Computation and Analysis of Antenna and Multipath Characteristics of Permanent GPS Stations

Hans van der Marel

H.vanderMarel@tudelft.nl

Department of Earth Observation and Space Systems (DEOS/MGP)
Faculty of Aerospace Engineering, TU Delft
Kluyverweg 1, 2629 HS Delft, Netherlands

May 8, 2006

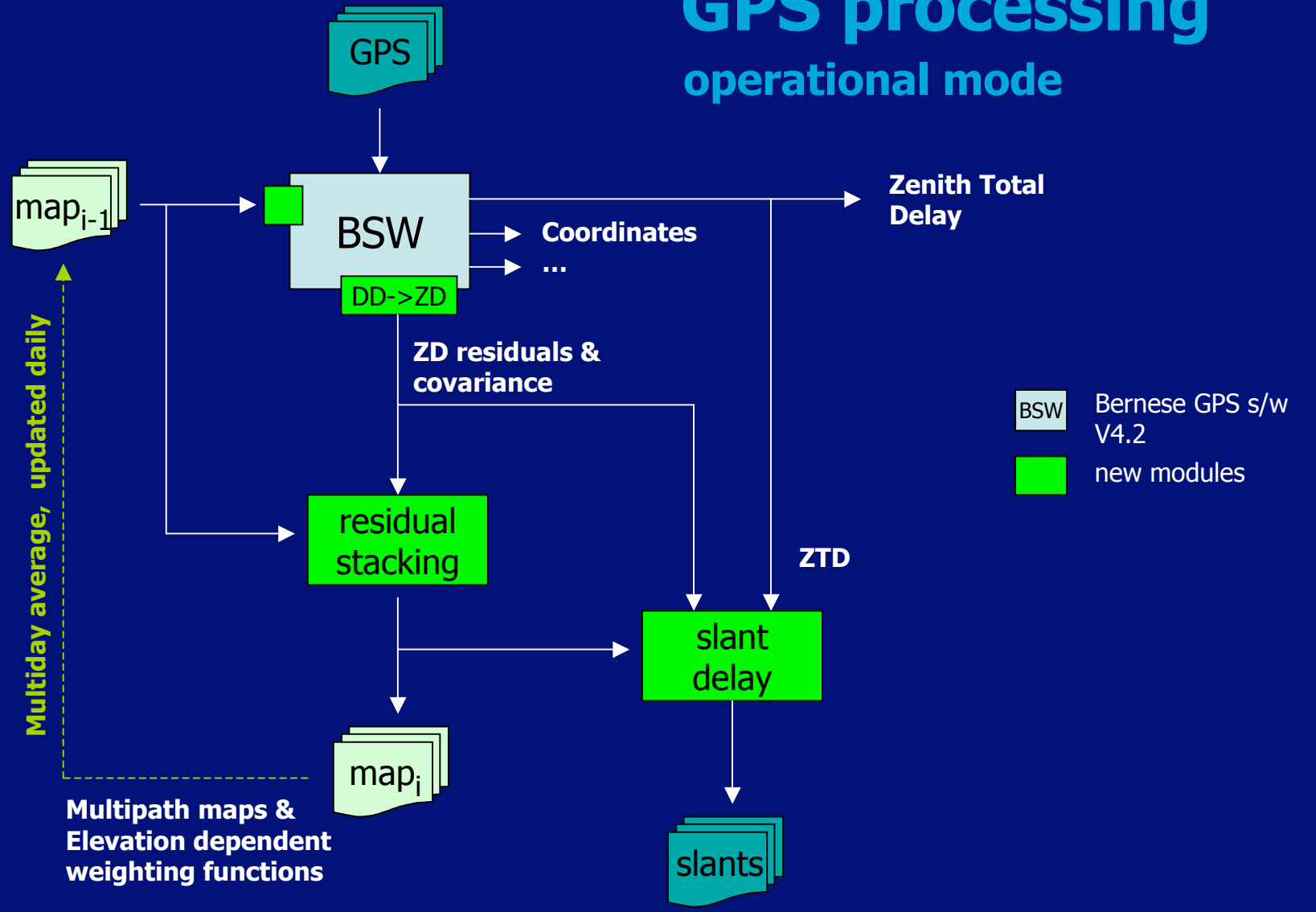
What has been done

- ✓ Developed code to retrieve undifferenced residuals and (co-) variance matrix information from the Bernese s/w
- ✓ Developed residual stacking code (Matlab) to estimate:
  - site dependent multipath and antenna phase center variations
  - elevation dependent weighting functions
- ✓ Adjusted the Bernese s/w to use previously determined multipath maps *and elevation dependent weighting functions (TBC)*
- ✓ Developed code for Slant Delay Estimation (not discussed here)
- ✓ Analysed 4 months of data for a small regional network
  - Several periods for 2000
  - Three month dataset for 2003 (May-July 2003)

Work carried out in the framework of TOUGH

GPS processing

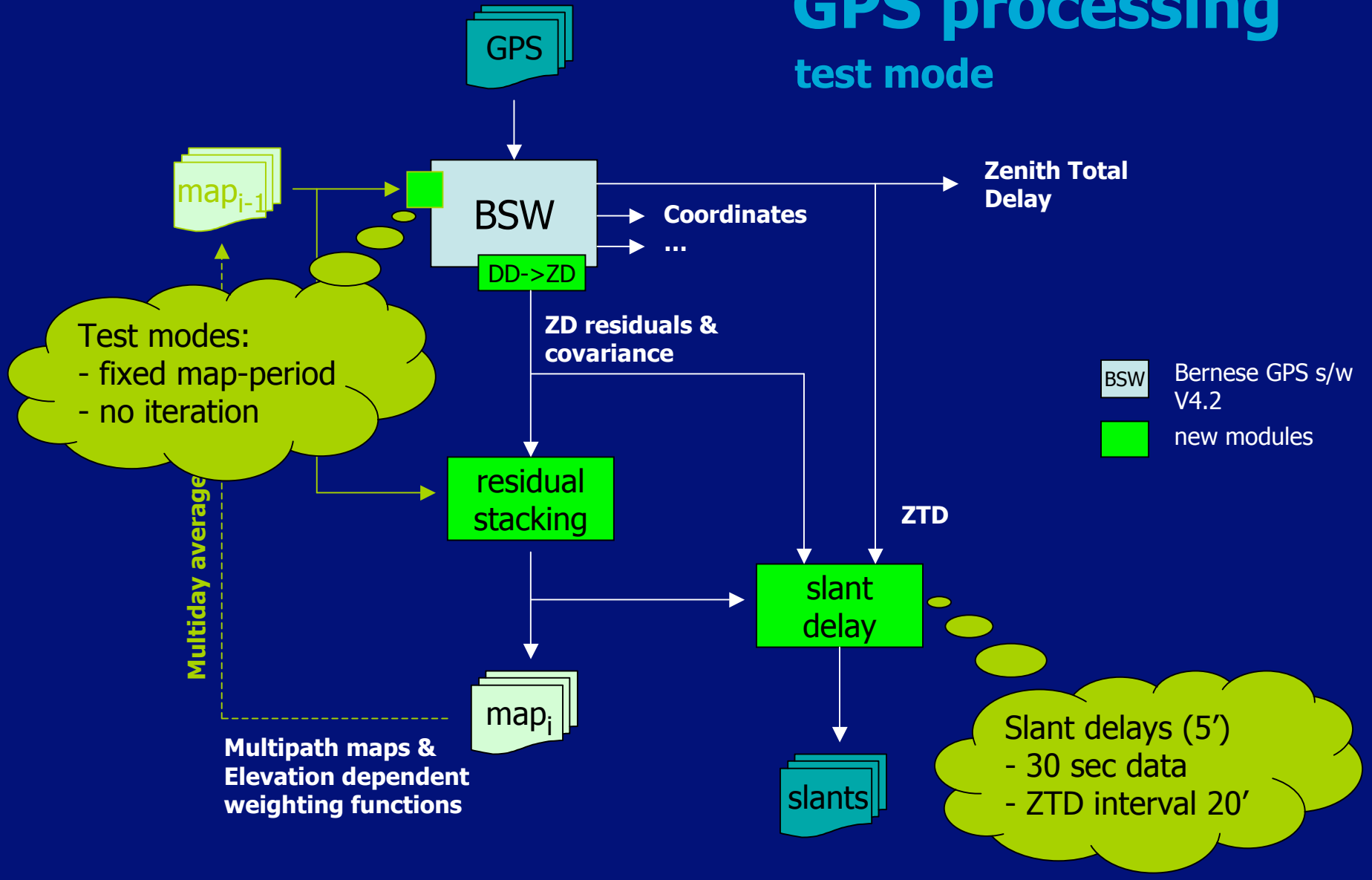
operational mode



TU Delft

GPS processing

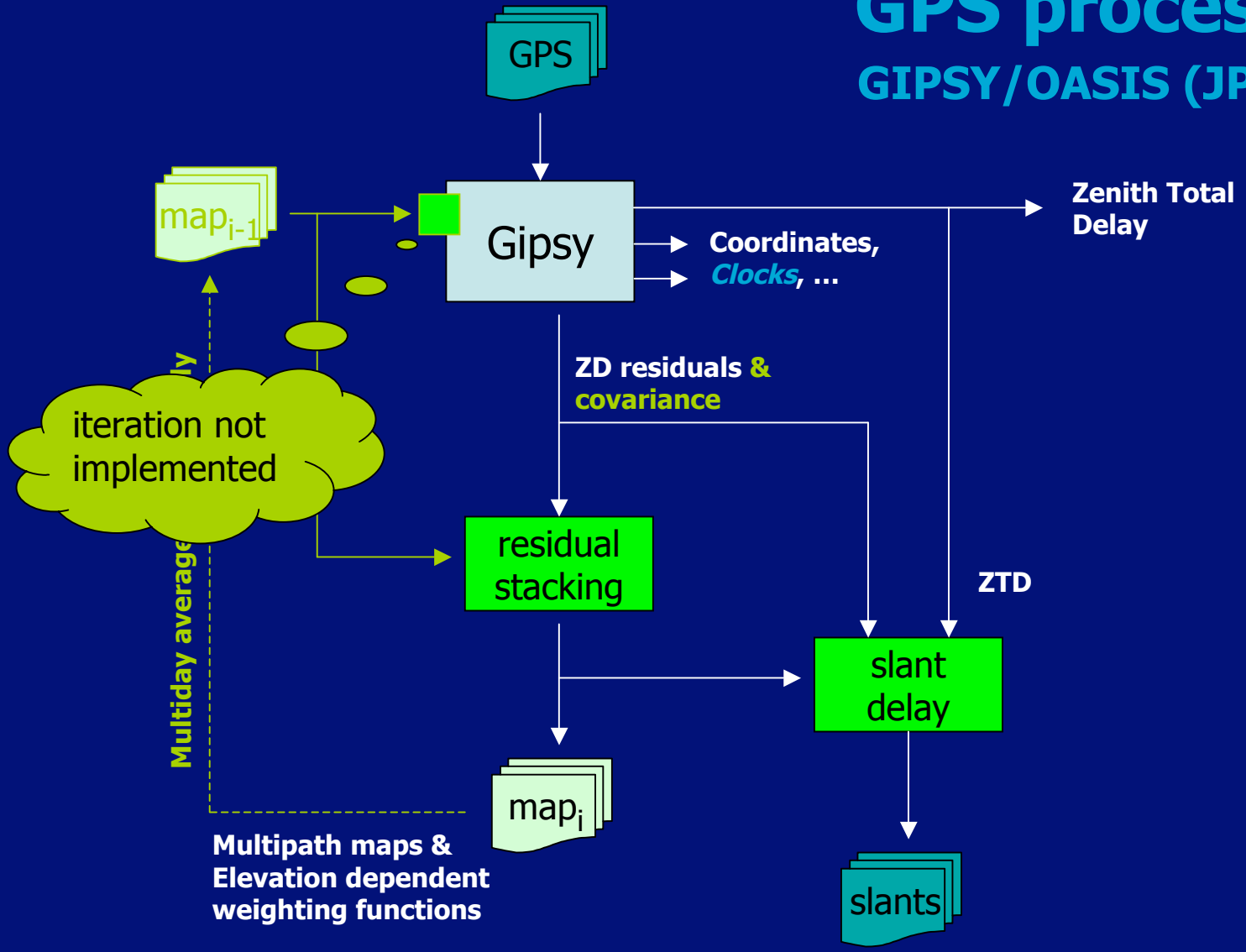
test mode



TU Delft

GPS processing

GIPSY/OASIS (JPL)



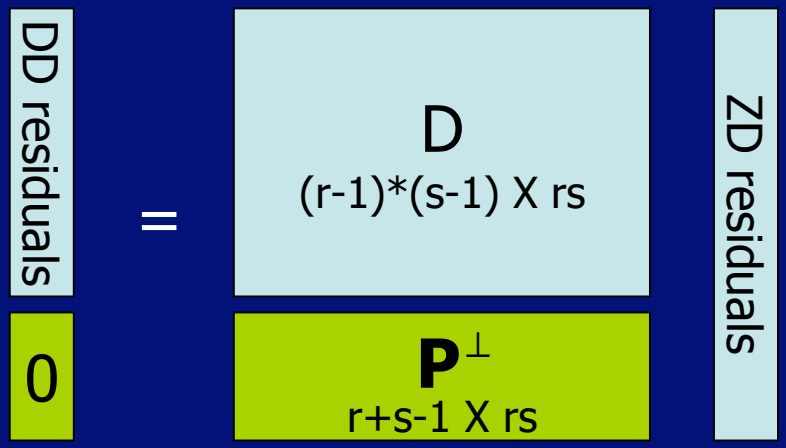
TU Delft

Undifferenced residuals (1)

