A Study of the Refractivity Bias in Occultation Retrievals Using End-to-End Simulations

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Overview

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    - Characteristics of the N-bias
    - Possible causes
2. **Simulation study**
    - Components of end-to-end system
    - Strategy
3. **Numerical results**
    - A single profile
    - Statistical comparisons
    - How does it compare with real data?
4. **Conclusions**
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Characteristics of the N-Bias

- **Fractional refractivity difference with respect to ECMWF:**

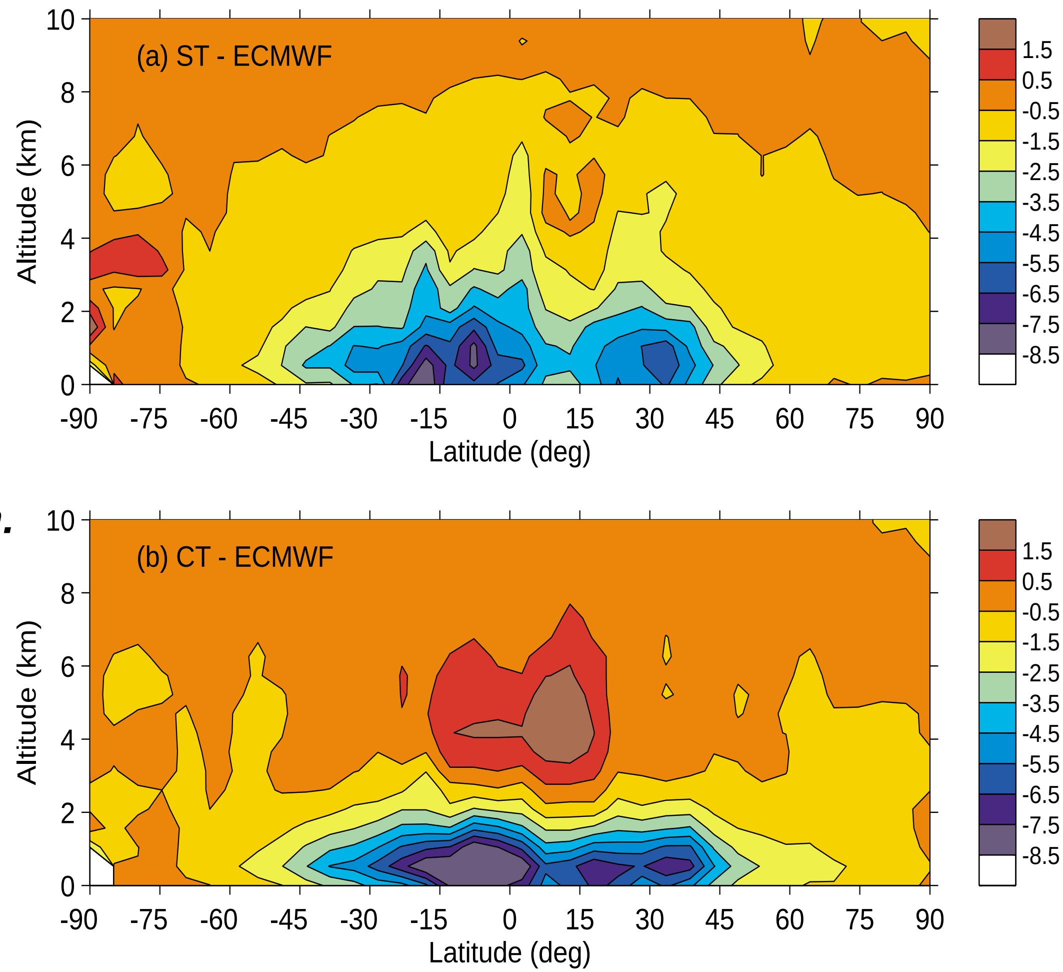
$$\delta N = \frac{N(\mathrm{retrieved}) - N(\mathrm{ecwmf})}{N(\mathrm{ecwmf})}$$

ST = standard "Doppler" retrieval

CT = canonical transform retrieval

- ***The bias is most severe in the tropics and at altitudes below 2 km.***
- ***The bias extends to mid-latitudes, and, for ST, reaches up to 8 km.***
- ***CT significantly reduces the ST bias above 2 km.***
- ***CT bias shows a well-defined latitudinal dependence.***

