

# **TerraSAR-X (& TanDEM-X) Radio Occultation processing at GFZ: Center-to-center comparison and validation**

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## Motivation

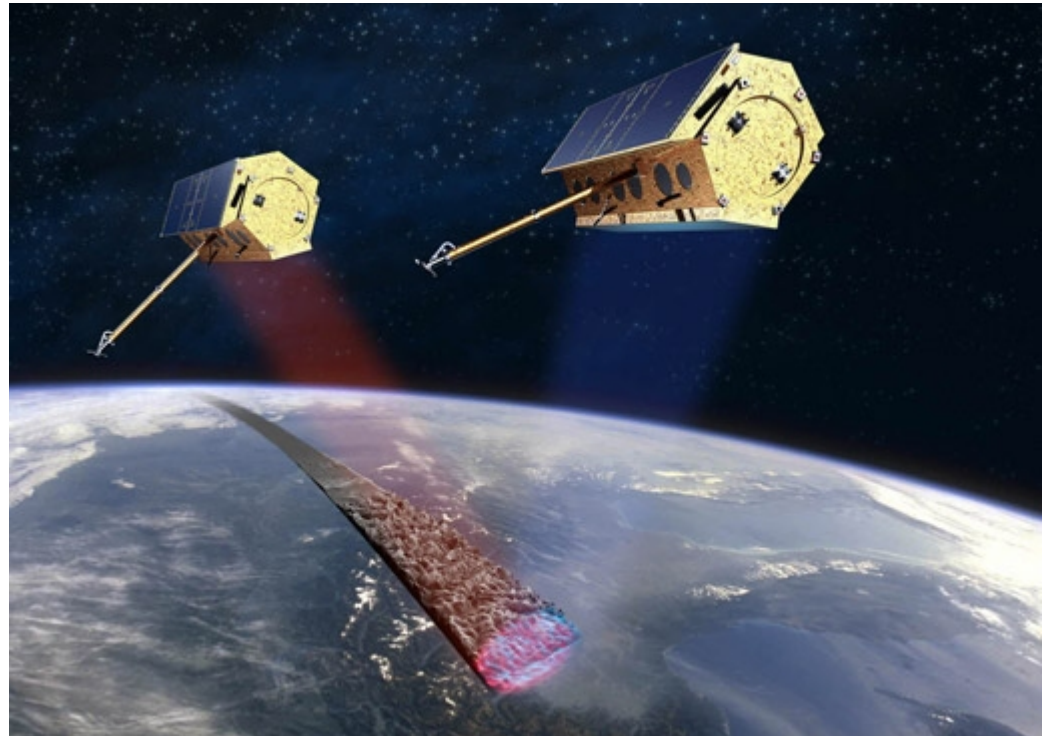
At GFZ (& UCAR) TerraSAR-X data are processed on a routine basis. Main finding: Open Loop (OL) signal tracking increases the data yield of RO retrievals in the Lower Troposphere (LT).

> We get a better inside into the uncertainty of RO retrievals in the LT.

TerraSAR-X has a companion; TanDEM-X (seperation ~ 200 m).

> This configuration provides another opportunity to estimate the precision of RO retrievals (Schreiner et al. 2007, GRL).

> We can study differences in RO retrievals for different signal tracking options.



## Outline

GFZs experimental processing software package POCS-X (Beyerle et al., 2011, ACP) is used to derive refractivity profiles:

- (1) RO 'structural uncertainty': Results from TerraSAR-X center-to-center comparison POCS-X minus UCAR are shown (UCAR data available at <http://cosmic-io.cosmic.ucar.edu/cdaac/>; product version 2010.2640).
- (2) RO 'precision': Results from TerraSAR-X and TanDEM-X profile-to-profile comparison are shown (collocated ROs).
- (3) Preliminary result: Differences between TerraSAR-X and TanDEM-X profiles for different signal tracking parameters (collocated ROs).
- (4) Summary.

## Data processing overview

### Level 1:

- The phase & amplitude is assembled from CL/OL data.
- The residual phase extraction requires Navigation Bits.  
The NavBits are collected by GFZ's ground station network (Beyerle et al., 2009, GPS Solutions).

### Level 2:

- The Full Spectrum Inversion (FSI) is used to obtain Bending Angles (BAs).
- FSI retrieved BAs are replaced by standard retrieved BAs above 12 km.
- Abel-transform BA to refractivity (N) profile.

## Data processing details

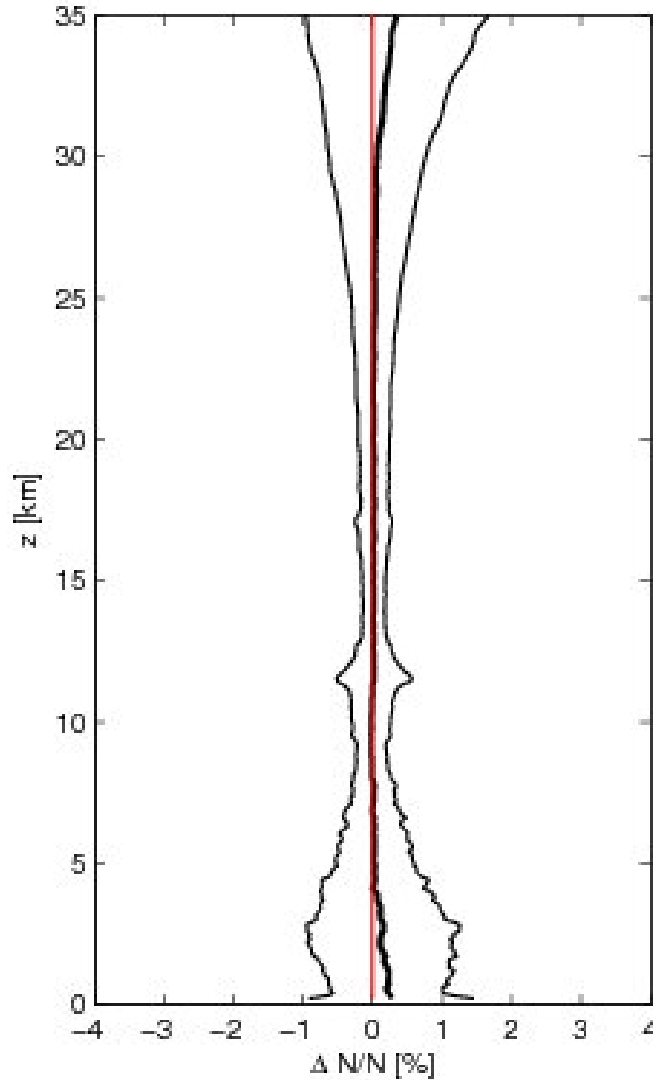
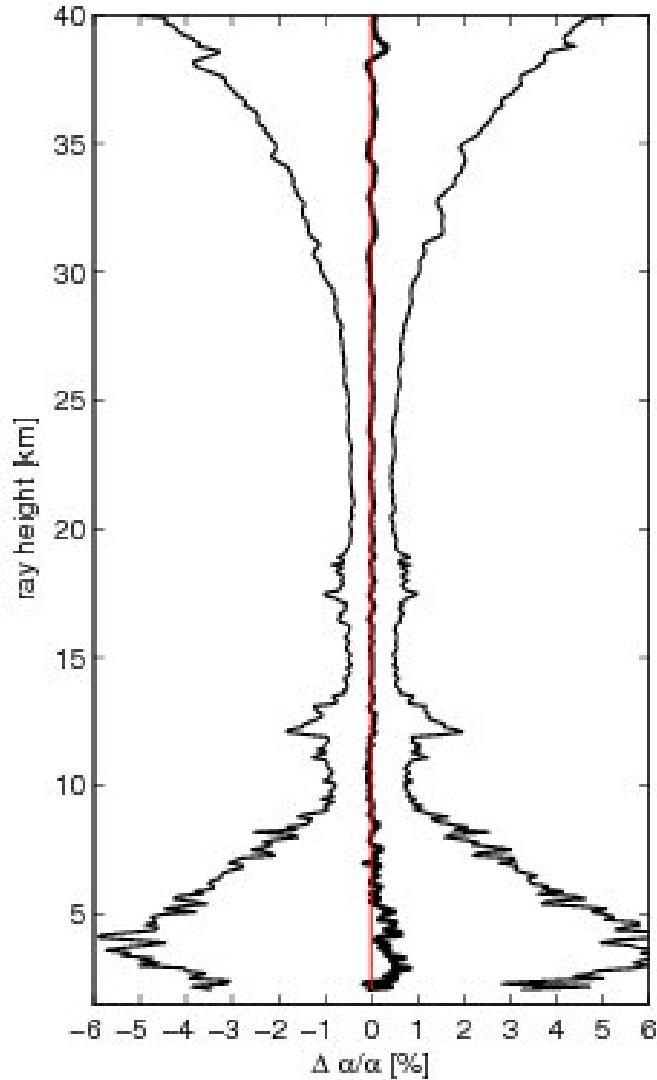
### FSI:

- Filtering: no.
- Signal truncation in the time-domain: no.
- Signal truncation in the impact parameter-domain: yes;  
the valid range is estimated using the FSI amplitude drop-off.