- Undifferenced residuals are needed for the residual stacking, etc., but the Bernese s/w uses double differencing…
- Double difference processing is in princpile the same as undifferenced processing
  - in undifferenced processing clock errors are estimated
  - in double difference processing clock errors are eliminated
- Undifferenced residuals computed from double difference residuals
  - Certain linear combinations of undifferenced residuals are zero (must be because satellite and receiver clocks were estimated epoch by epoch)!
  - Use this information to solve the inverse relation
- Also compute covariance matrix of undifferenced residuals
- Implemented by Brigitte Gundlich into BSW 4.2, Alber et al.,…

Undifferenced residuals (2)

- Relation between double differenced residuals and undifferenced residuals

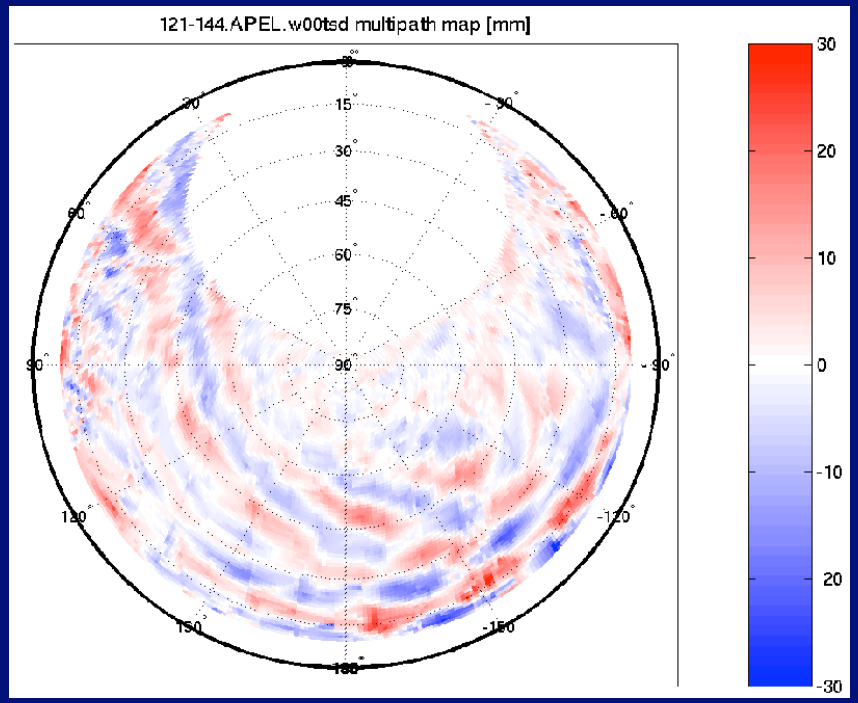


The matrix ■ follows from the clock estimation and depends on the weighting of the observations

- Undifferenced residuals follow from the inverse relation

TU Delft

Residual stacking – multipath maps



Example of a multipath map for Apeldoorn, May 1-24 2003 (1x1 degree bins in an equal area projection)

- To correct residuals (slant delays) for multipath [no iteration]
- To correct GPS observations for multipath (affects all parameters, including slants) [iteration]
- To quantify and visualize multipath/antenna effects:
  - Polar plots (w/ interpolation -> see example)
  - Elevation dependent phase delay plots (next)
  - Elevation dependent standard deviation plots (next)
- To re-weight observations

Residual Stacking – implementation

1. Equal area projection of the sky
2. Update daily binned maps (in equal area projection) with
   - Mean residual
   - Sum of squares of the residual
   - Number of data points (or cumulative weight)
3. Compute multi-day average of the binned maps
   - multi-day running average of the total effect
   - running average of previous days already applied in GPS processing software
   - daily maps are increments to this running average
4. Interpolate for visualization purposes and project back on the sphere (see previous slide)
5. Other visualizations

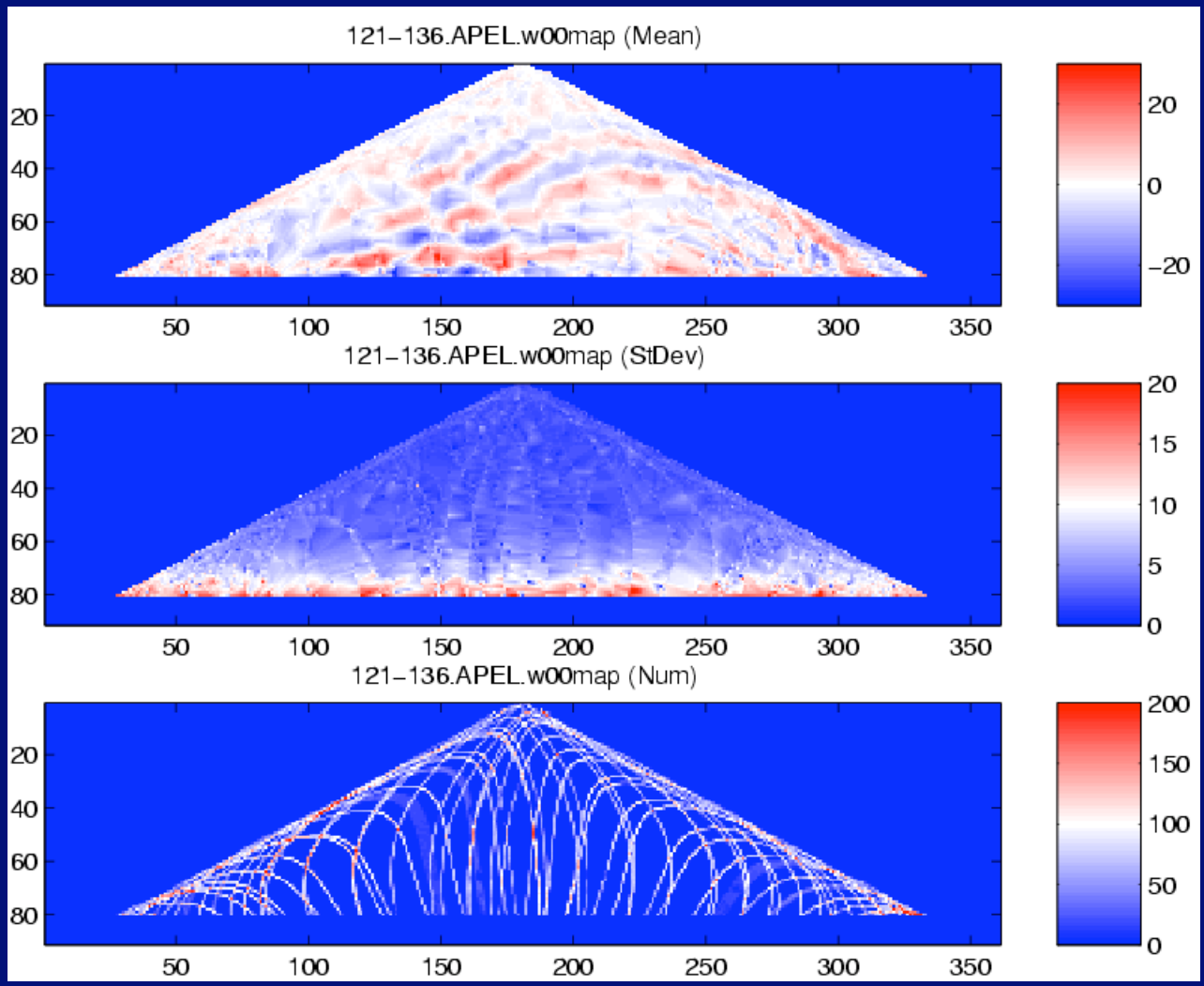
Residual stacking – basic maps

mean

RMS

(sum of squares)