CHAMP & SAC-C October 2001



Causes of the N-Bias

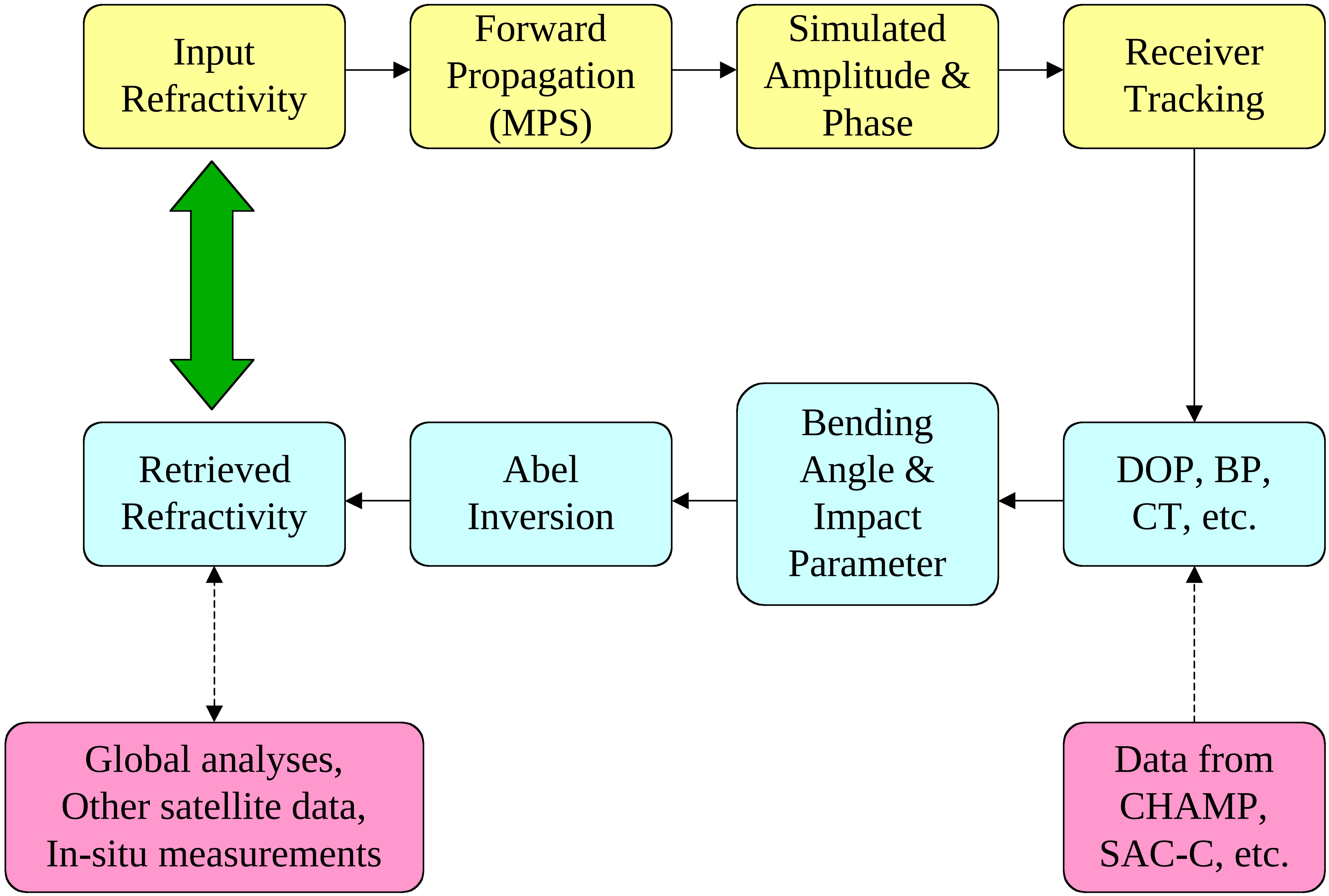
I. Occultation retrievals are wrong.

- ***Retrieval errors***
  - Sharp refractivity structure in lower troposphere leads to atmospheric multipath, superrefraction, and ducting.
  - Breakdown of spherical symmetry.
- ***Tracking errors***
  - Low SNR in the lower troposphere causes problems for the tracking loop.

II. NWP models are wrong.

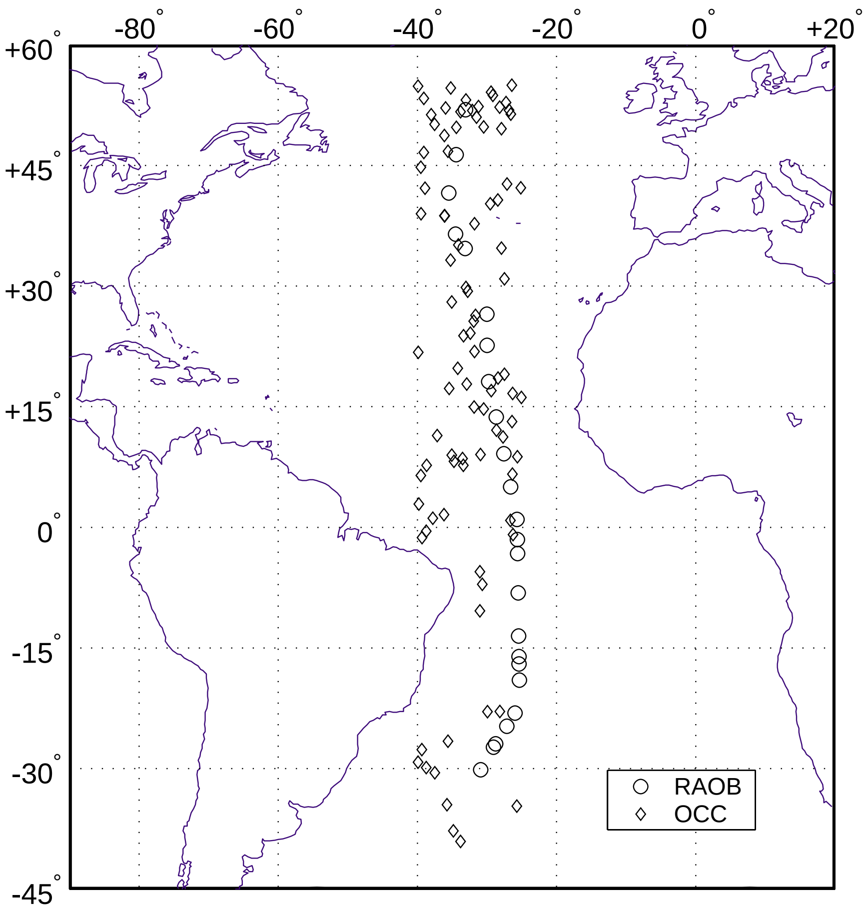
- Insufficient data to assimilate in some regions.
- Low spatial and temporal resolution.