### Doppler:

- Savitzky-Golay smoothing filter applied to excess phase rate;  
polynomial degree  $p=3$ , window width  $w=71$ .
- Statistical Optimization of BAs for ray-heights  $> 40$  km  
using MSIS climatology as the background.

# (1) TerraSAR-X (POCS-X - UCAR)

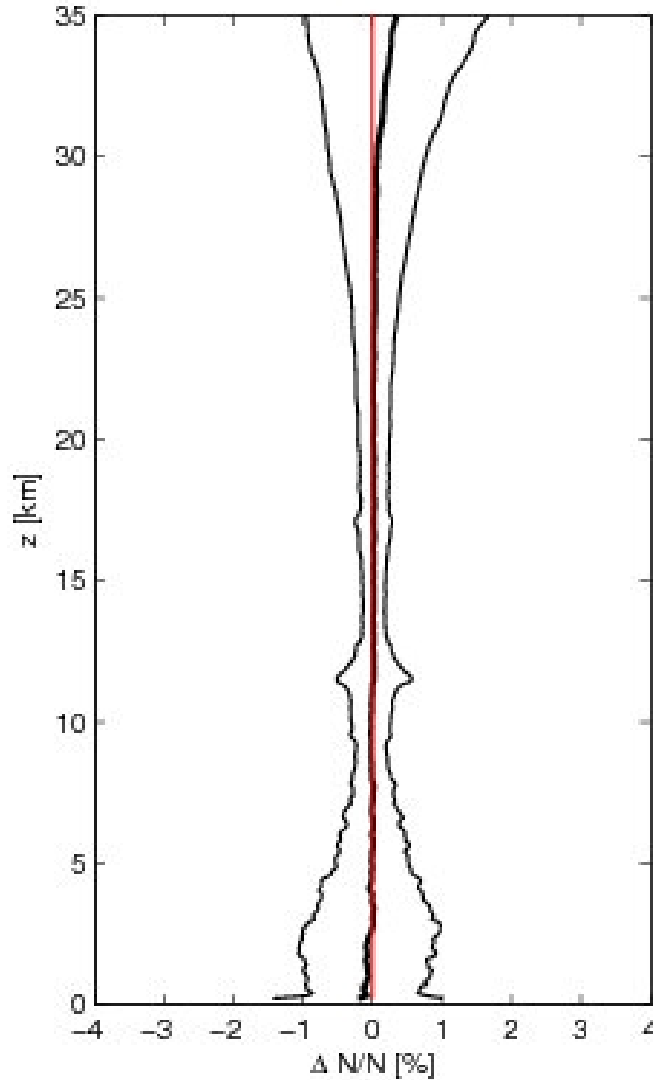
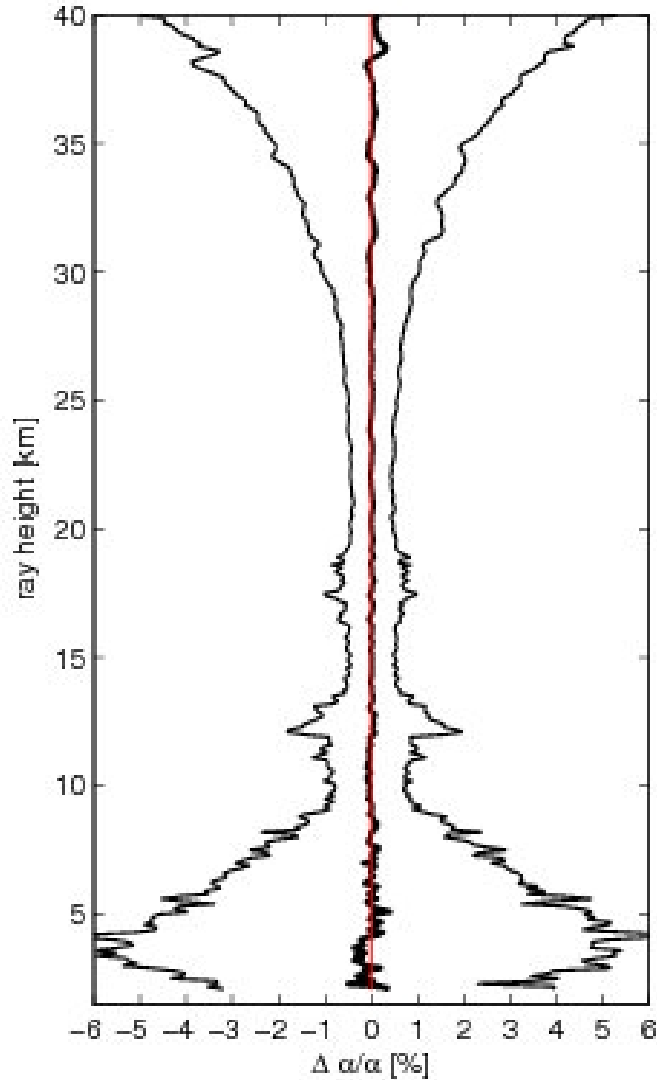


Fractional BA/N-deviation versus ray height/altitude. The thick/thin line indicates the mean/one-sigma deviation.

Period: Y2009, DOY 359-365 (~ 170 profiles / DOY).

A possible explanation for the mean deviation at altitudes < 5 km is the following ...

## POCS-X(\*) - UCAR



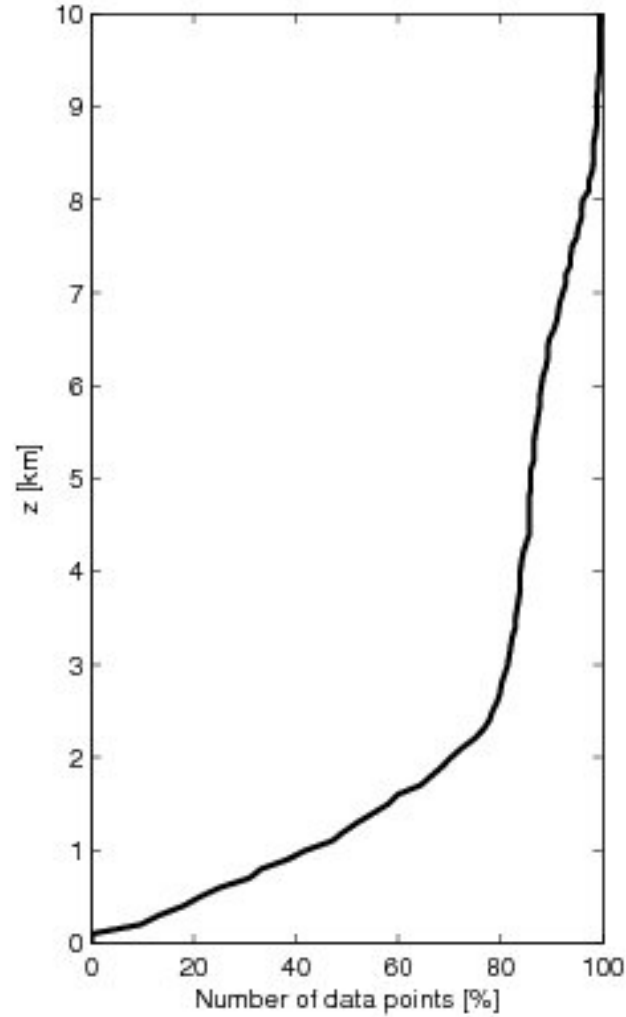
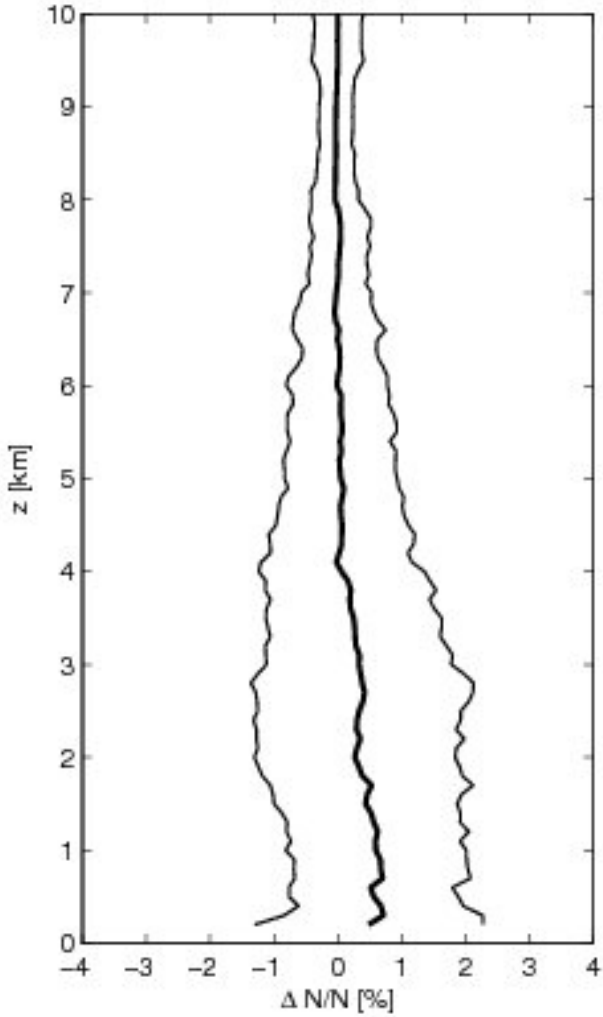
Fractional BA/N-deviation versus ray height/altitude.