count

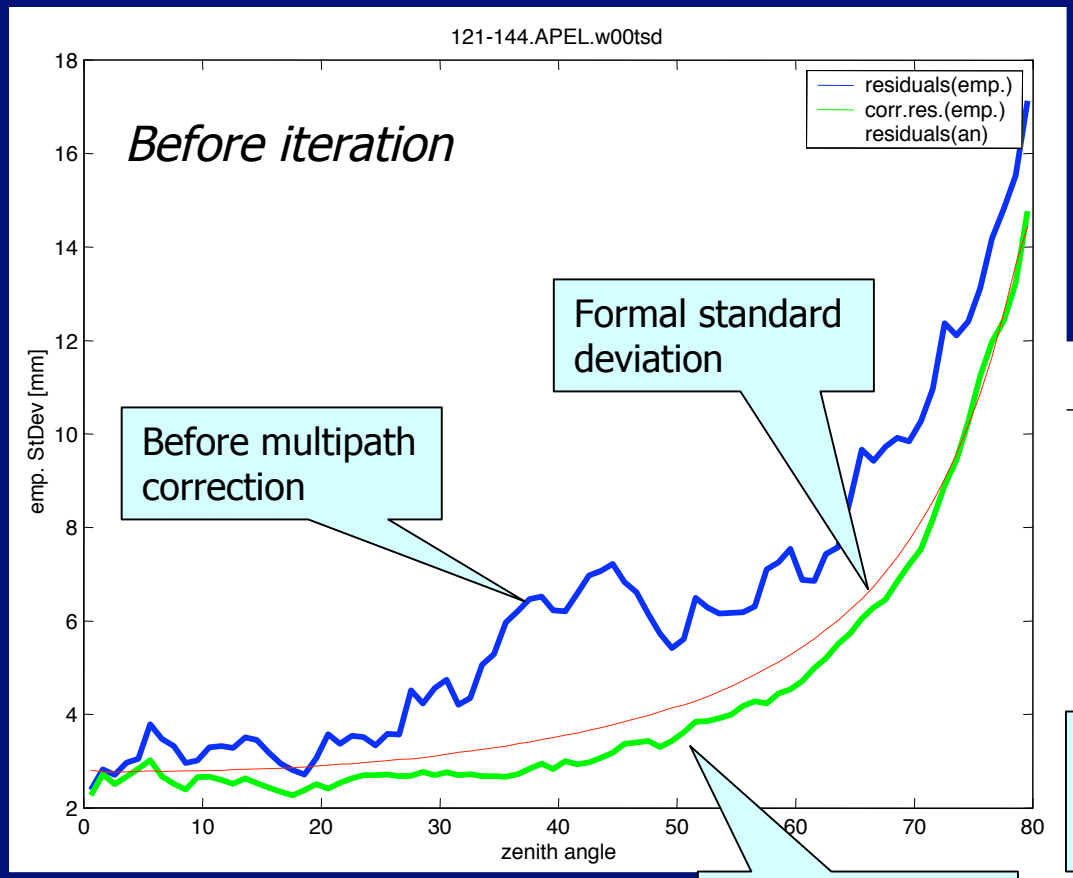


Equal area projection

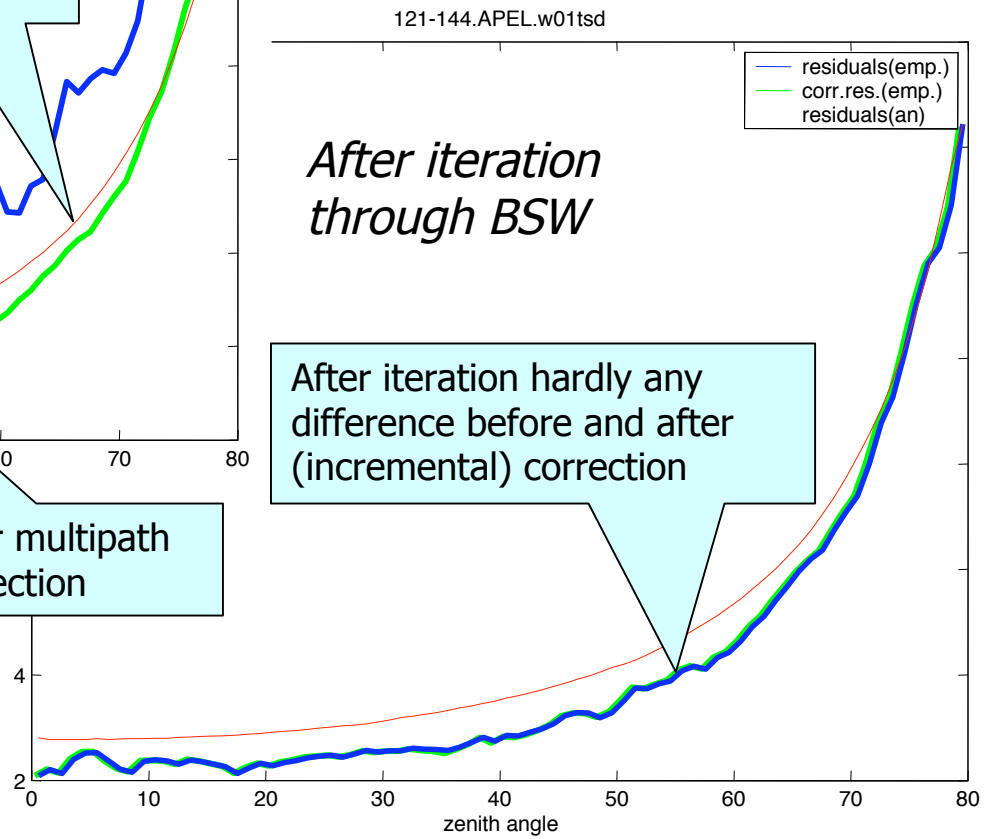
Interpolated for visualization purposes

TU Delft

Residual stacking – elev.dep. weighting

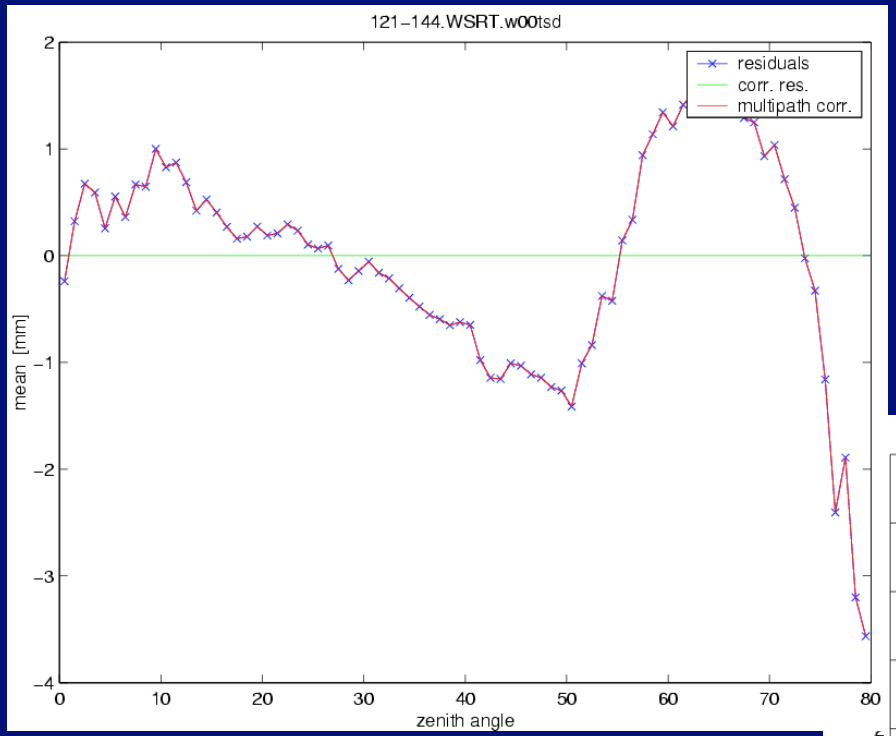


Example of elevation dependent standard deviation for Apeldoorn, May 1-24 2003



Big improvement in standard deviation

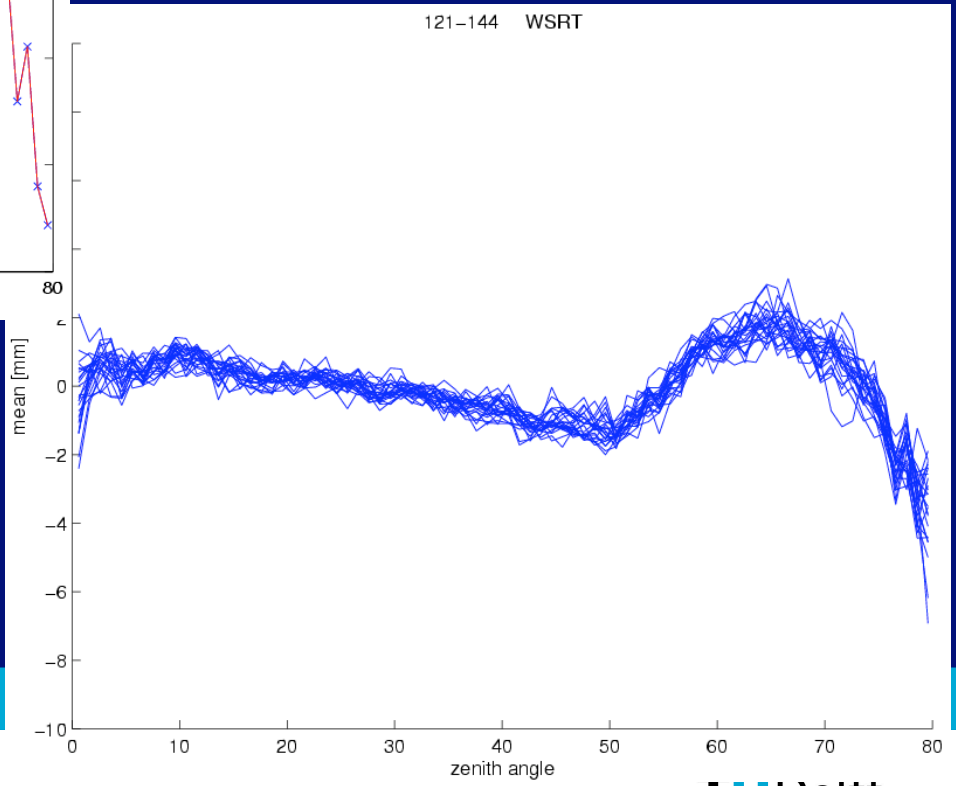
Residual stacking – elev.dep. Delay (1)



Example of a elevation dependent delay map for Westerbork (WSRT), May 1-24 2003 (1 degree bins)

Caused by un-modeled antenna radome

Multiday average



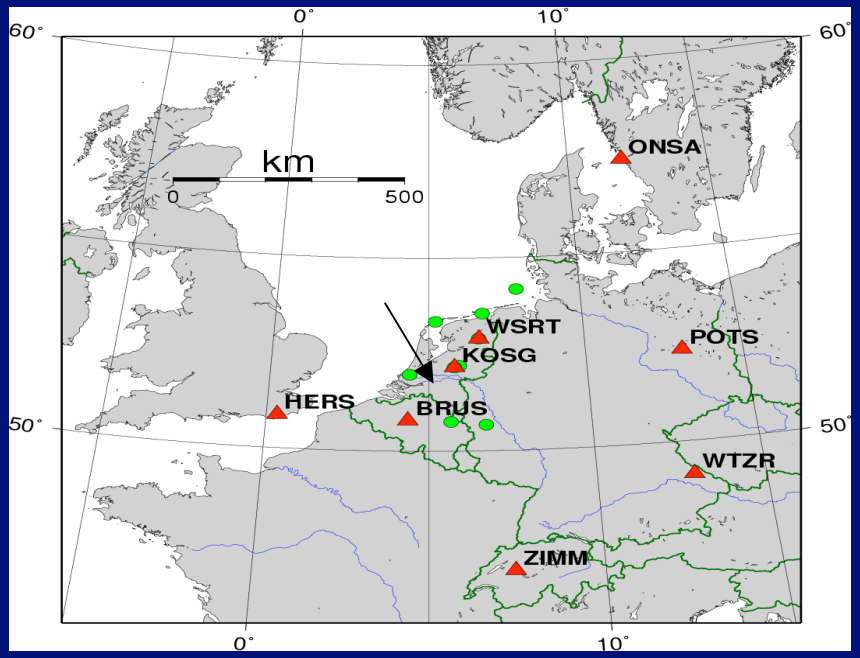
Daily results

Cannot correct all problems

Residual stacking – elev.dep. Delay (2)

- Can we use the elevation dependent residuals stacks as antenna or radome calibrations? Answer: "no"
- Several functions of observations have already been used
  - A constant delay $d(z)=a_1$ will show up in the clocks
  - $d(z)=a_2*\cos(z)$ will show up as a error in height
  - $d(z)=a_3/\cos(z)$ will show up as ZTD error
- $a_2*\cos(z)$ and $a_3/\cos(z)$ functions will therefore not be present in the residuals maps, unless we constrain the height and ZTD
- "Yes" in a local setup with calibrated reference antenna on an nearby marker with good local survey data
- "Yes" during an antenna change??

Test Dataset



2003 dataset:
- BBC2 campaign
- Cabauw incl. (GPS, WVR, RS,…)
- ZTD interval 20 min

Selected periods for 2000 and 2003
Network of 16 receivers
Various receivers types
Several co-located stations
Bernese s/w 4.2 (wet Niell)
Residual stacking
  - Multipath maps
  - Elev. Dep weighting fie

  Iterated through bernese

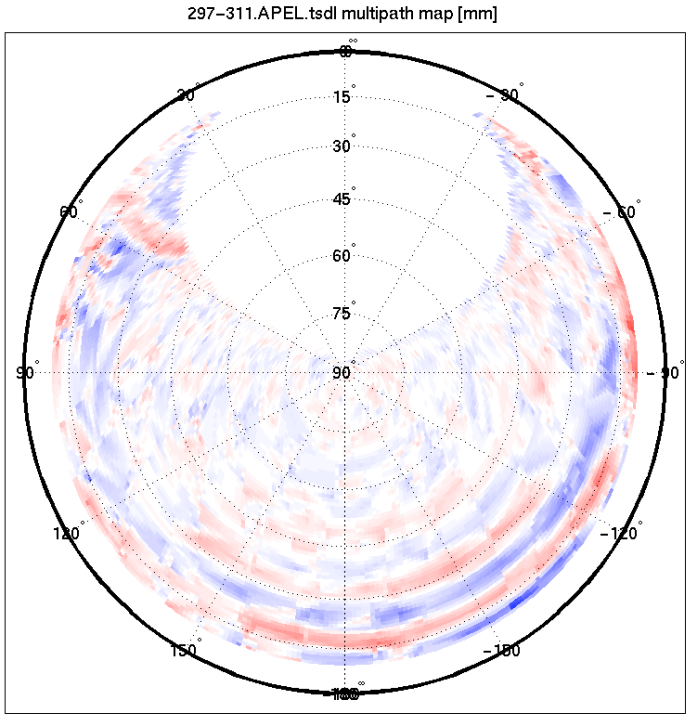
Slant delays
  - Corrected for multipath
  - More frequent than ZTD