End-to-End Simulation



Strategy

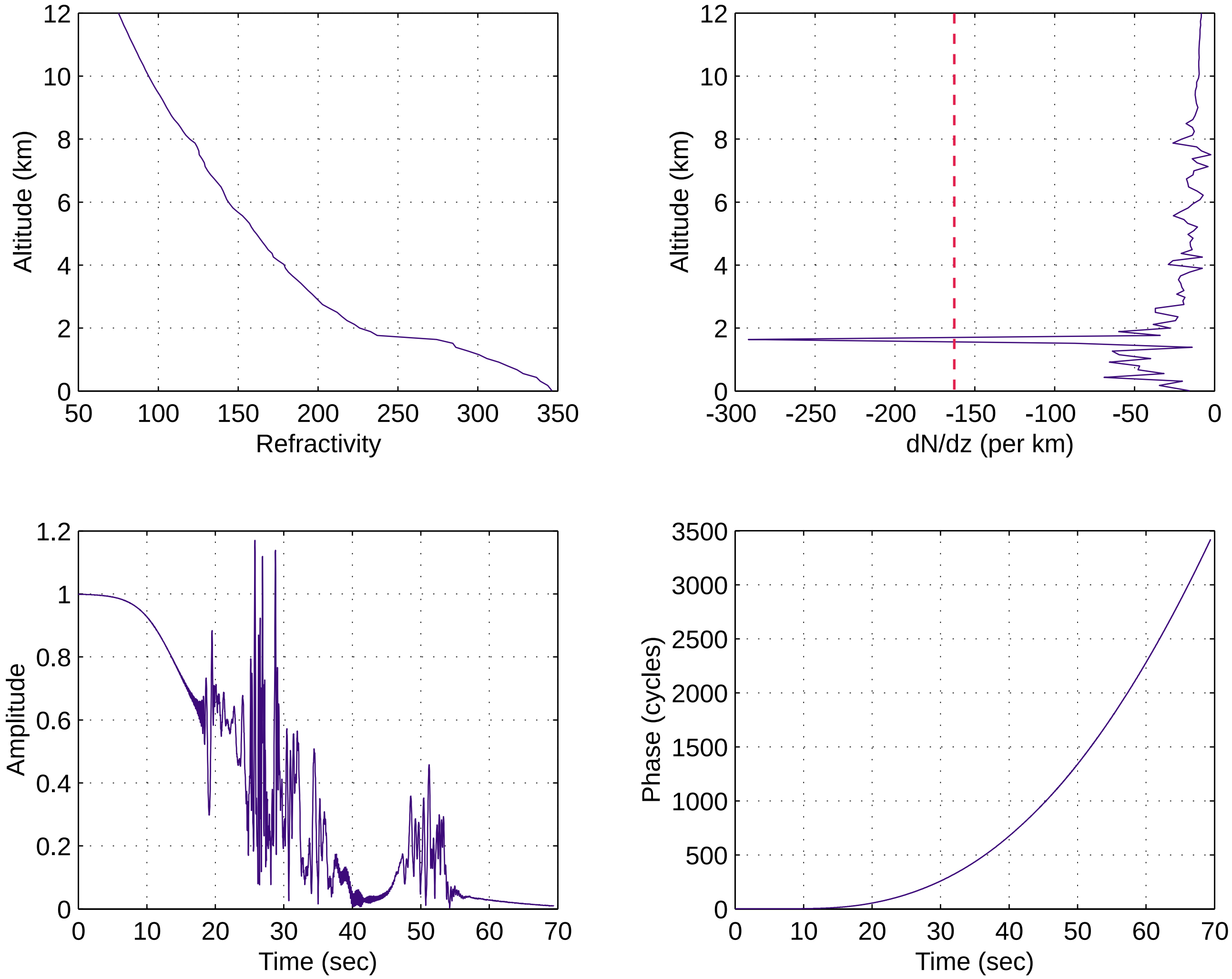
1. **24 simulated occultations from 24 high resolution radiosonde profiles ***
   - 2 datasets: one with receiver tracking and noise, one without.
   - 2 retrieval methods are used: ST & CT.