\* The RO signal is truncated in the time-domain following the procedure proposed by Sokolovskiy et al. 2009, Radio Science.

Differences in the LT mainly stem from the tropics ...

# LT: Tropics POCS-X - UCAR

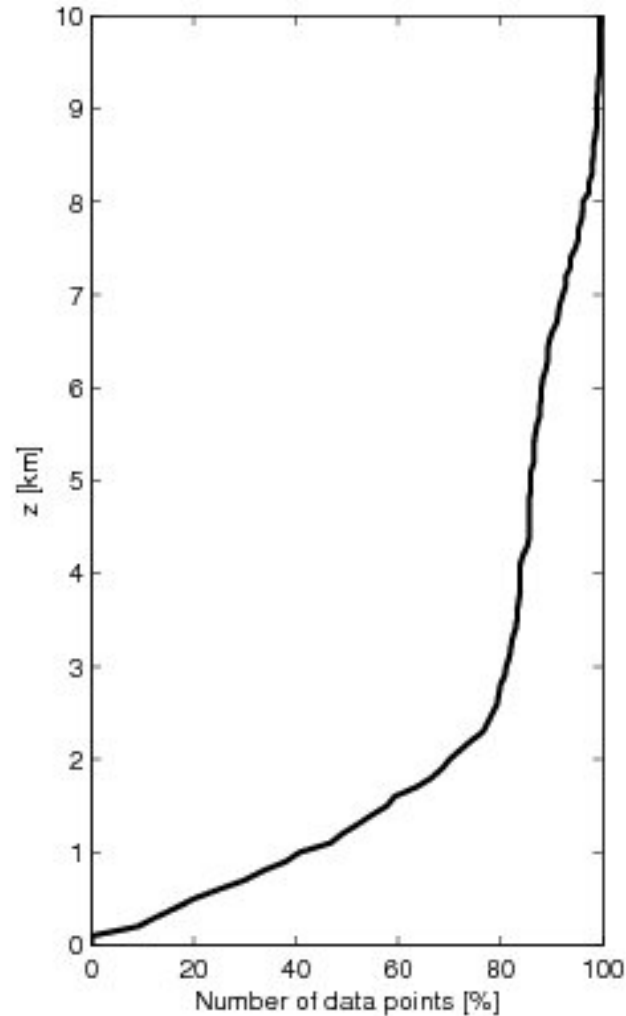
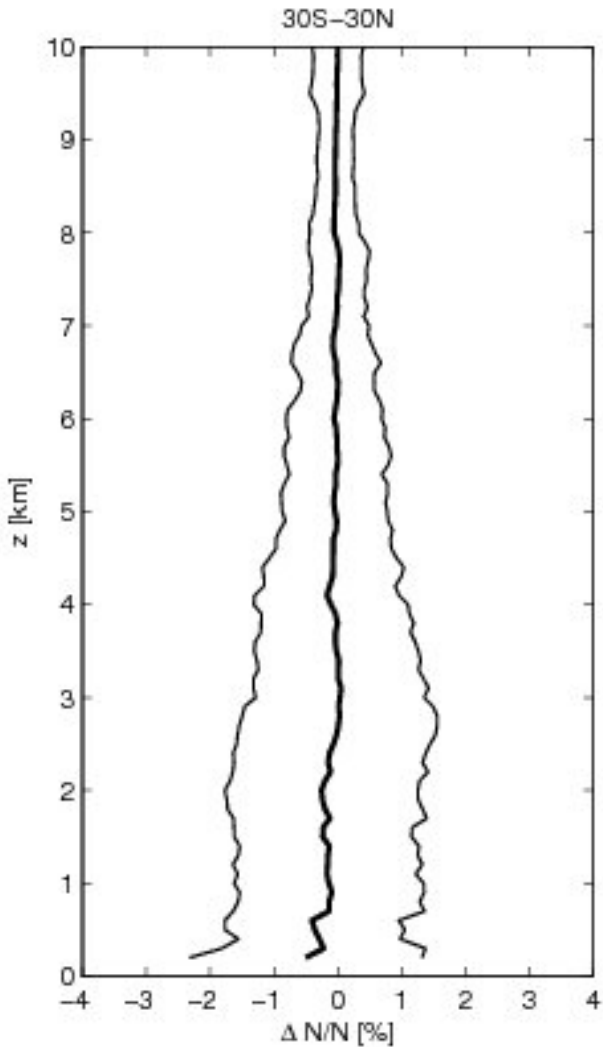
30S-30N



Fractional N-deviation & number of data points versus altitude.



## LT: Tropics POCS-X(\*) - UCAR

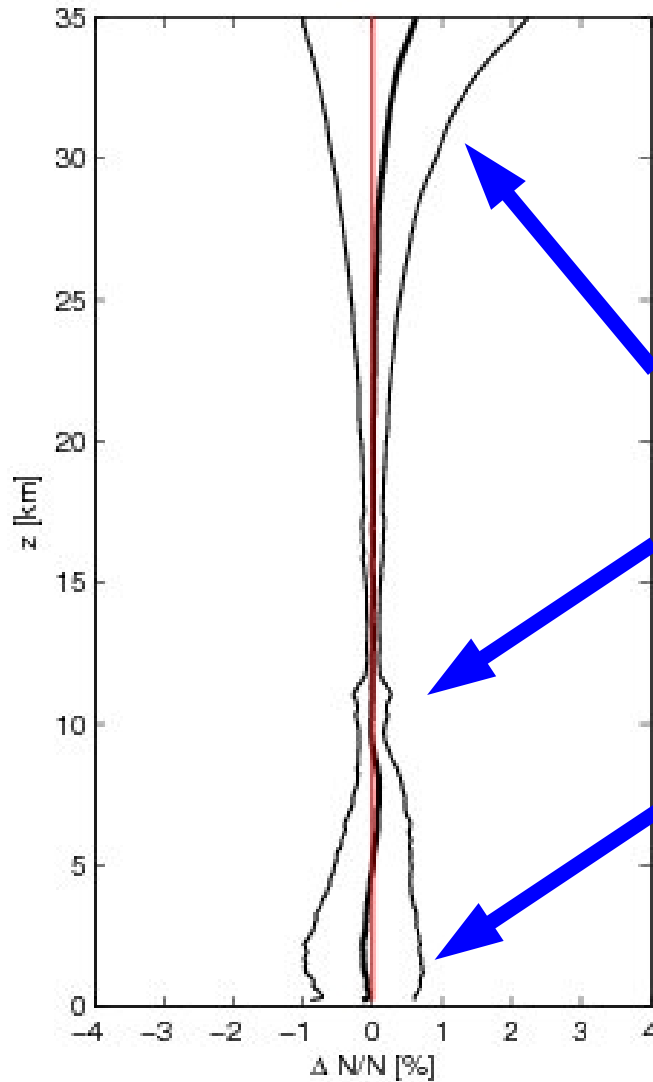
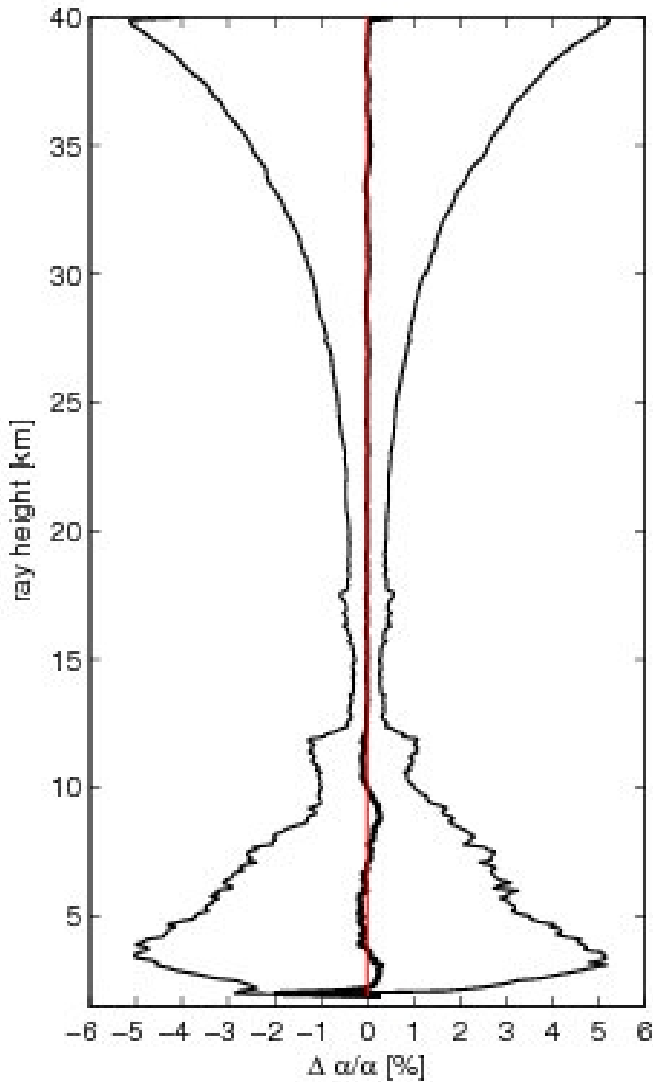