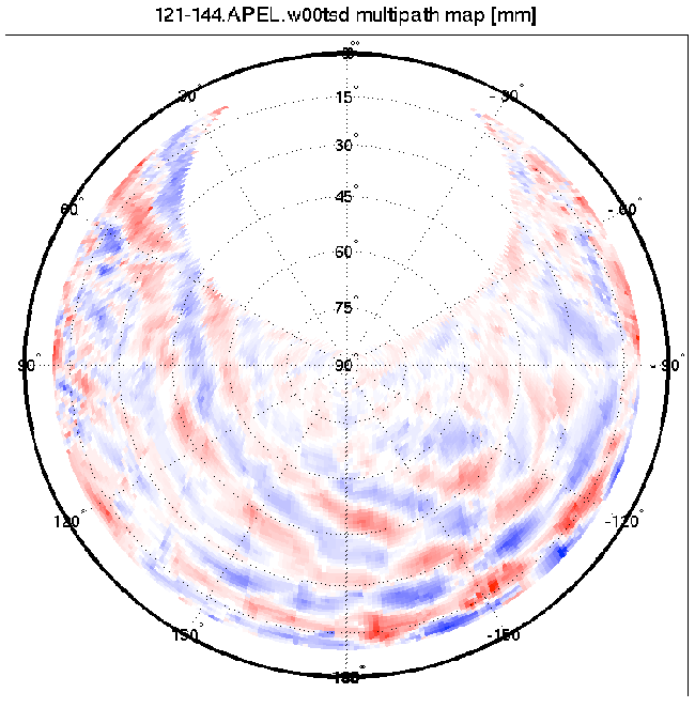
http://gnss1.lr.tudelft.nl/tough

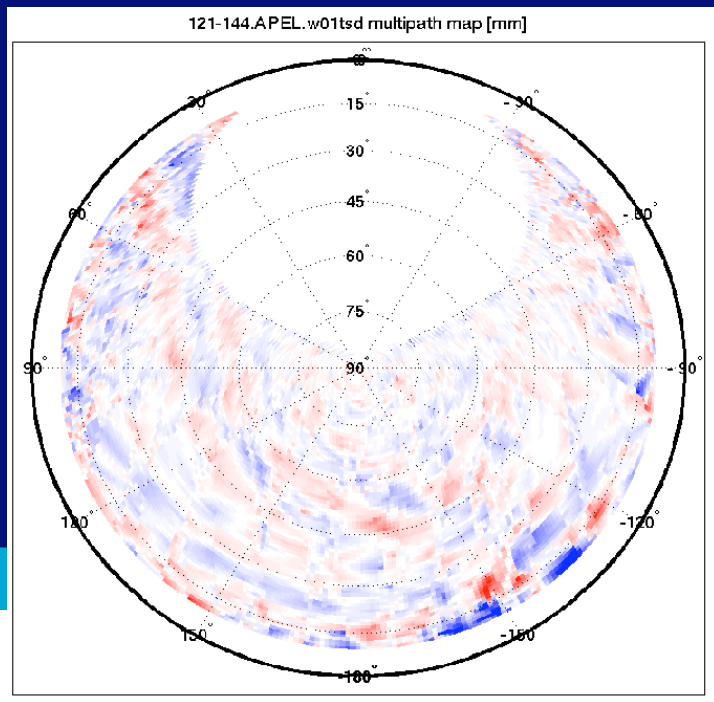
TU Delft

Multipath maps

2000 Iter 0	
2003 Iter 0	2003 Iter 1

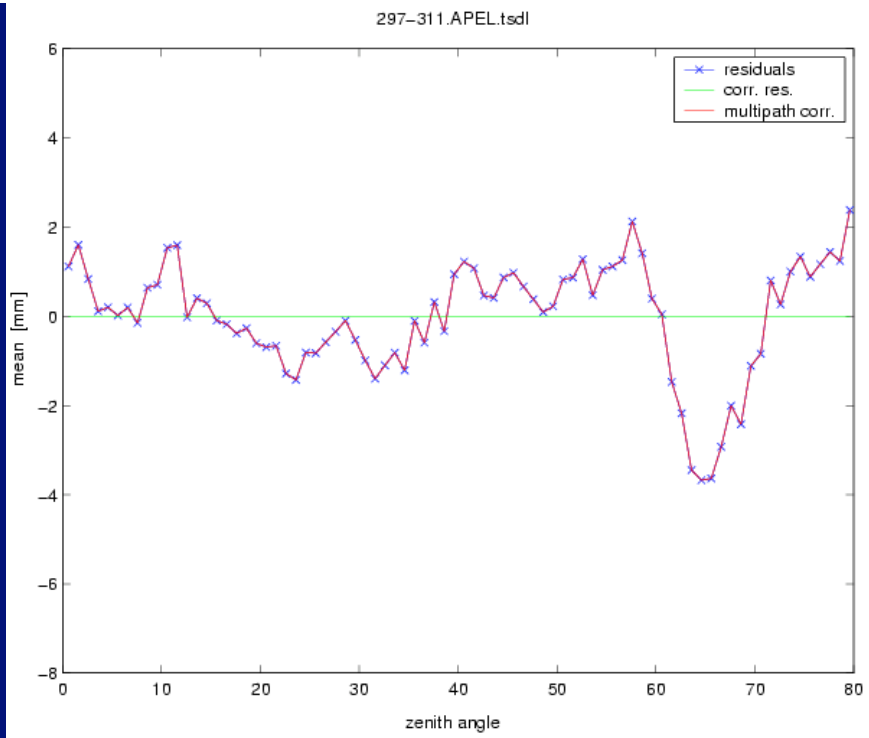


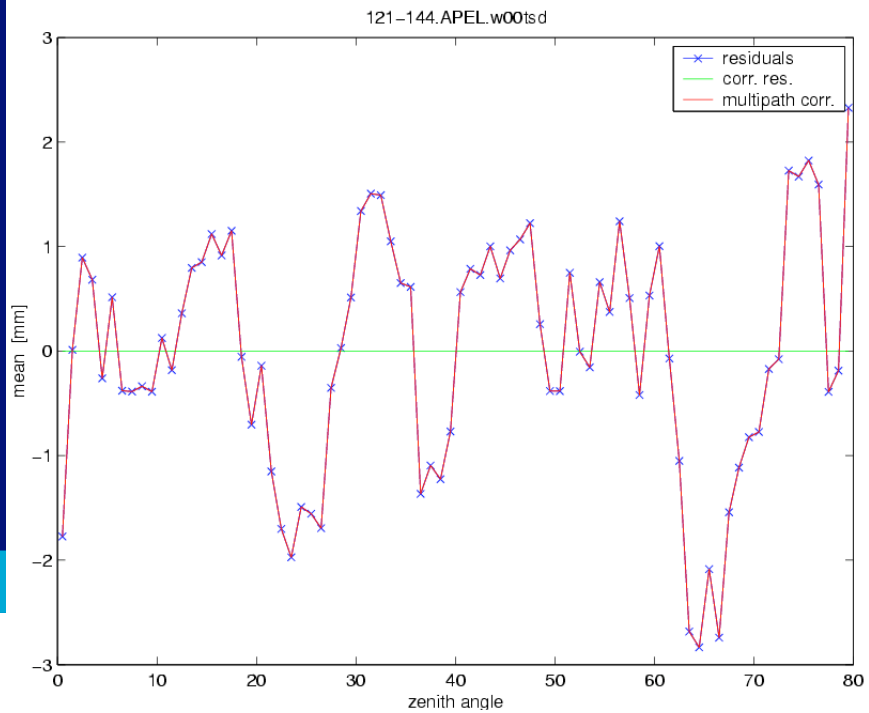


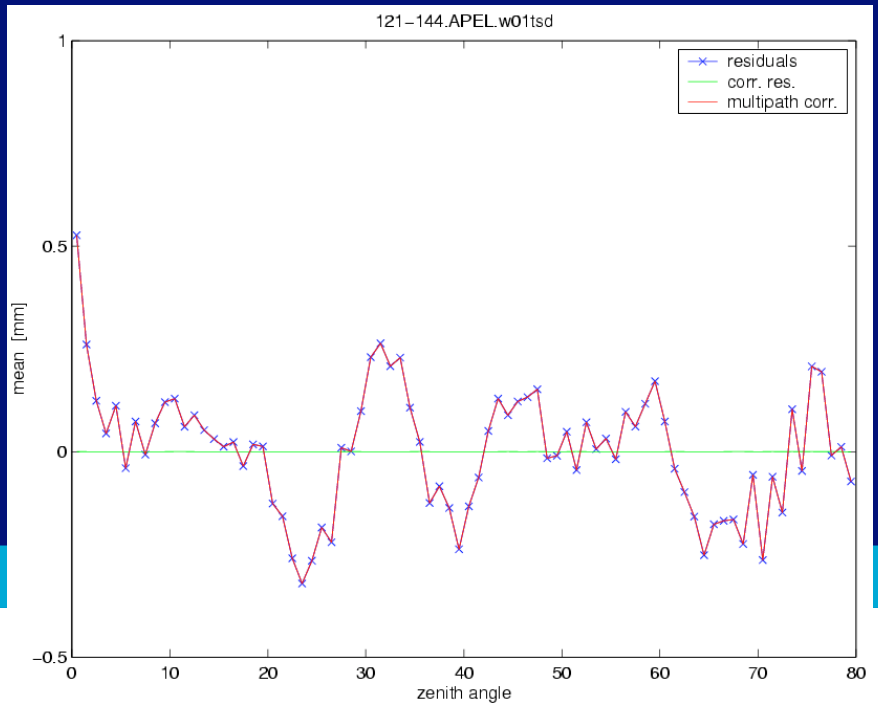


Elevation Dependent Delay

2000 Iter 0	
2003 Iter 0	2003 Iter 1

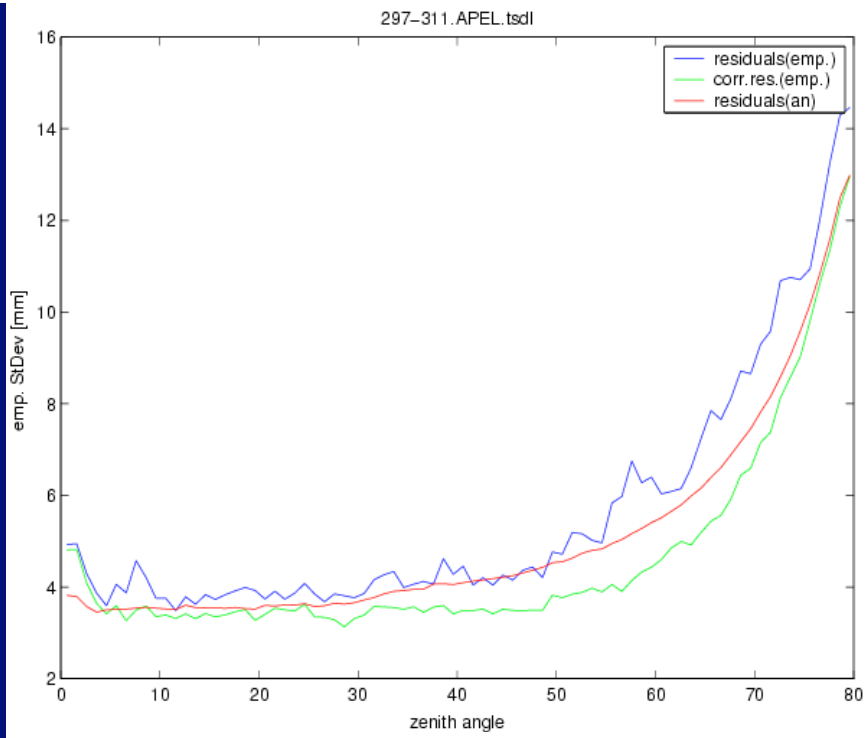