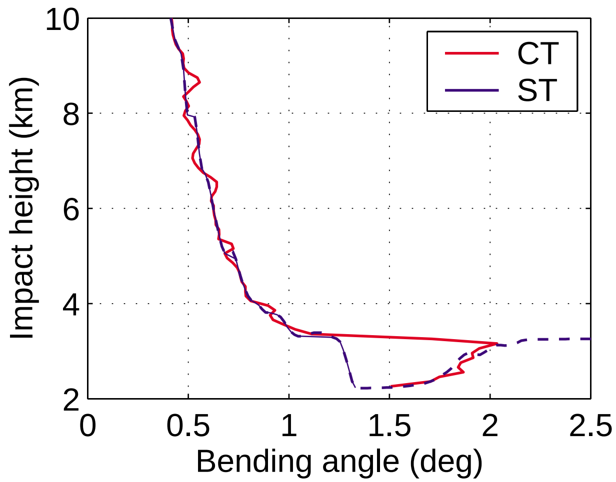
2. **Compare with true profiles to evaluate errors.**
3. **Compare with ECMWF to evaluate the N-bias.**
4. **Compare with observed N-bias from a selected list of CHAMP and SAC-C occultations.**

* *Courtesy of R. Weller, Alfred Wegener Institute for Polar and Marine Research, Germany.*

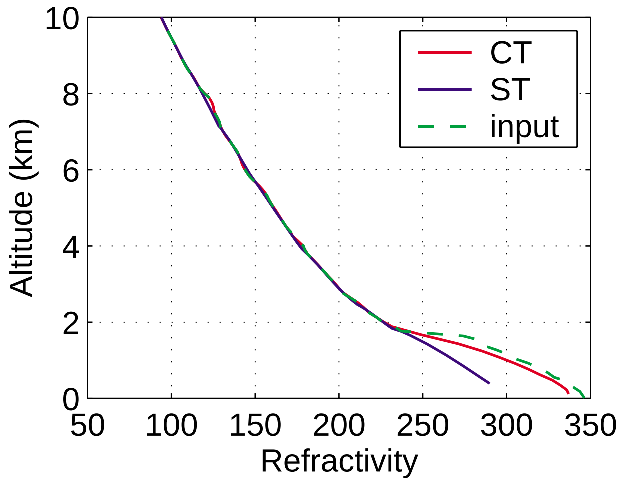
Single Profile: Amplitude and Phase

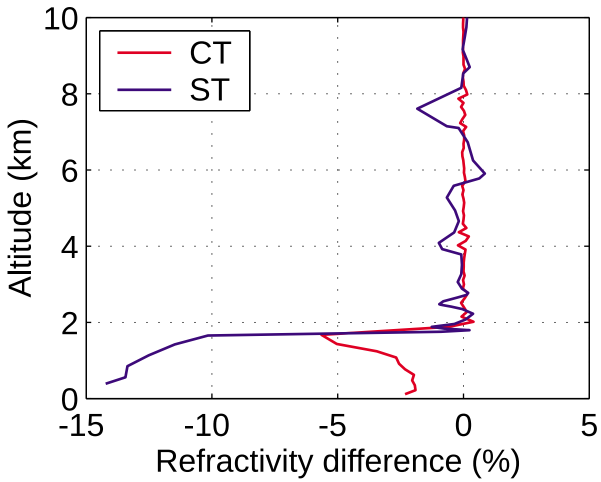


Retrievals

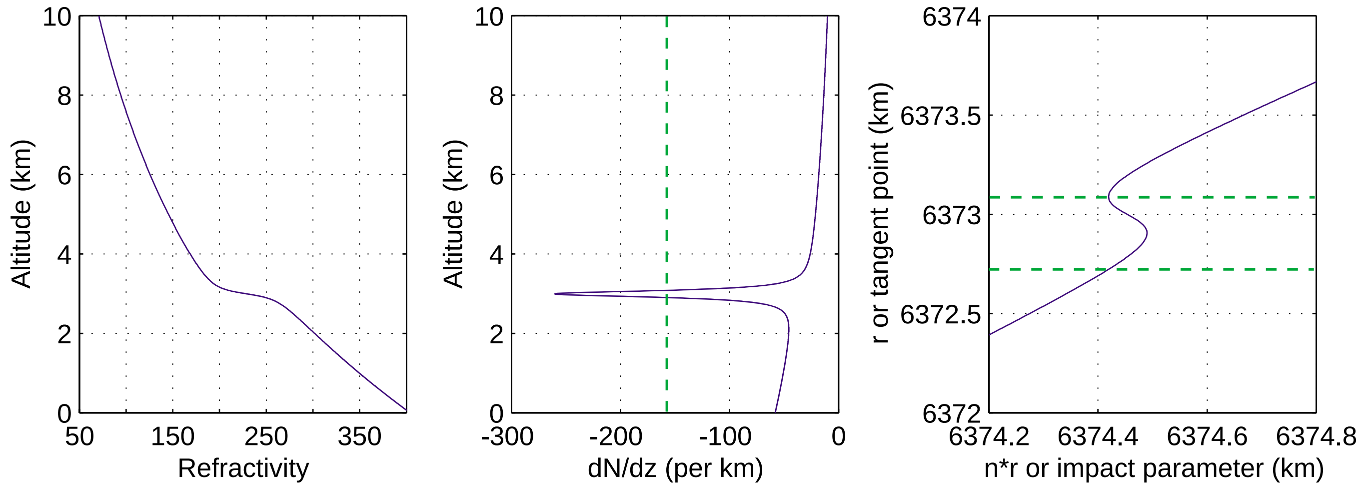


- ST is plagued by multipaths and has vertical resolution limited by Fresnel diffraction.
- CT works extremely well above 2 km.
- Significant errors exist below 2 km.