Fractional N-deviation & number of data points versus altitude.

\* The RO signal is truncated in the time-domain.

This was only for illustration. By default & in the following we do not truncate RO signals in the time-domain ...

## Ideas about the origin of the differences:



Fractional BA/N-deviation  
versus ray height/altitude.

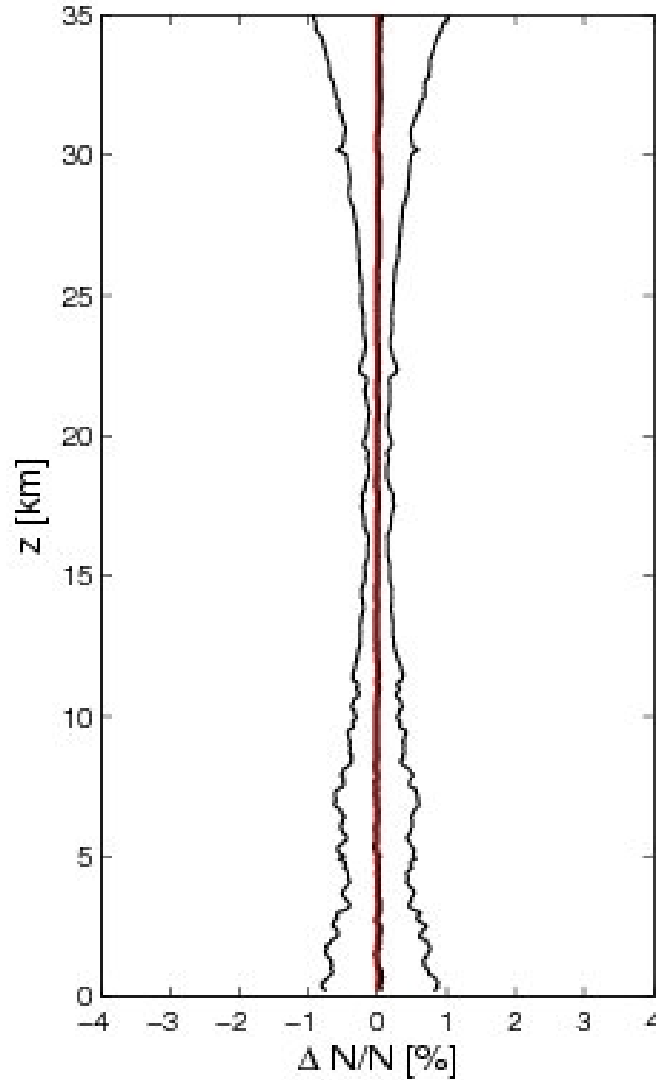
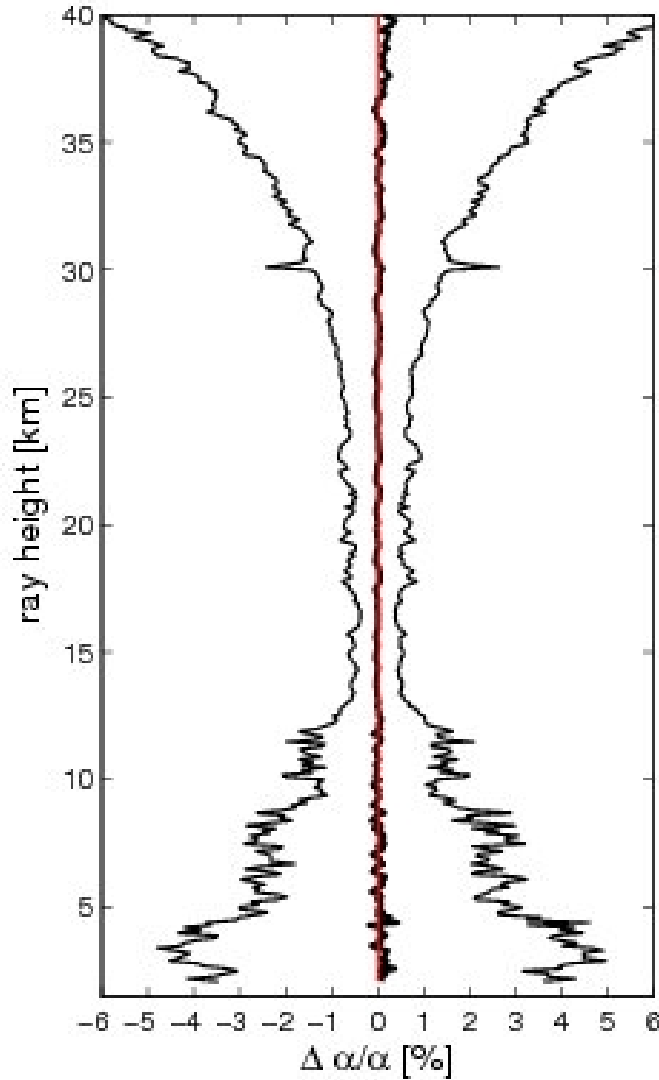
Period: Y2008, DOY 277-316.

Statistical Optimization.

The FSI to Doppler transition  
and the extrapolation of L1-L2  
phase/bending angle (?)

Differences in the LT depend  
on tunable parameters, e.g.  
the length of the RO signal  
(Sokolovskiy et al. 2010, JGR).

