs down to (beyond) the horizon. The simulations tell us that:

STDs close to the horizon corrupted by errors are more effective in retrieving the refractivity compared to STDs close to the zenith (ZTDs) without errors.

(6) When is there a benefit from low-elevation STDs?

The relative error of STDs should be smaller than the relative error of ZTDs.

HYMEX field campaign



Station heights are between 50 m and 1400 m; great potential for WV tomography.