Ducting & Abel Inversion

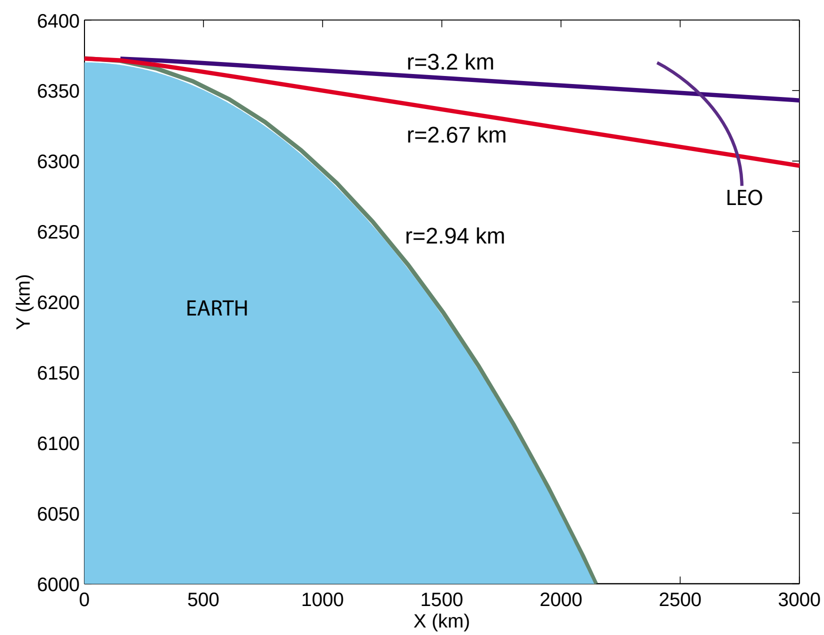


Ducting Condition:

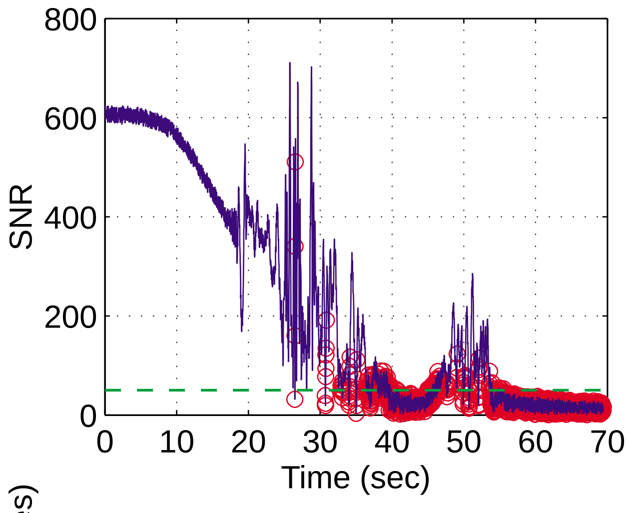
$$\boxed{\frac{dn}{dr} < -\frac{1}{r}}$$

$$\ln n(r) = \frac{1}{\pi}\int_a^\infty da' \, \frac{\alpha(a')}{\sqrt{a'^2 - a^2}}$$