## (2) TanDEM-X - TerraSAR-X



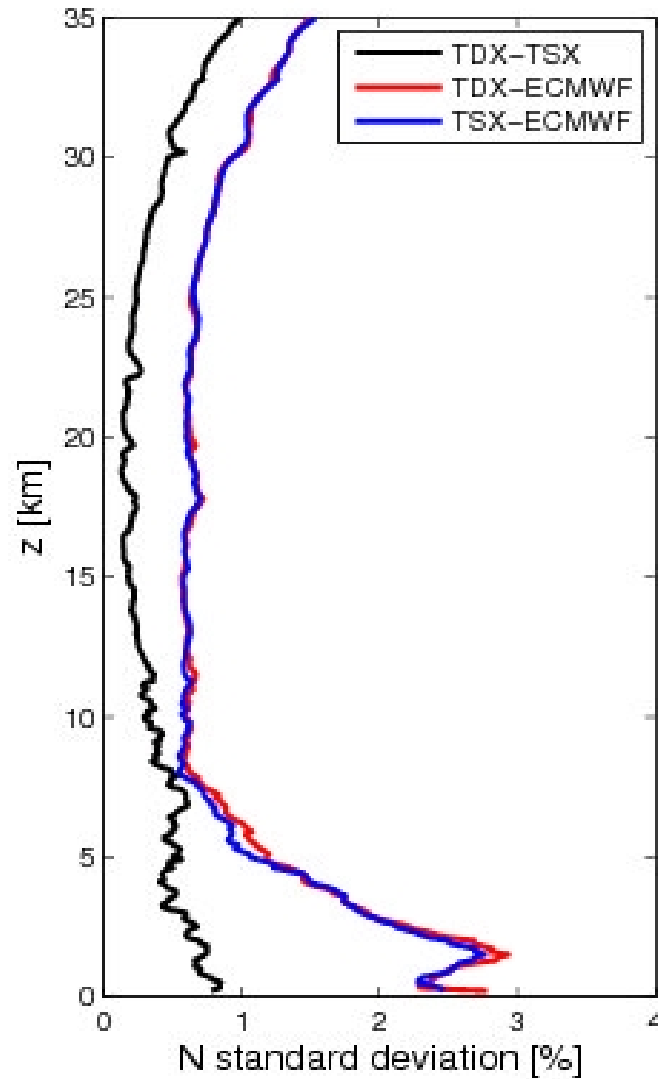
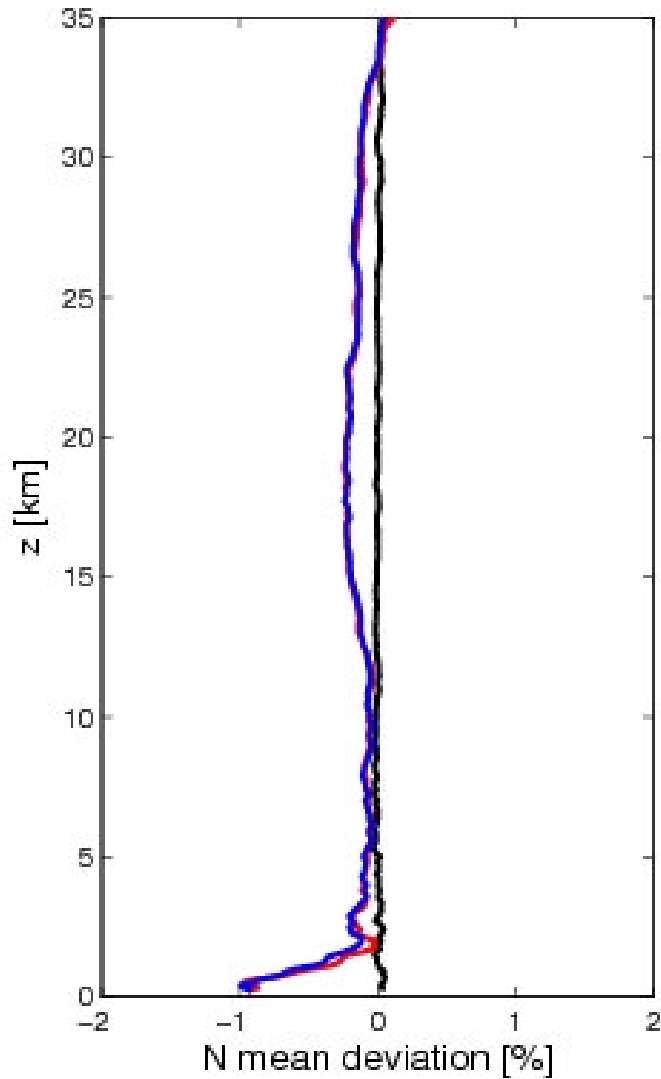
Fractional BA/N-deviation  
versus ray-height/altitude.

Period: Y2011, DOY 337-343.

The mean Tangent Point (TP)  
difference is  $\sim 500$  m.

The statistic is very close to the  
COSMIC early in the mission  
collocated profile statistic by  
Schreiner et al. 2007, GRL.

## Comparison with Numerical Weather Model (ECMWF):



Fractional N-deviation versus altitude for different pairs; mean deviation (left) & standard deviation (right).

The mean deviation between TSX (TDX) & ECMWF shows known features:

- > A negative bias above 10 km.
- > A negative bias below 3 km.

Note: The TSX BAs are assimilated at ECMWF.

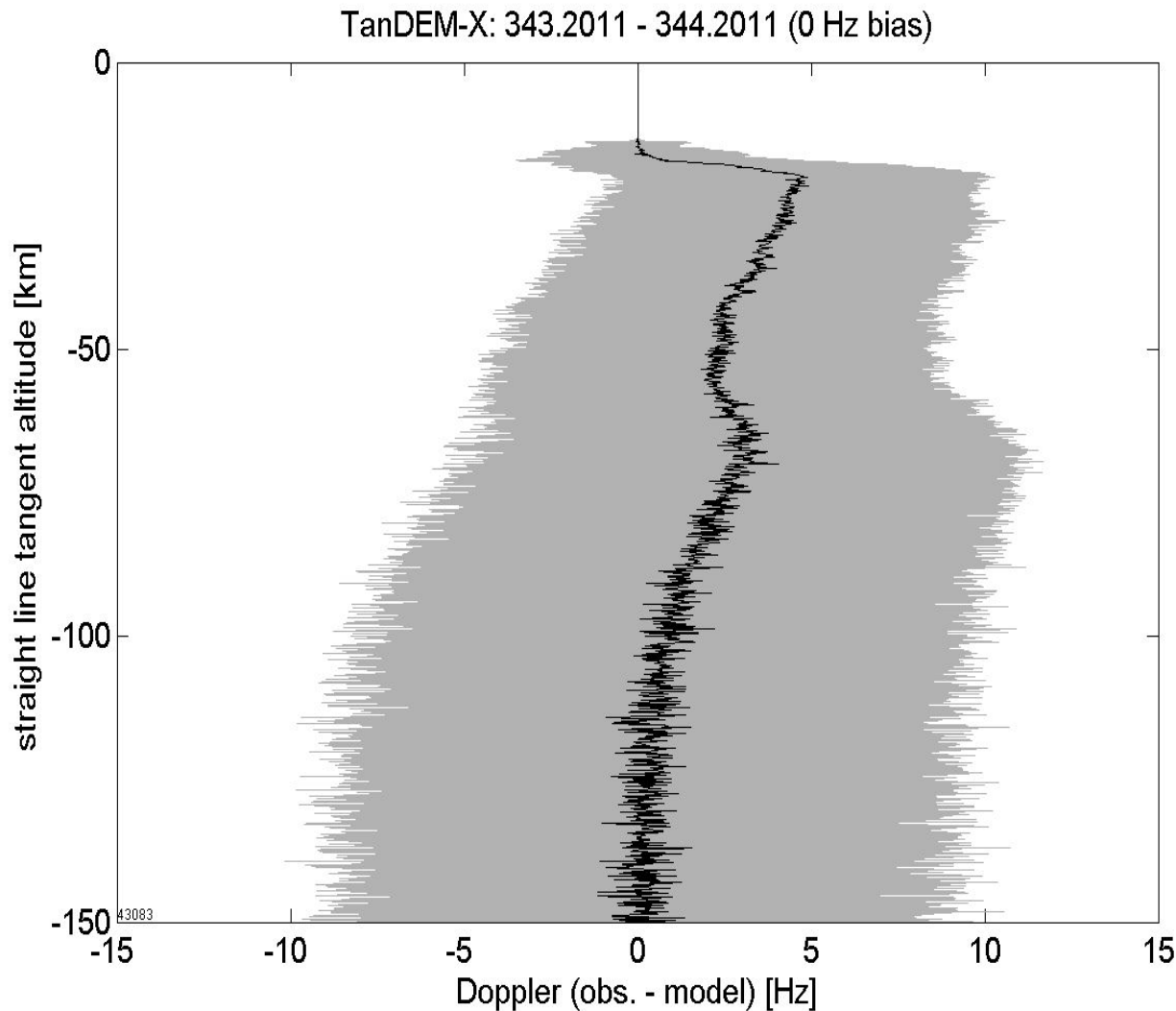
### (3) TanDEM-X testing

#### Protocol:

- P1)** Y2011 DOY 341 - 343 (Default)  
OL Doppler model + 0 Hz  
CL/OL transition height (DDBottomLimit) = -15 km
  
- P2)** Y2011 DOY 349 - 353  
OL Doppler model + 10 Hz  
DDBottomLimit = -15 km
  
- P3)** Y2011 DOY 353 - 356  
OL Doppler model - 10 Hz  
DDBottomLimit = -15 km
  
- P4)** Y2011 DOY 356 - Y2012 DOY 5 (not yet analyzed)  
OL Doppler model + 0 Hz  
DDBottomLimit = -100 km