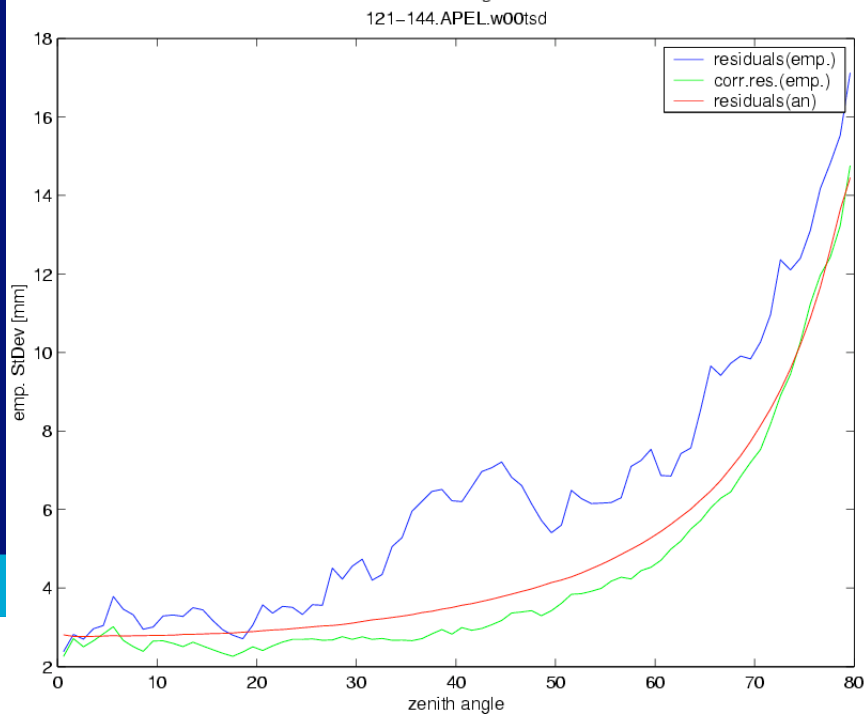


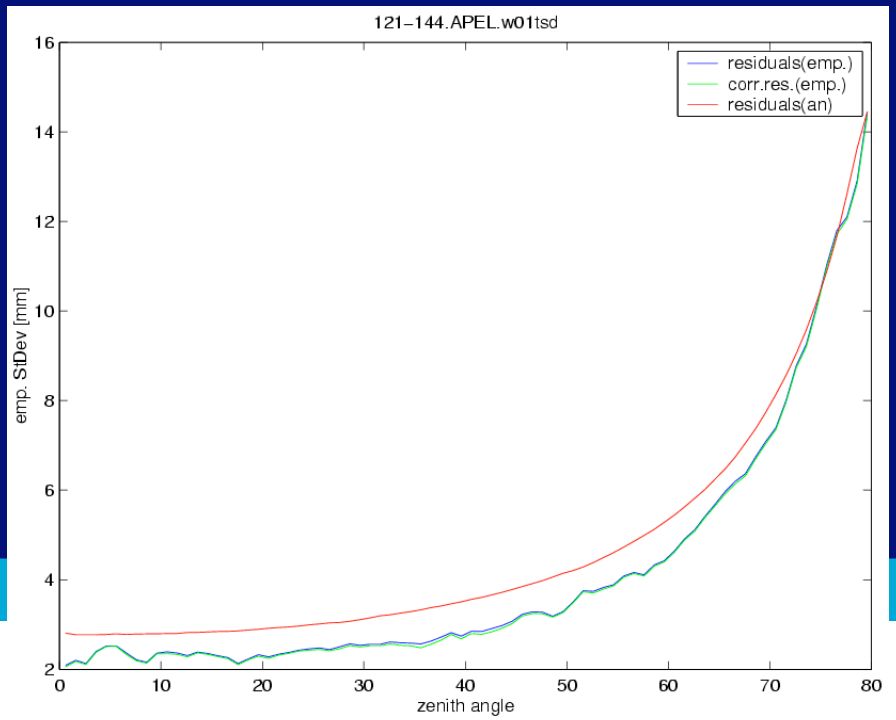


Rms of the residuals

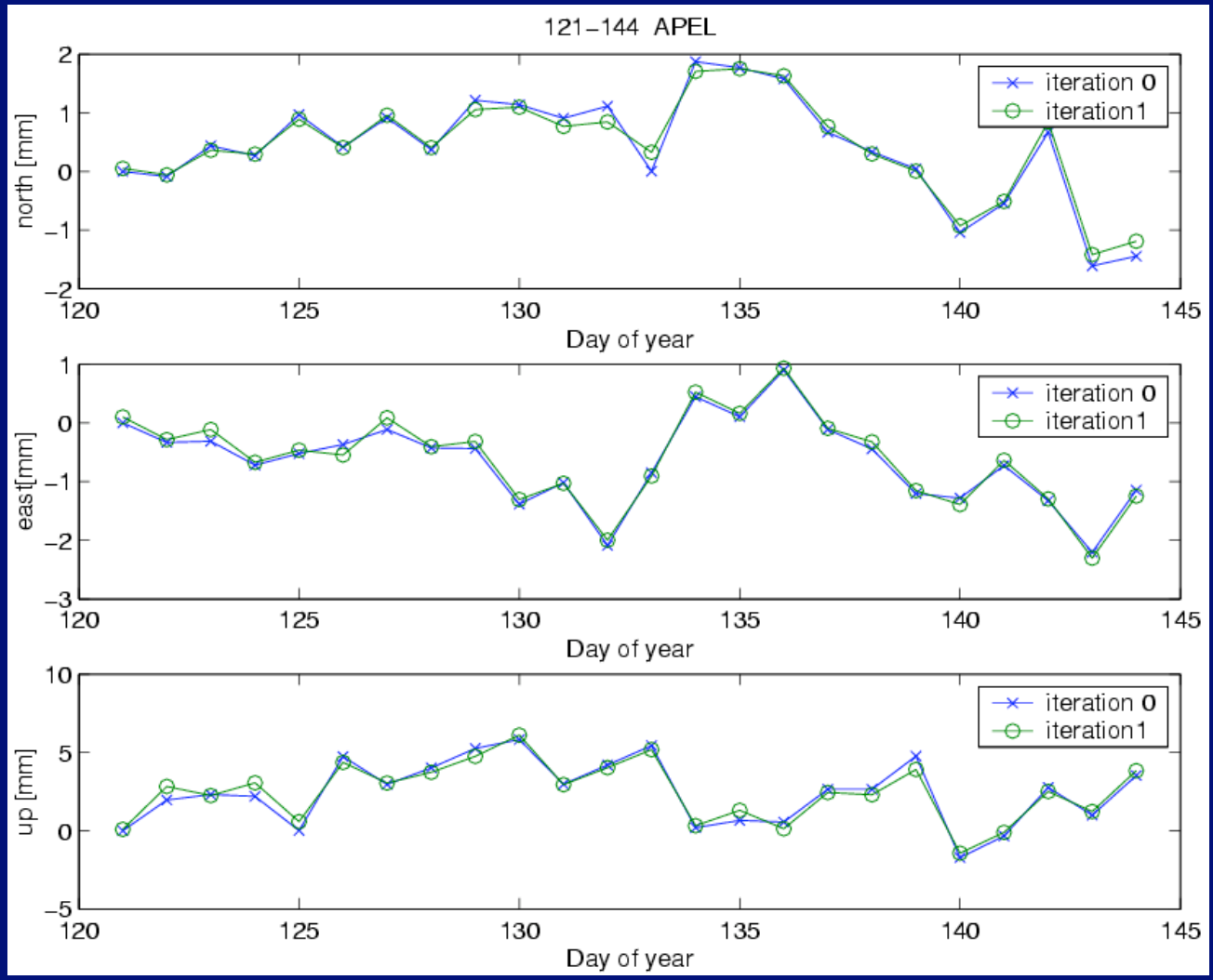
2000 Iter 0	
2003 Iter 0	2003 Iter 1





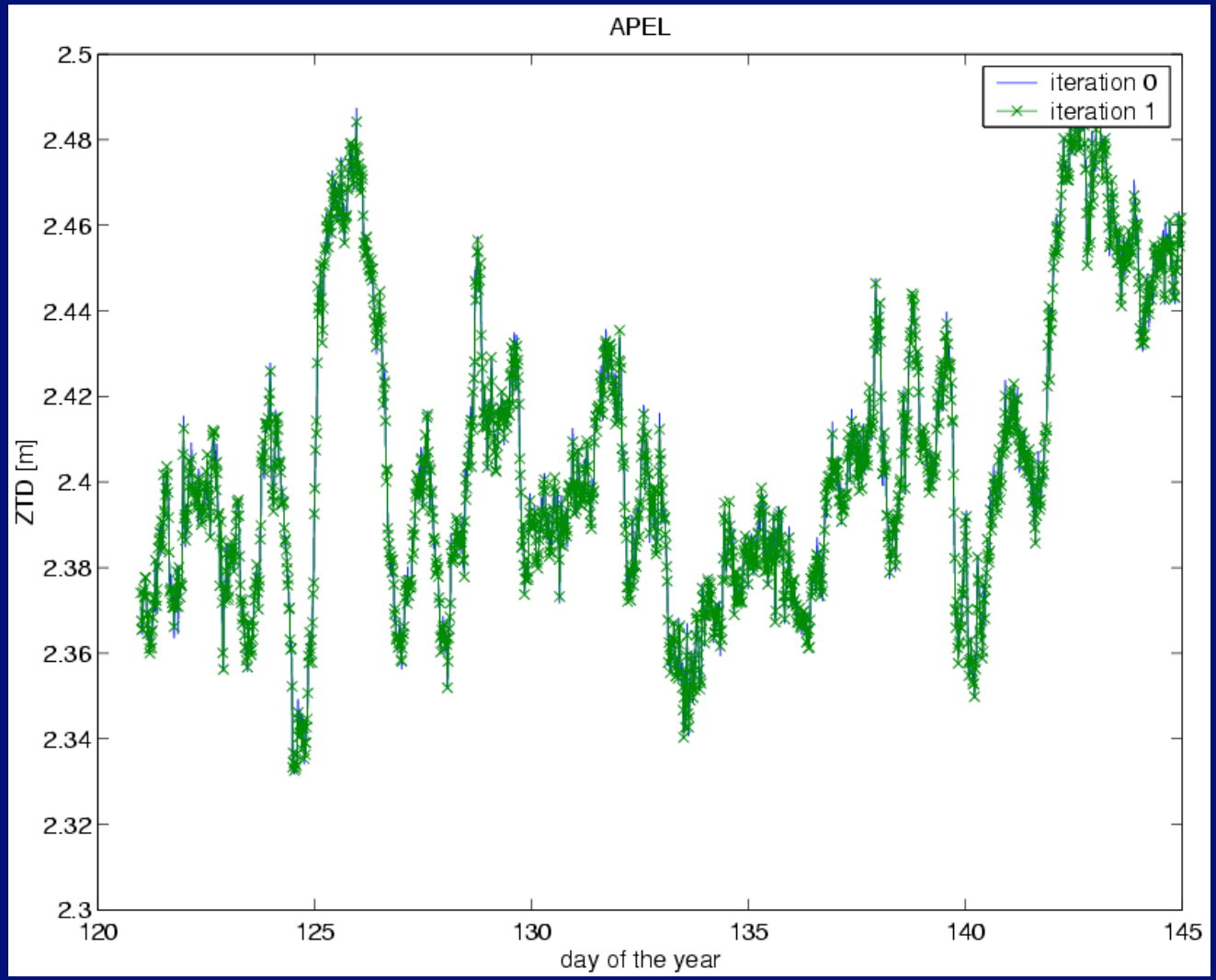


Effect on coordinates



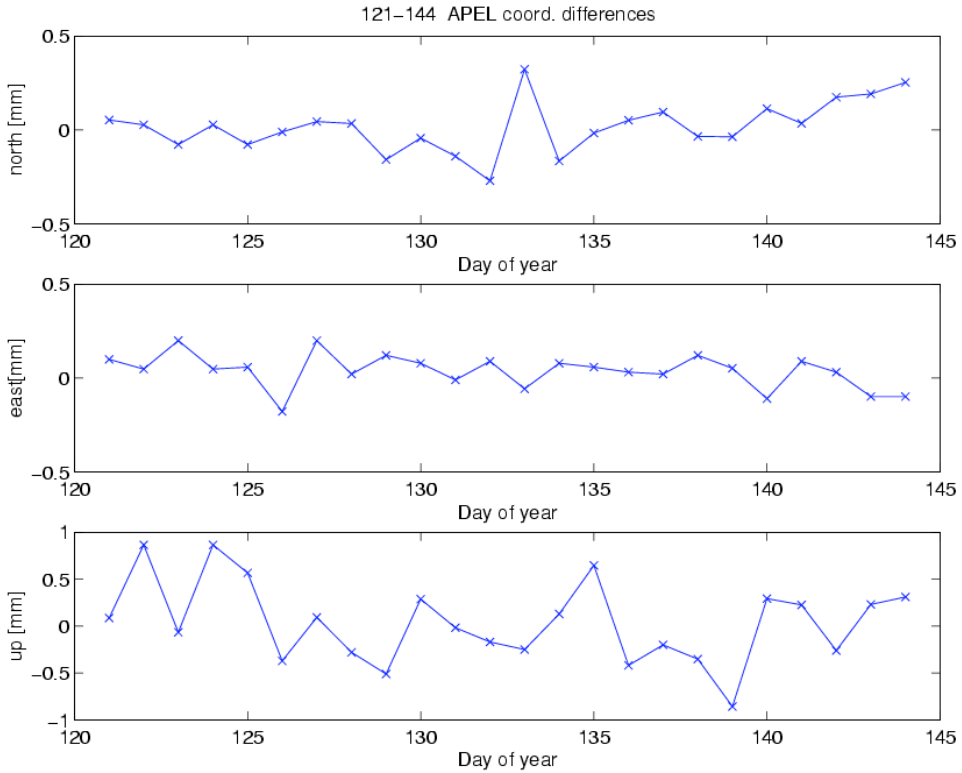
TU Delft

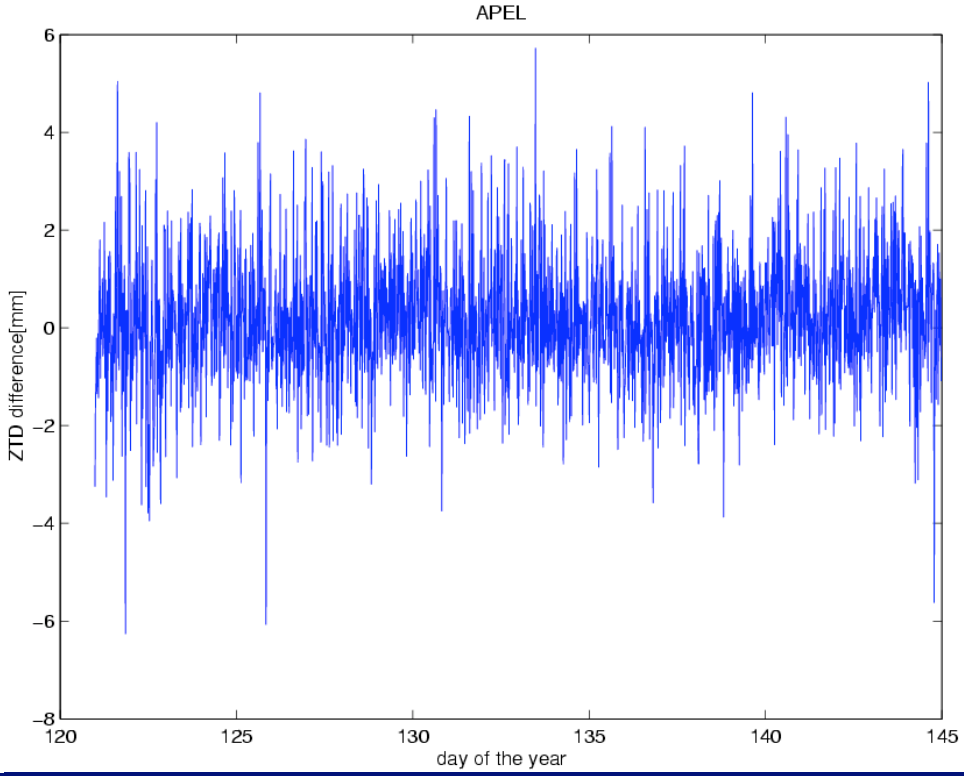
Effect on ZTD



TU Delft

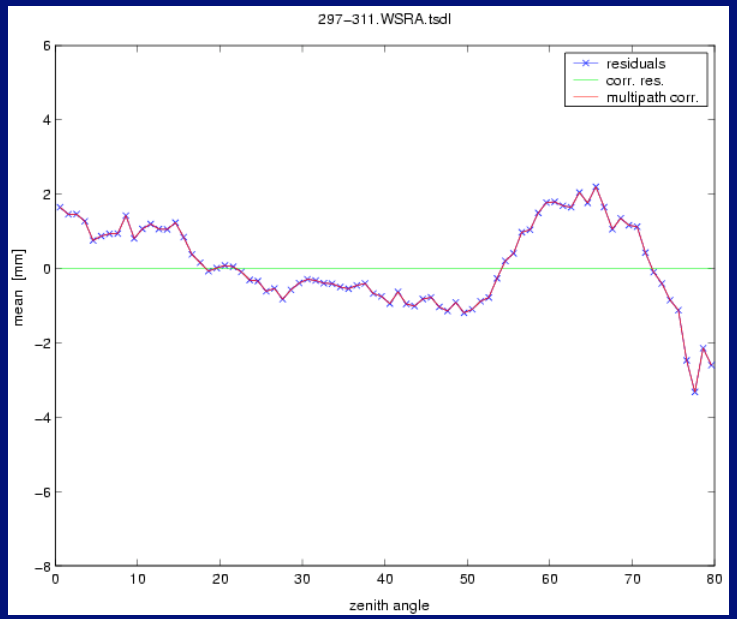