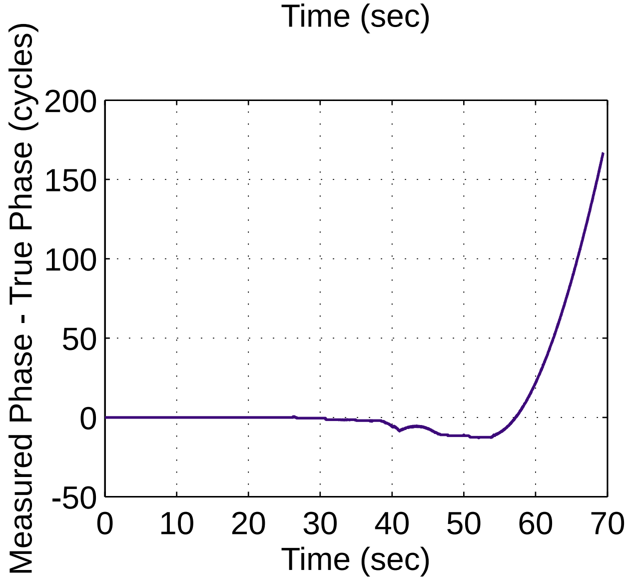
$$a = r\,n(r)$$

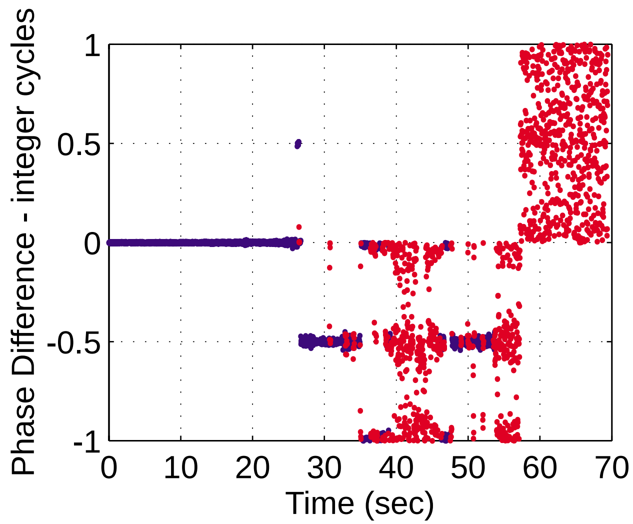


Receiver Output

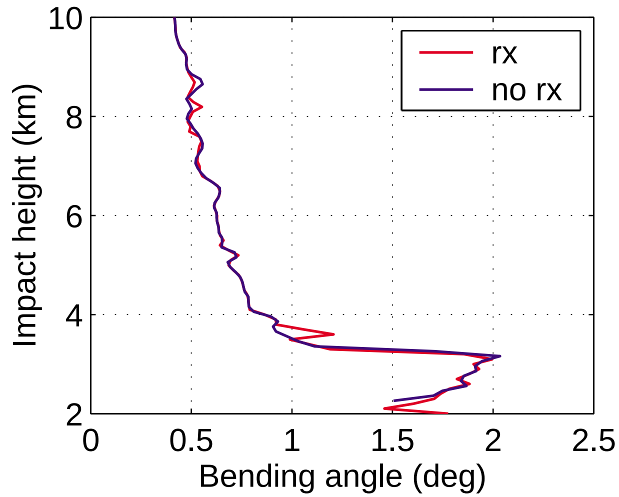


- ***SNR large***: **PLL accurately reproduces the phase.**
- ***SNR small*** **(below 50): the receiver enters flywheeling (FW) mode. The model Doppler is constructed based on extra-polation of non-FW data.**