**etc ...**

# TanDEM-X (Default)

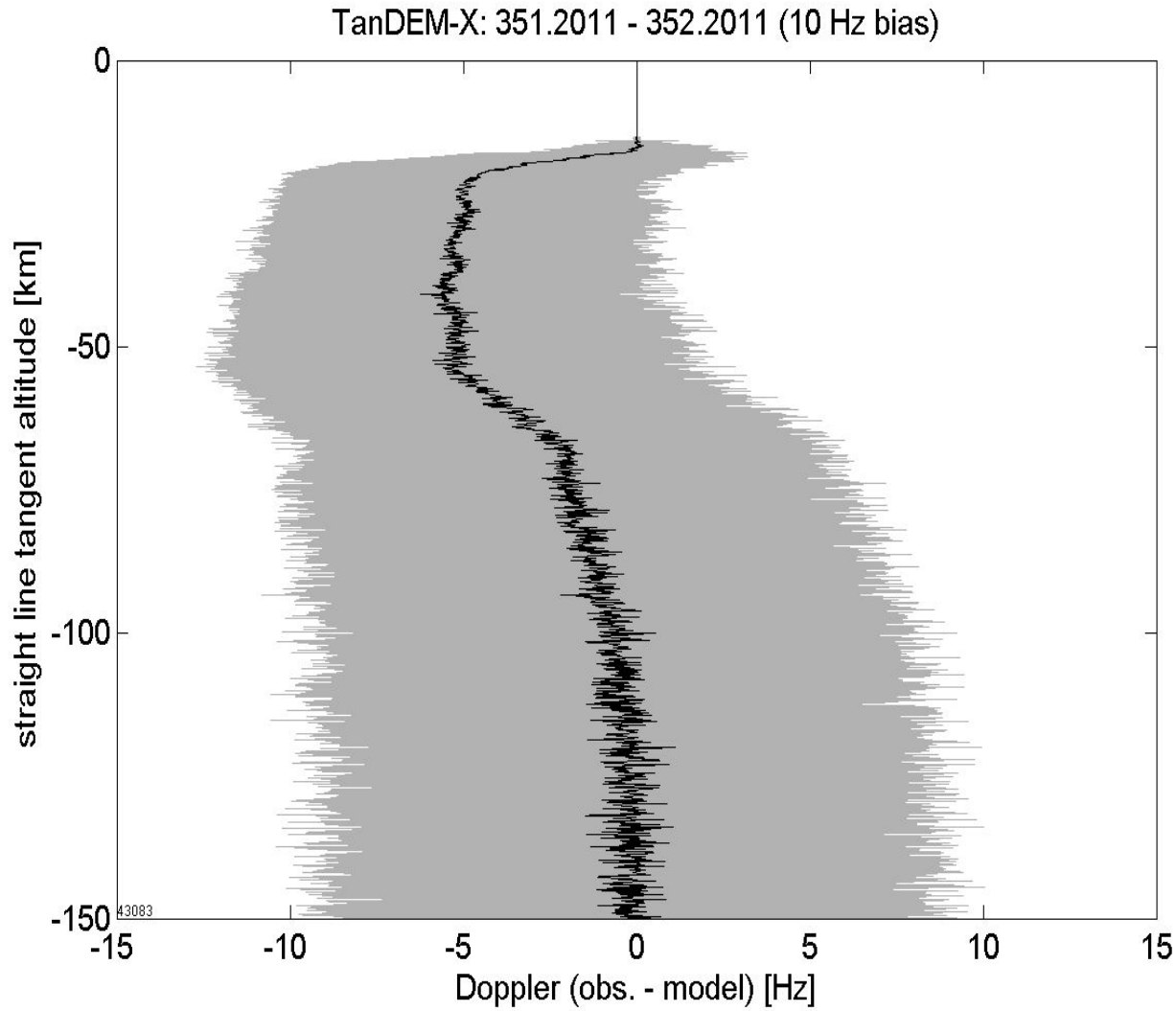


Difference between total ('true') and NCO (model) Doppler versus SLTA (Straight Line Tangent Altitude).

Period: Y2011, DOY 343-344.

At very low SLTA (low SNR) the mean deviation tends to zero, i.e. the residual Doppler is randomly distributed around the NCO Doppler.

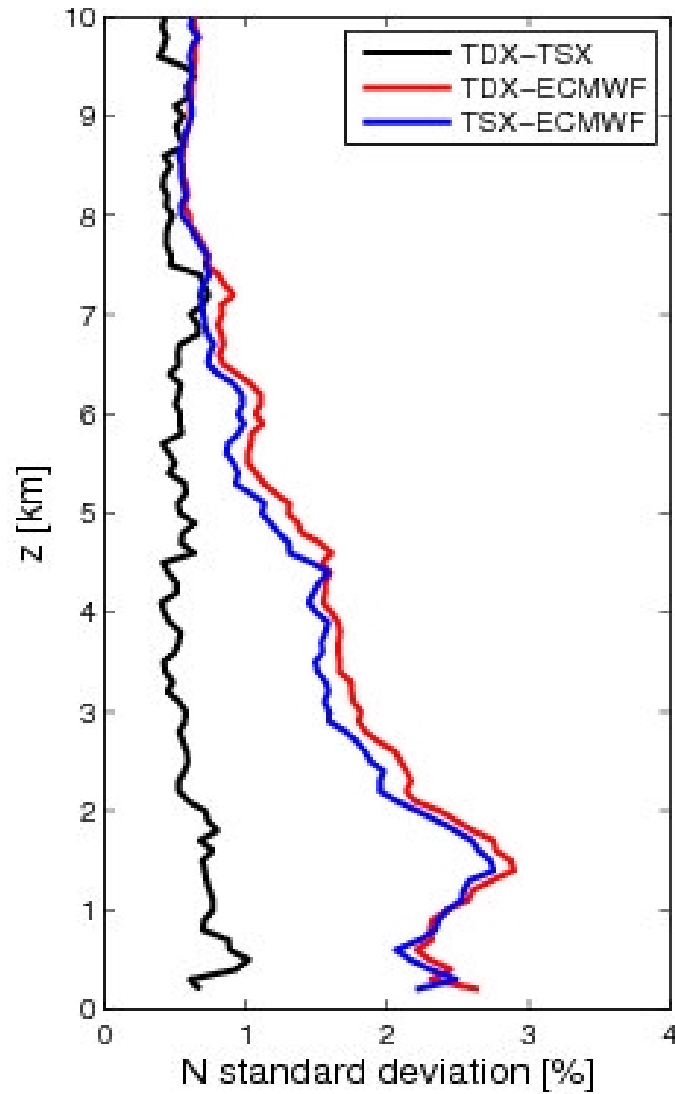
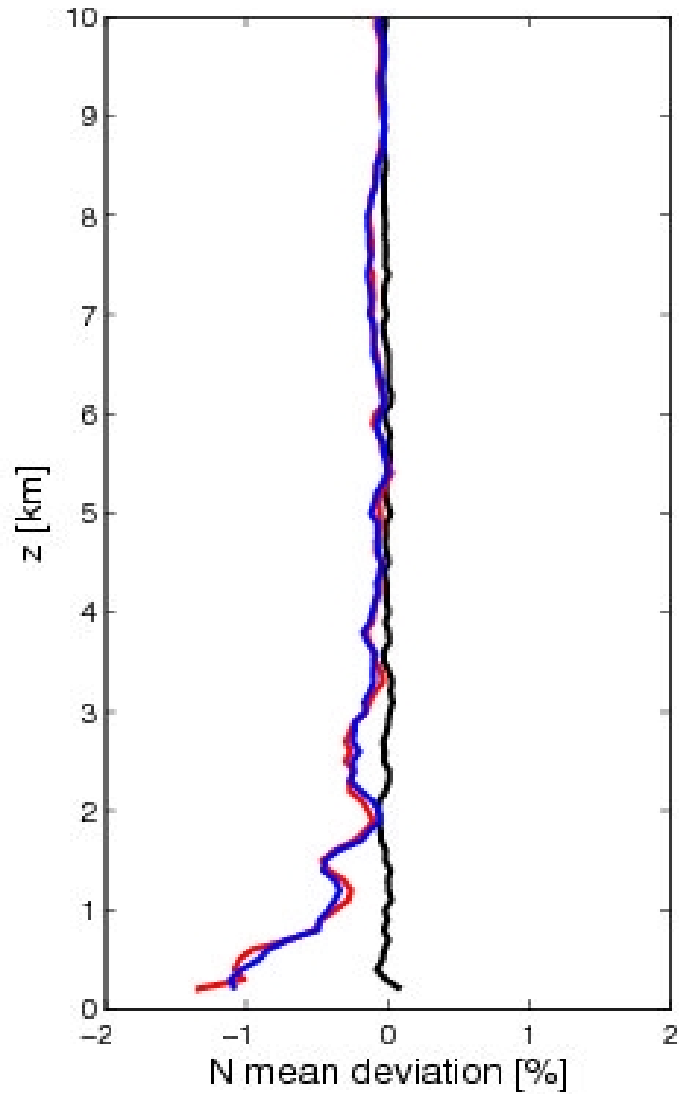
# TanDEM-X (Doppler model + 10 Hz)



Difference between total and NCO  
Doppler versus SLTA.