Iteration 01 – Iteration 00

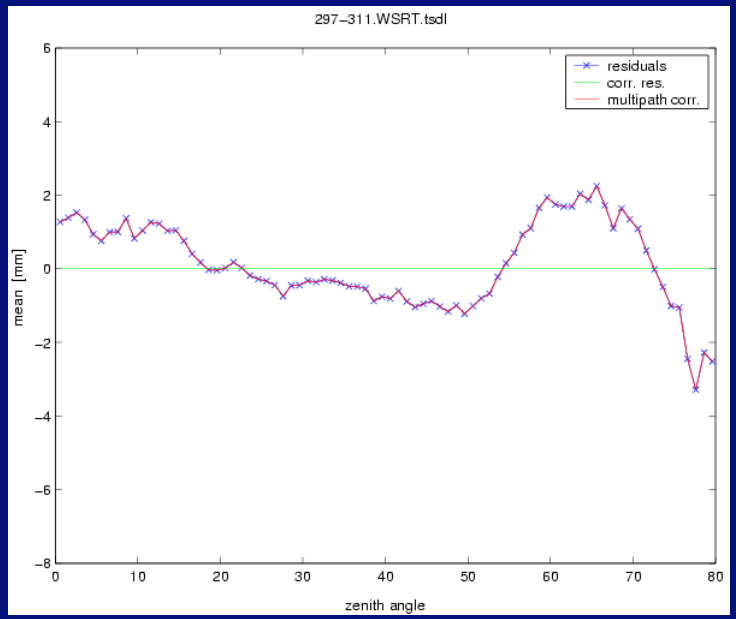


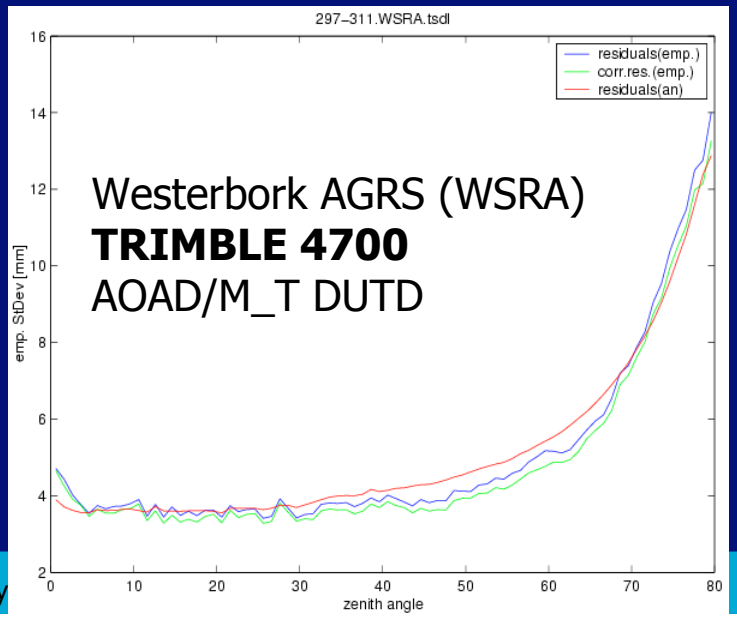


TU Delft

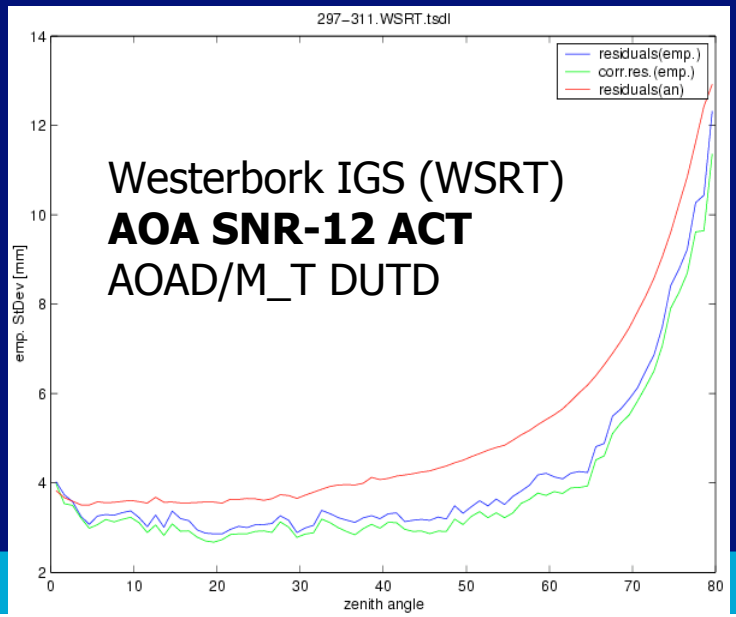
Same antenna; different receivers







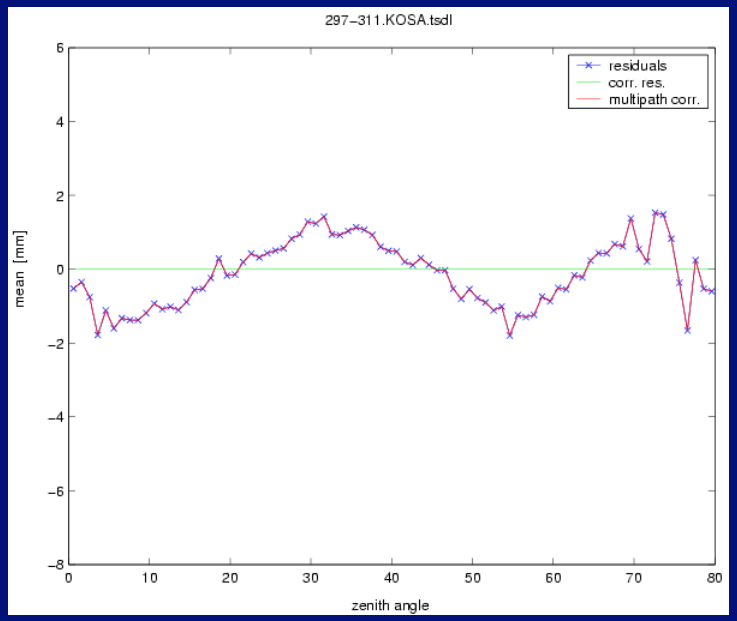
Westerbork AGRS (WSRA)
TRIMBLE 4700
AOAD/M_T DUTD

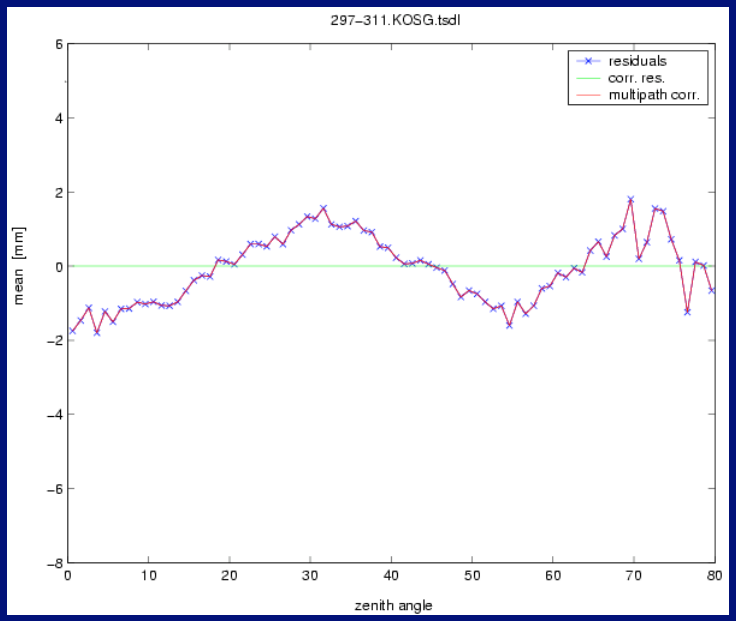


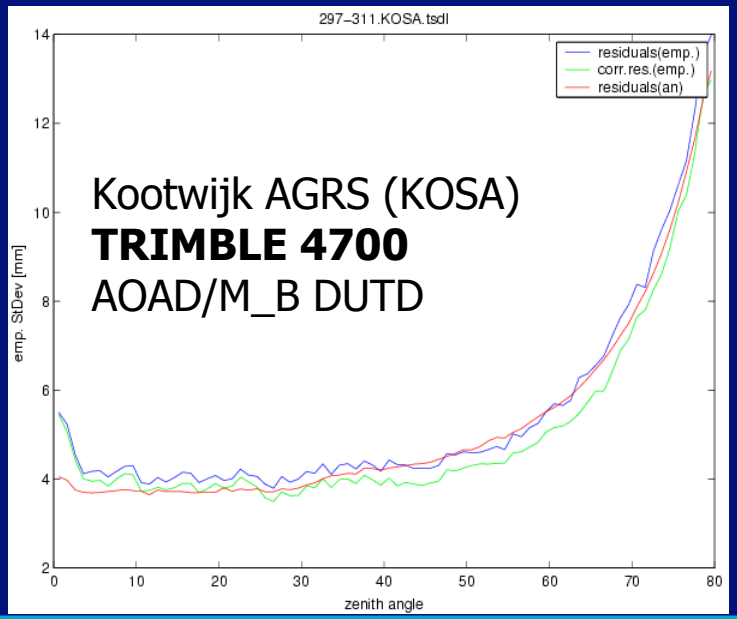
Westerbork IGS (WSRT)
AOA SNR-12 ACT
AOAD/M_T DUTD