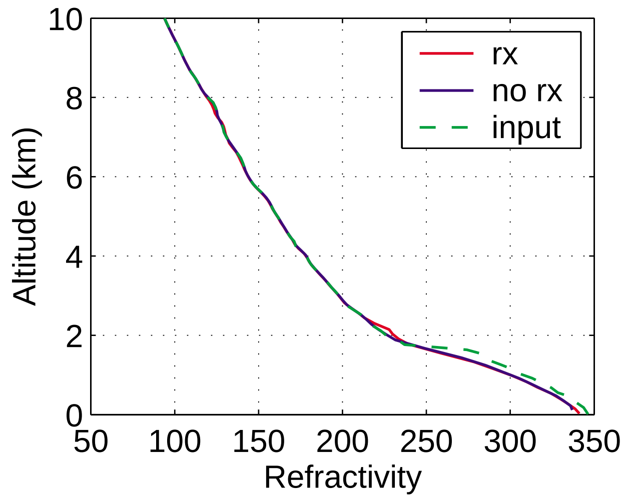


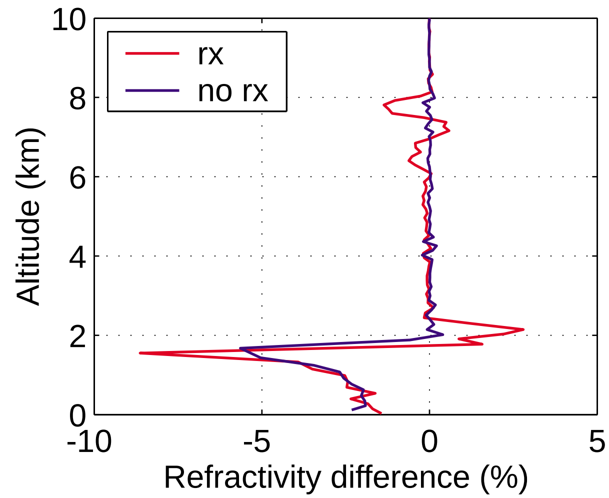


Retrievals with Receiver

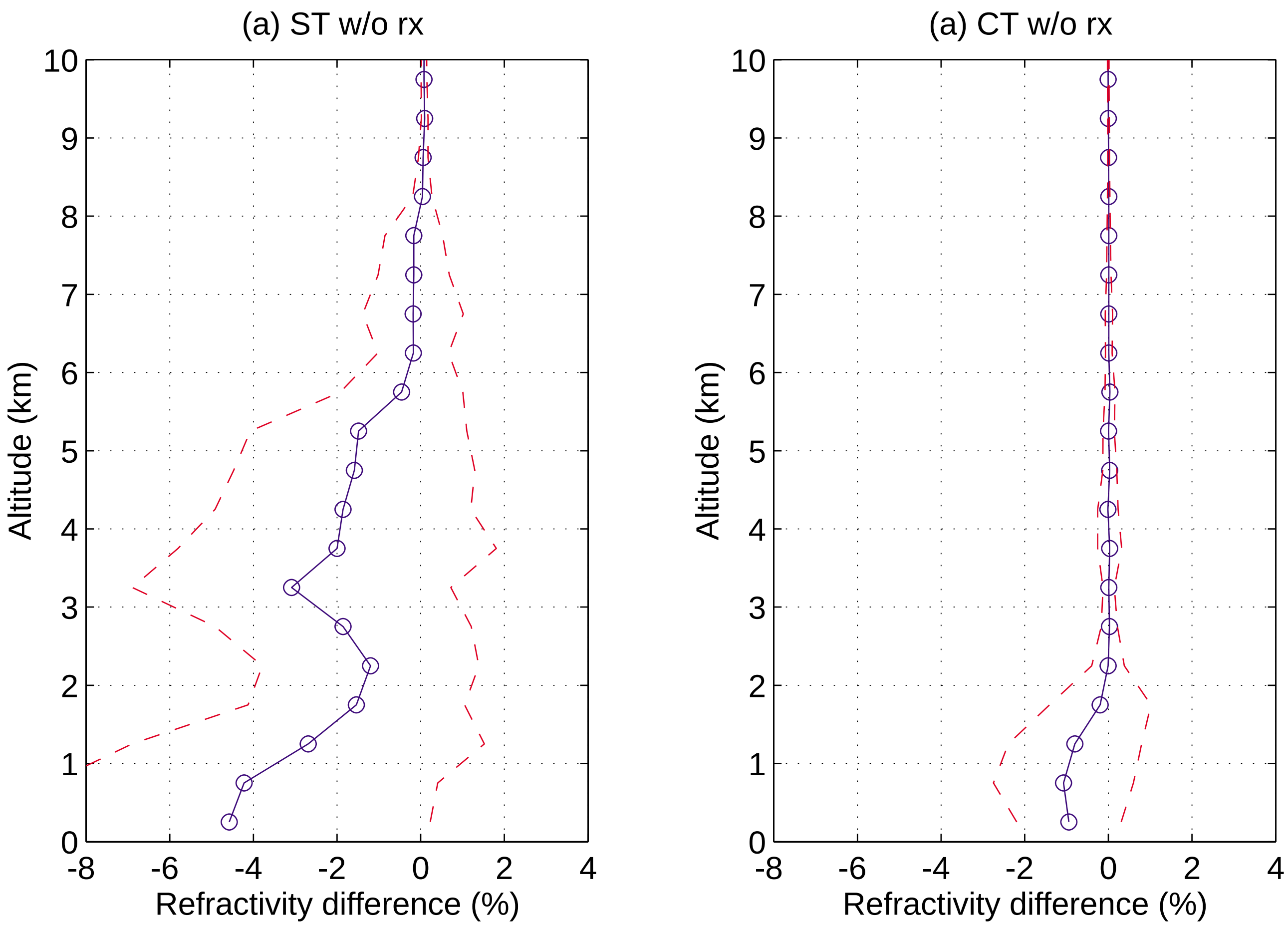


- ***Above 2 km*, CT refractivity error is caused by half-cycle slips.**
- ***Below 2 km*, refractivity error is due to inaccuracy from the tail-end of the occultation.**