Period: Y2011, DOY 351-352.

# LT: TanDEM-X (Default)



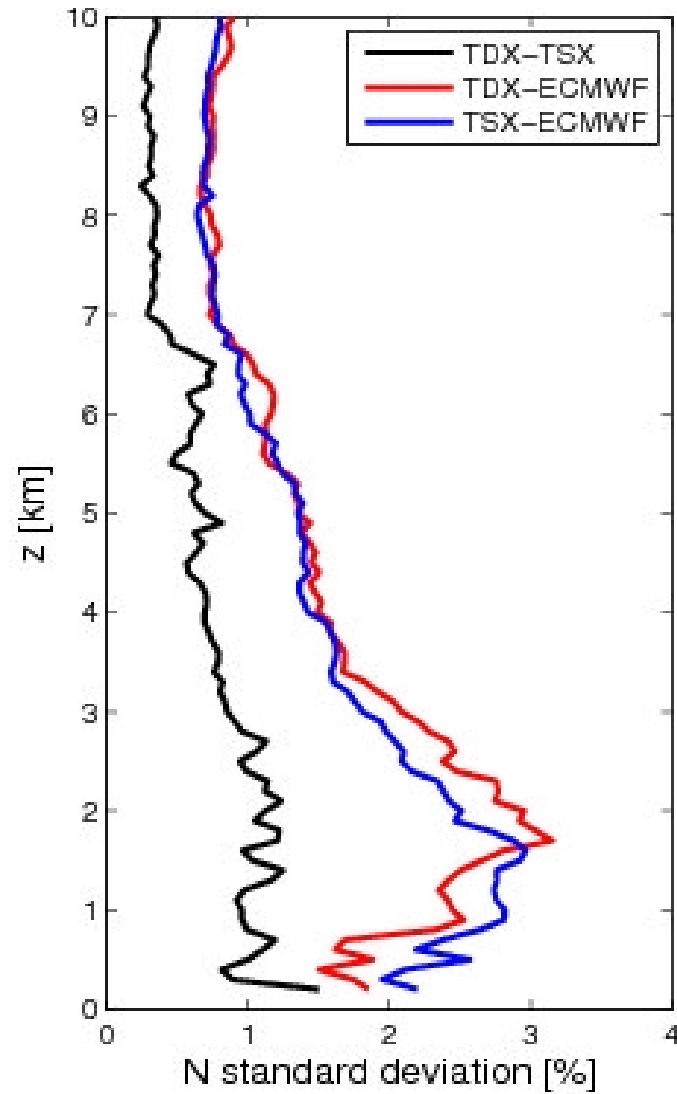
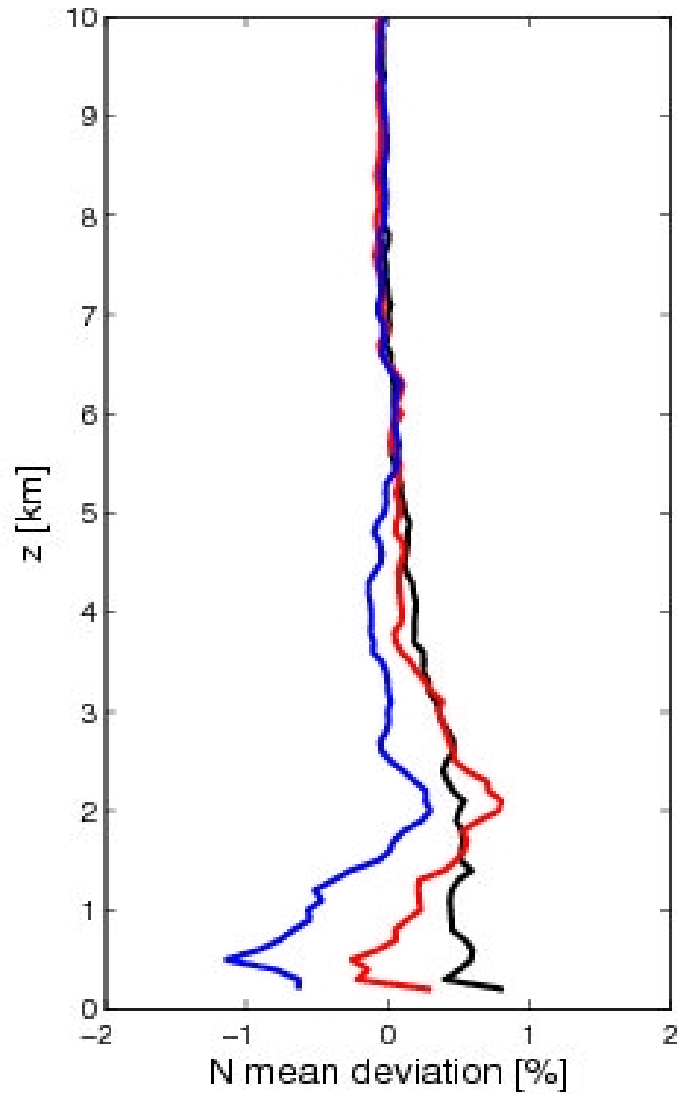
Fractional N-deviation versus altitude for different pairs; mean deviation (left) & standard deviation (right).

Period: Y2011, DOY 342-343.

The negative bias in the LT is well known from other RO missions.



# LT: TanDEM-X (Doppler model + 10 Hz)



Fractional N-deviation versus altitude for different pairs; mean deviation (left) & standard deviation (right).

Period: Y2011, DOY 350-351.

TSX shows a negative bias; This is what we expected.

TDX shows a positive bias(!?)

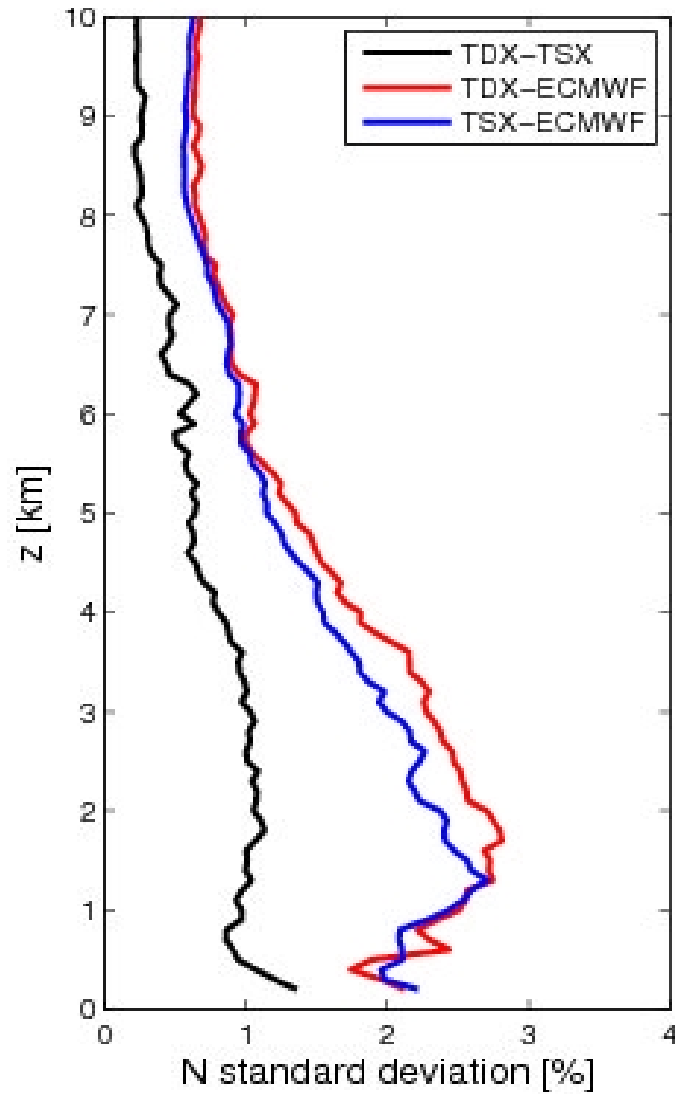
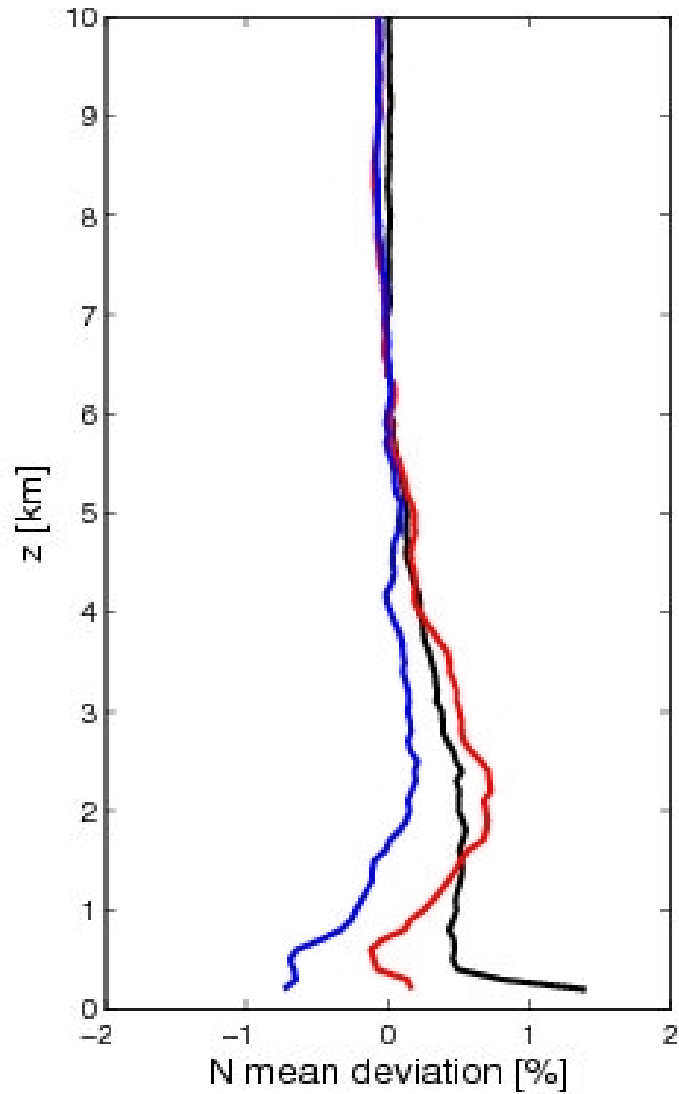
## (4) Summary