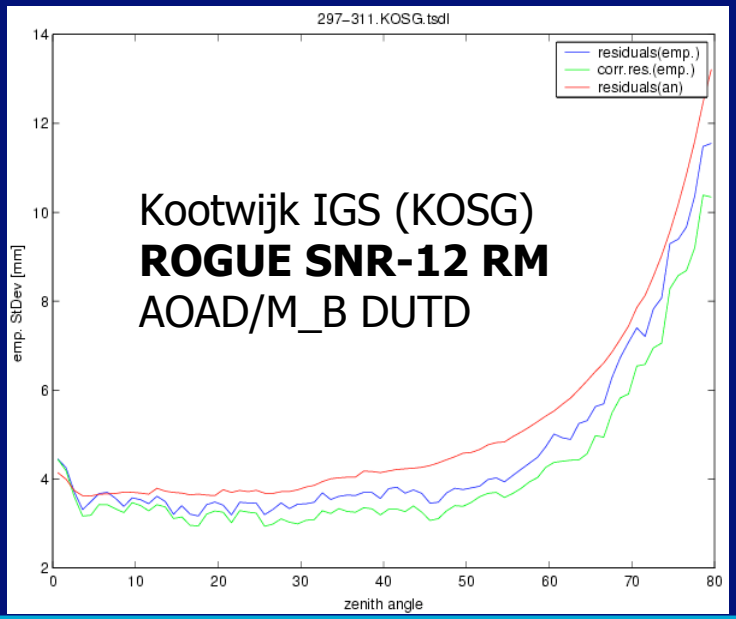
TU Delft

Same antenna; different receivers



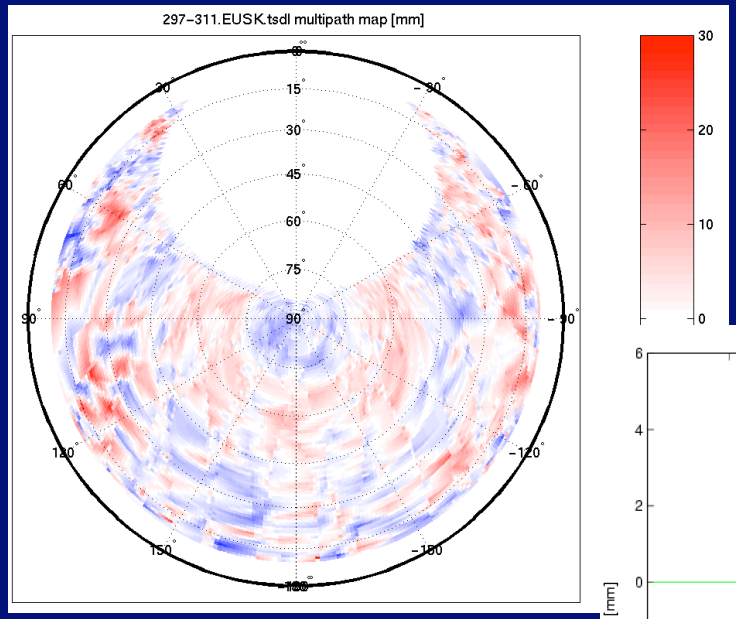


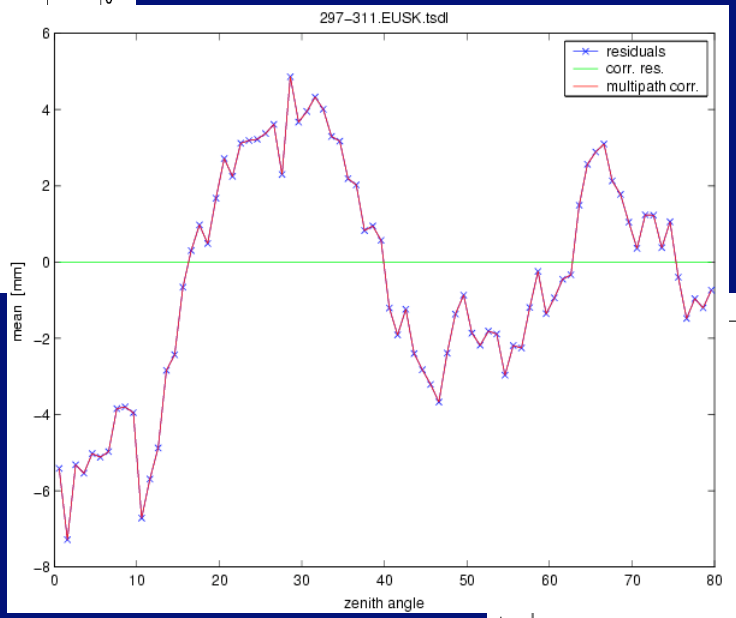


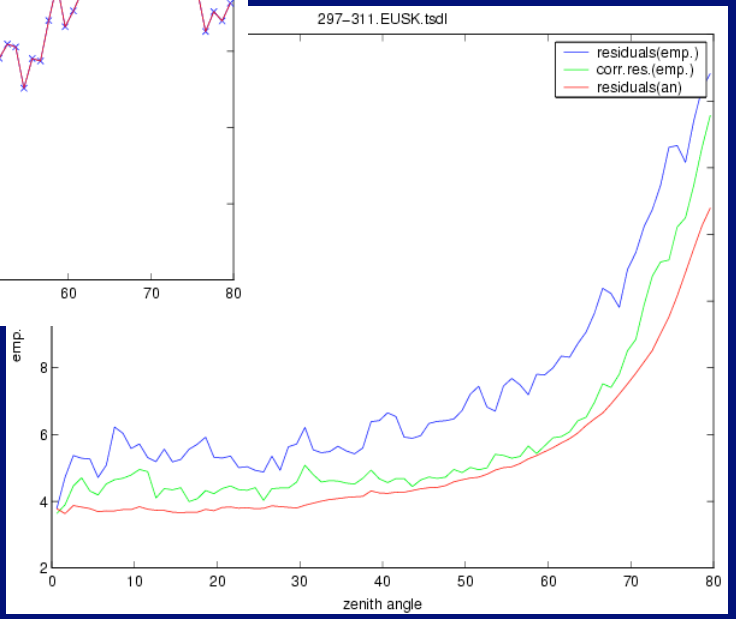


TU Delft

Euskirchen (EUSK)
TRIMBLE 4000SSI
TRM22020.00+GP

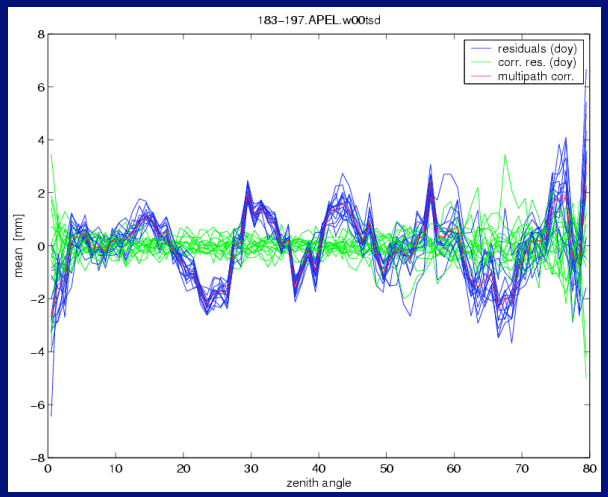


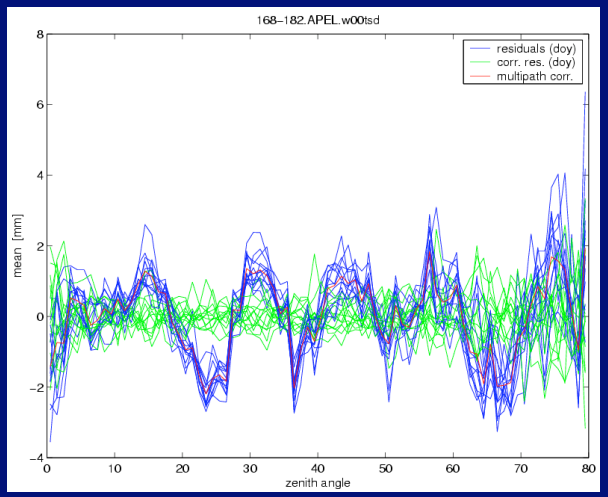


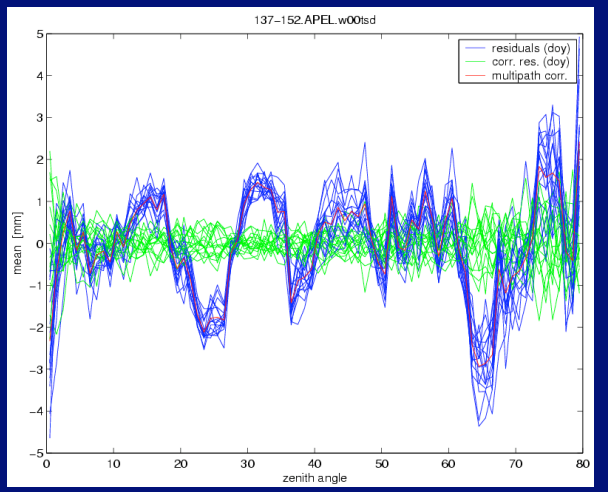


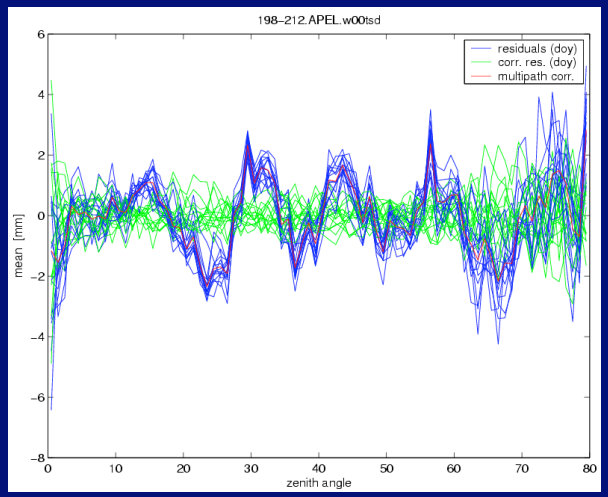
TU Delft

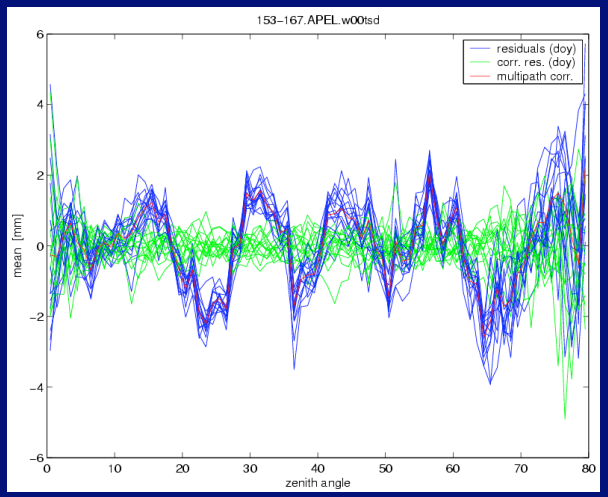
Example of 3 Month repeatability

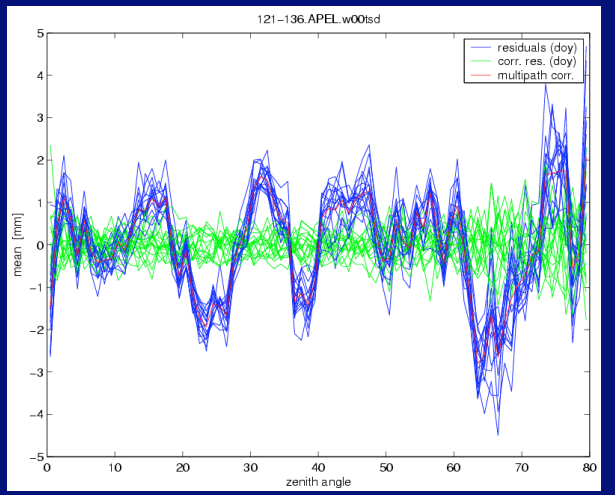




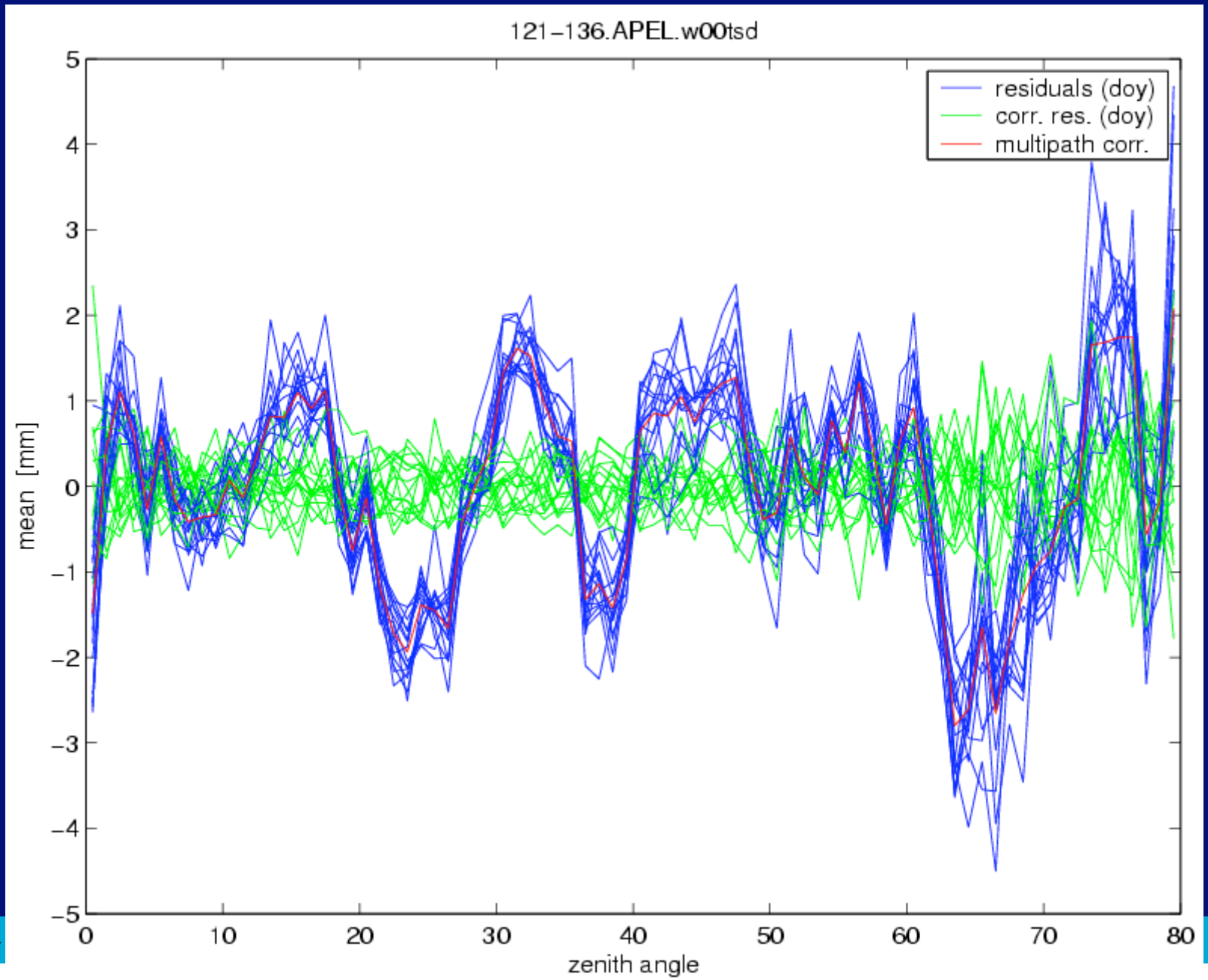






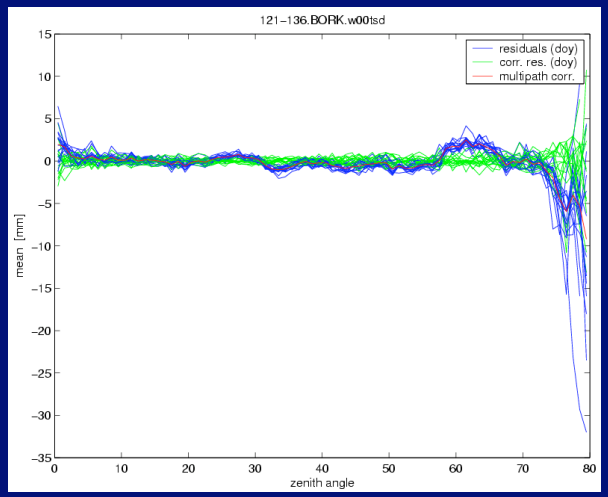


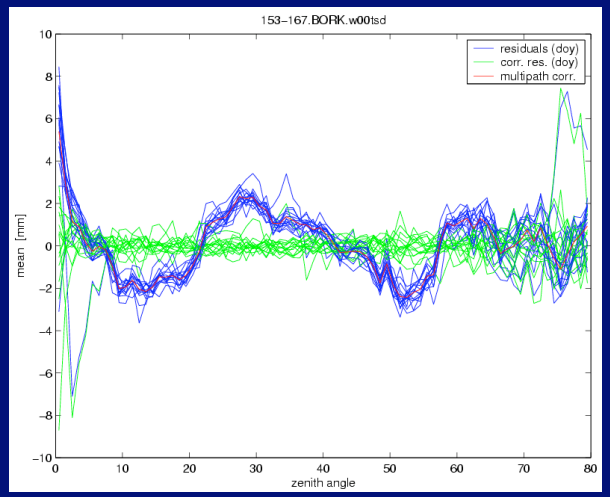
TU Delft

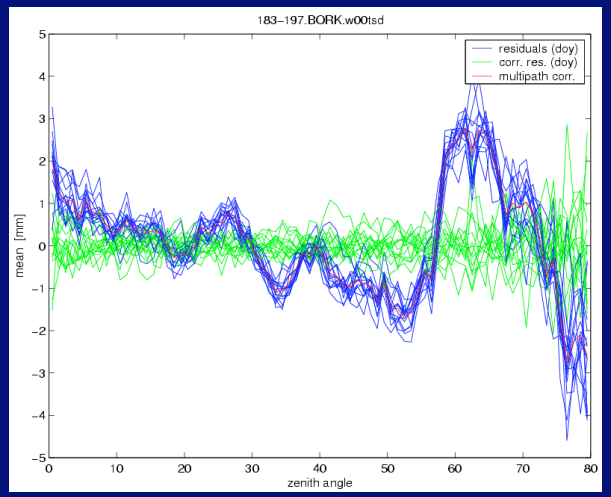

121–136.APEL.w00tsd
residuals (doy)
corr. res. (doy)
multipath corr.
mean [mm]
zenith angle
5
4
3
2
1
0
−1
−2
−3
−4
−5
0
10
20
30
40
50
60
70
80

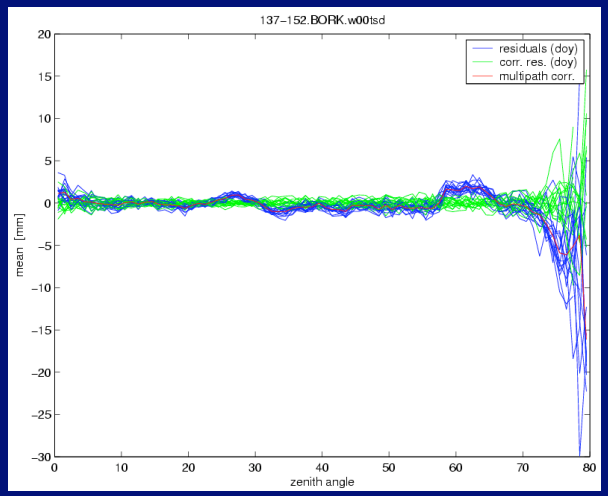
TU Delft

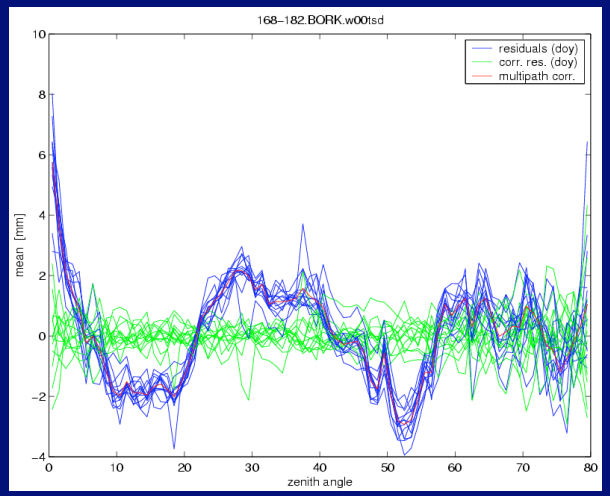
Effect of antenna changes (BORK, 2x)

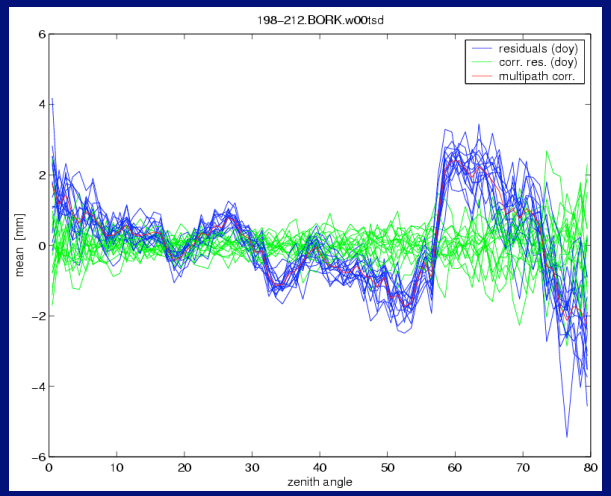






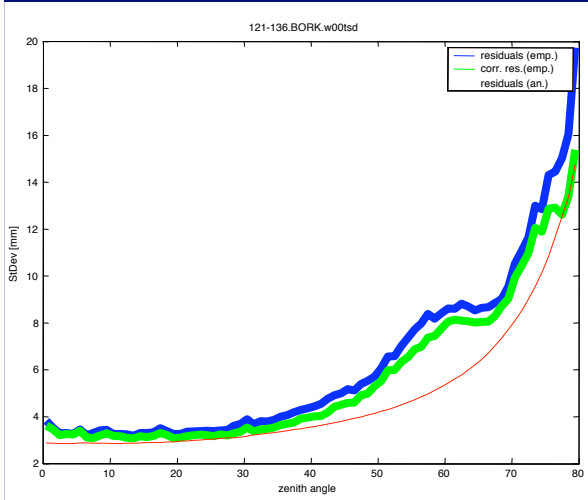


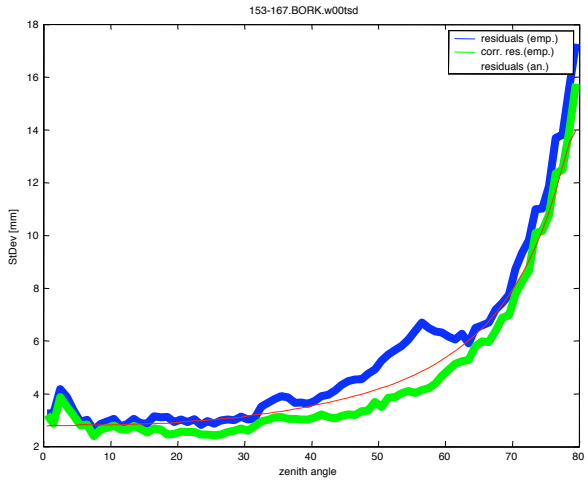


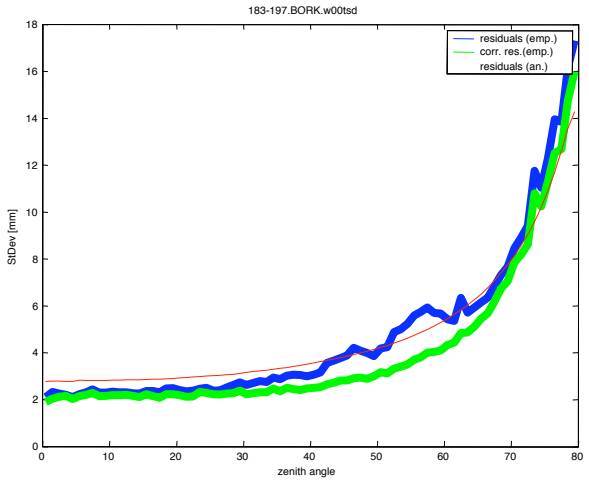


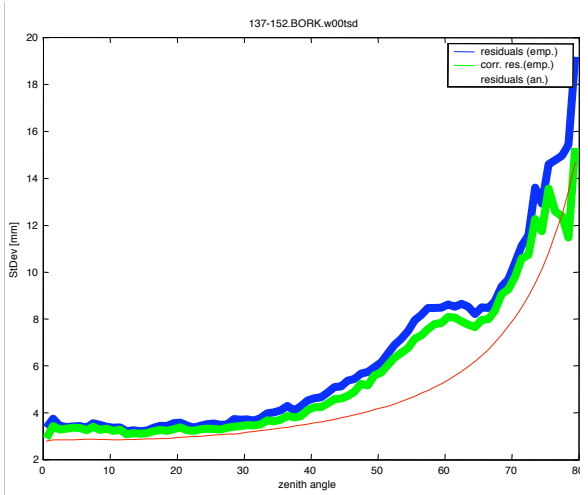