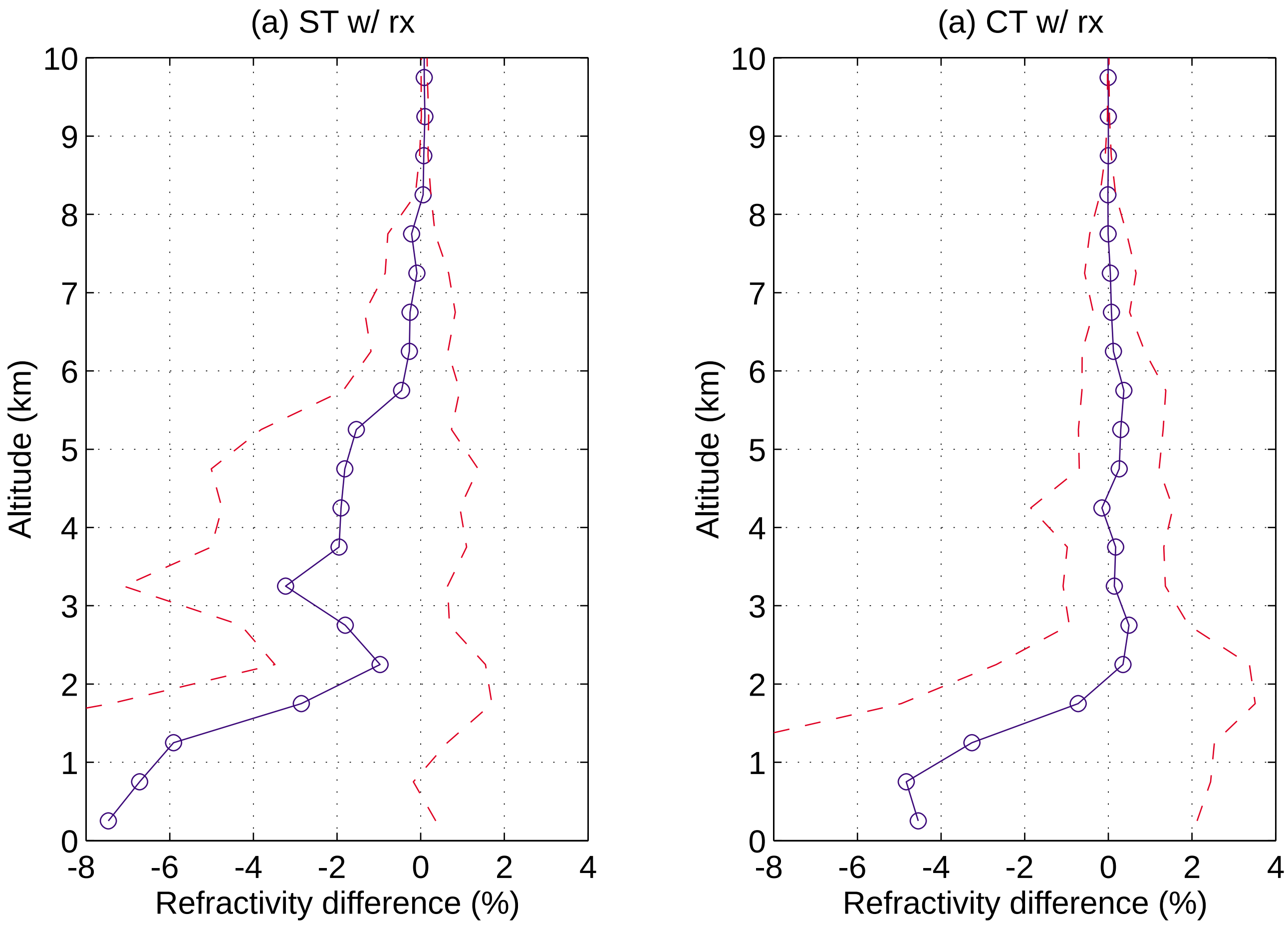




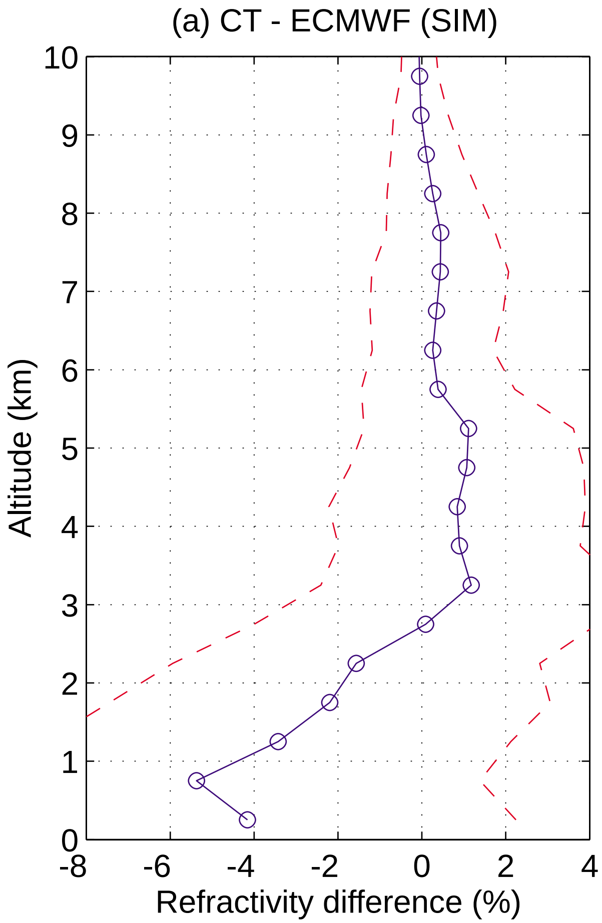
Statistical Comparison without Receiver

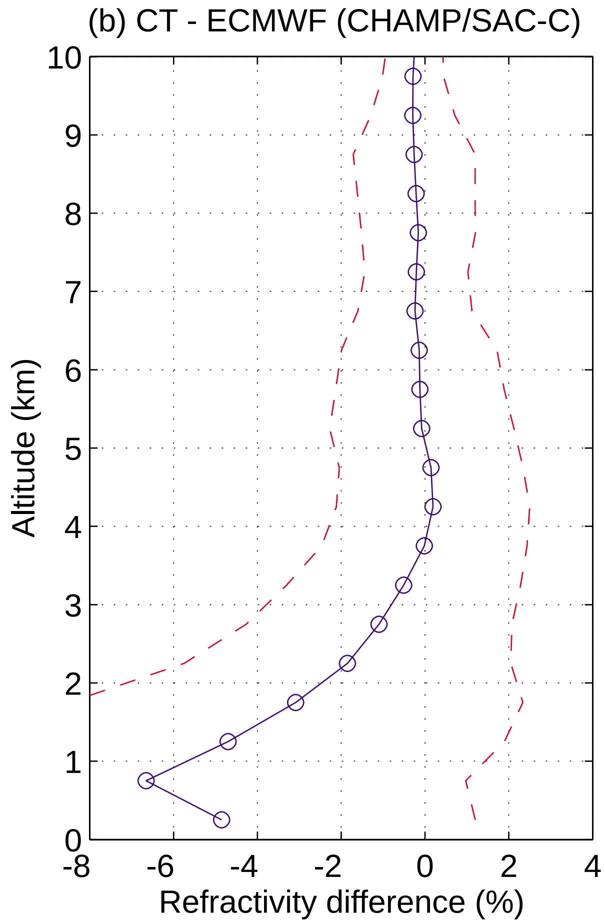


Statistical Comparison with Receiver



Statistical Comparison with ECMWF





Conclusions

- ***The negative N-bias are investigated with simulations:***

  1. **With perfect data, CT retrievals give a small negative N-bias below 2 km. This represents a fundamental limitation of Abel inversion when atmospheric ducting exists.**
  2. **Receiver errors increase the N-bias below 2 km. No bias is introduced above 2 km.**
  3. **NWP errors are non-negligible.**

- ***How often does ducting occur in real occultations? How well do the refractivity profiles used in the simulations represent reality?***
- ***How can we identify these cases? Can we rescue Abel inversion?***
- ***What are the effects of non-spherically symmetric structures?***
- ***What modifications can we make to the receiver tracking algorithms that would reduce retrieval errors?***