- TerraSAR-X center-to-center comparison shows good agreement. Differences are comparable with differences found in a recent study using COSMIC data (Gorbunov et al. 2011, JAOT).
- The agreement between collocated TerraSAR-X & TanDEM-X profiles is excellent. Our findings about RO precision support those by Schreiner et al. 2007, GRL.
- A preliminary result: An off-set in the OL Doppler model of + 10 Hz introduces a bias in the retrieved refractivity of + 0.5 % in the LT (globally). Do you have similar experience?

Note: Retrievals from setting events observed by TerraSAR-X are available in NRT (output of GFZ's operational software POCS). Retrievals from rising events observed by TanDEM-X potentially follow in near future (summer 2012).

# Appendix

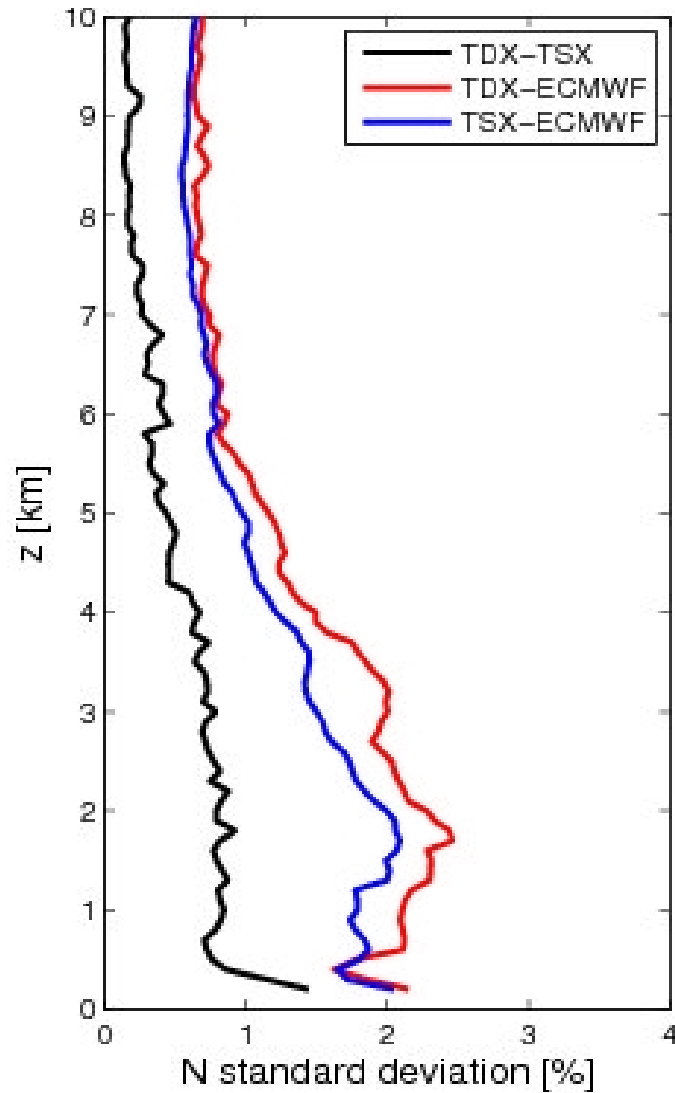
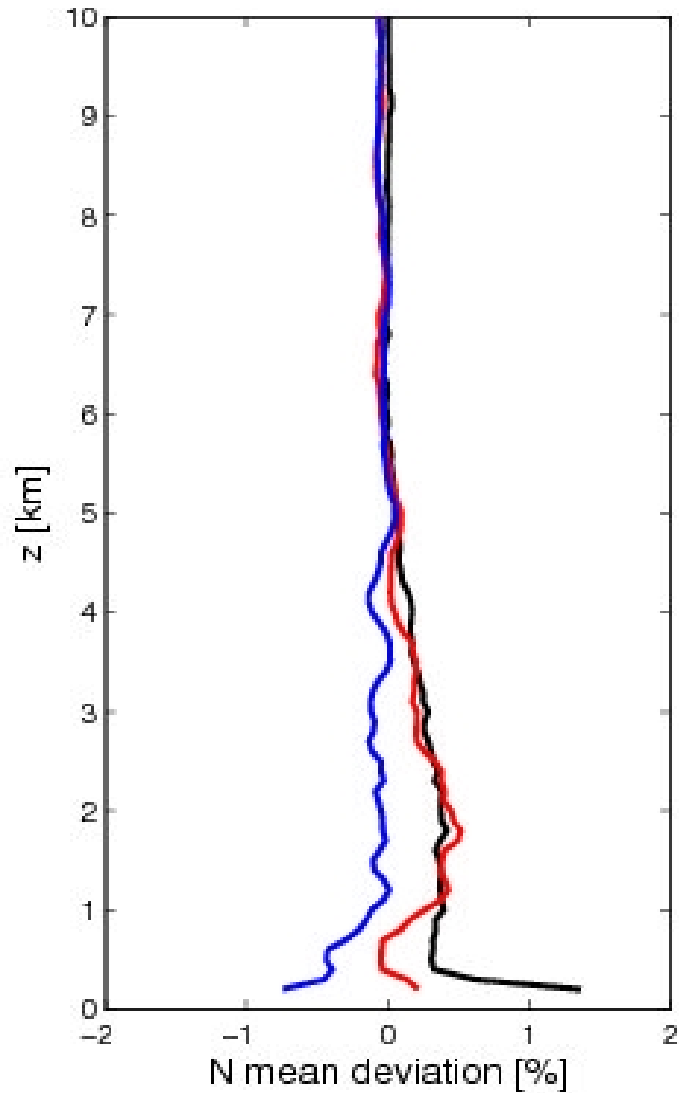
# LT: TanDEM-X (Doppler model + 10 Hz 'Repeatability')



Fractional N-deviation versus altitude for different pairs; mean deviation (left) & standard deviation (right).

Period: Y2012, DOY 49-55.

# LT: TanDEM-X (Doppler model + 10 Hz 'Repeatability')



Fractional N-deviation versus altitude for different pairs; mean deviation (left) & standard deviation (right).

Period: Y2012, DOY 49-55.

We only consider profiles where the minimum SLTA difference is < 1 km.