TU Delft

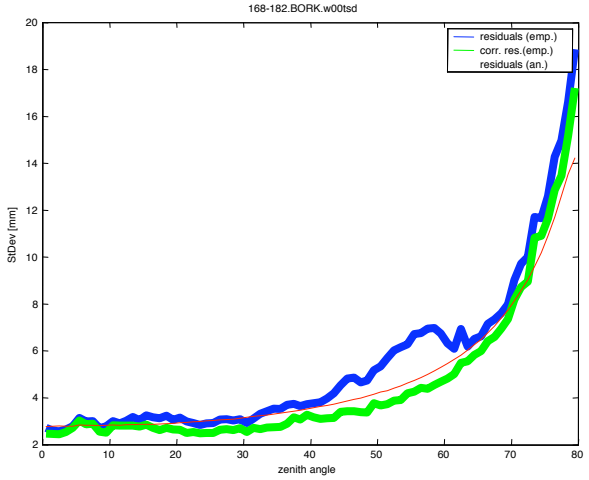
Effect of antenna changes (BORK, 2x)

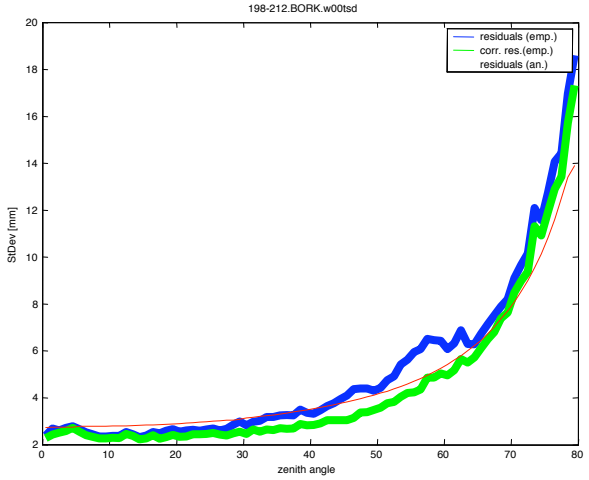












TU Delft

Other applications of ZD residuals

- Computation of slant-delays
- Quality control
  - Detecting misbehaving satellites
  - Detecting misbehaving stations
  - Dececting bad data periods
- Variance component estimation
  - Standard deviation for different systems/signals (e.g. GPS, GLONASS)
  - Satellites, receivers, stations,…
  - …

Conclusions

- Residual stacking useful tool to study multipath; antenna phase delays, antenna changes and antenna models; and receiver performance
- Multipath correction feature:
  - Absolutely necessary for slant delays (multipath can be 2-3 cm)
  - Affect the coordinates only at the mm level and the ZTD's at the level of a few mm
- Is not really necessary to implement in the AC's operational processing; maybe only as diagnostic tool
- Needs to be ported to BSW 5.0

Contact information

H. Van der Marel
Faculty of Aerospace Engineering (DEOS/MGP)
Kluyverweg 1, 2629 HS Delft
P.O.Box 5058, 2600 GB Delft
Netherlands
Fax: +31 15 278 3711 Tel: +31 15 278 4907
H.vanderMarel@tudelft.nl

http://gnss1.lr.tudelft.nl/tough/