This work has been supported by the Polish National Agency for Academic Exchange as part of the Bekker programme under the project entitled „Remote sensing of the atmosphere with airborne GNSS radio occultations" (PPN/BEK/2020/1/00250/U/00001).

First results from two-dimensional bending angle operator for airborne radio occultations

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Motivation

Develop a 2D forward operator for airborne radio occultations (ARO)

1. *Based on ROPP 2D bending angle operator.*
2. *Minimum possible modifications to existing spaceborne operator.*
3. *Keep it simple and computationally-efficient.*
4. *To be used in JEDI software for data assimilation.*

ARO obs data

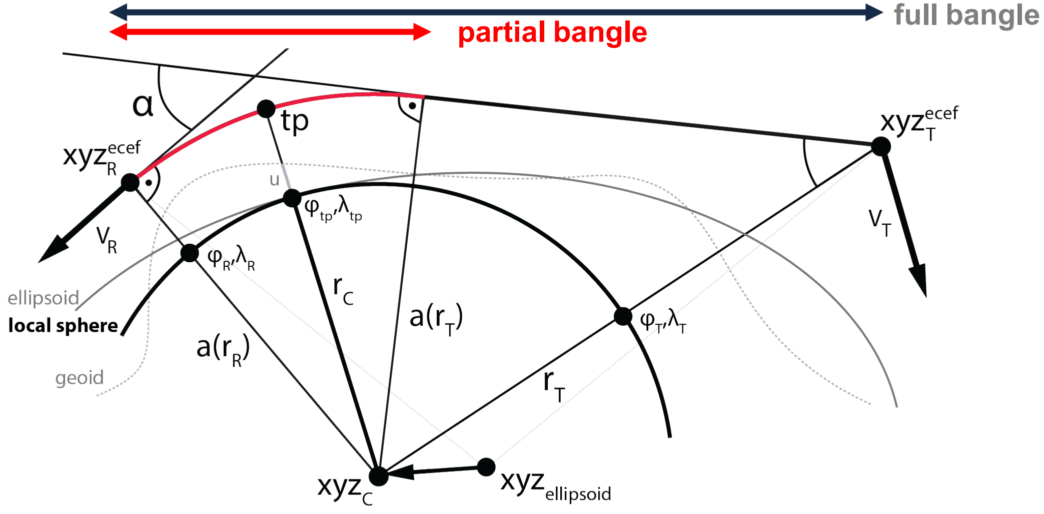
ARO data:

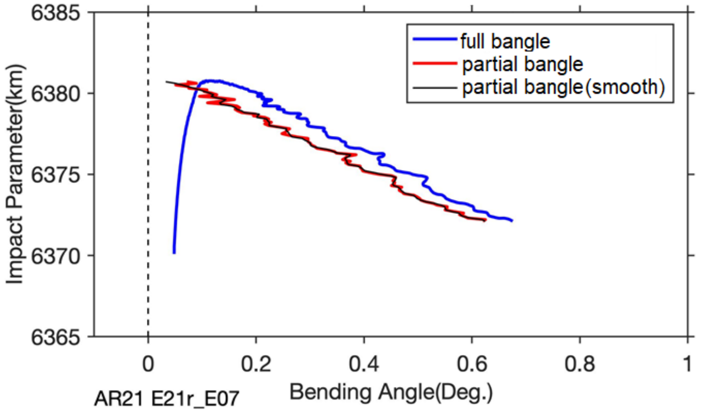
- geometrical optics (closed-loop receiver),
- positive and negative elevation angles,
- significant tangent point drift (particularly at uppermost levels at the aircraft).

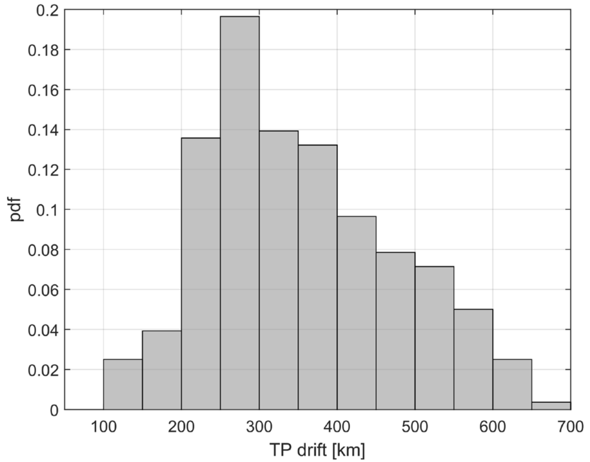
Two variants of the bending angle:

partial: symmetrical section of the raypath around the occultation point below aircraft altitude

full: partial raypath section together with assymetrical section towards GNSS







ARO data formats

We follow UCAR/CDAAC data formats

Level1b atmPhs: atmospheric excess phase file
with time as an independent variable

Level2 atmPrf: atmospheric profile
with vertical coordinate as an independent variable

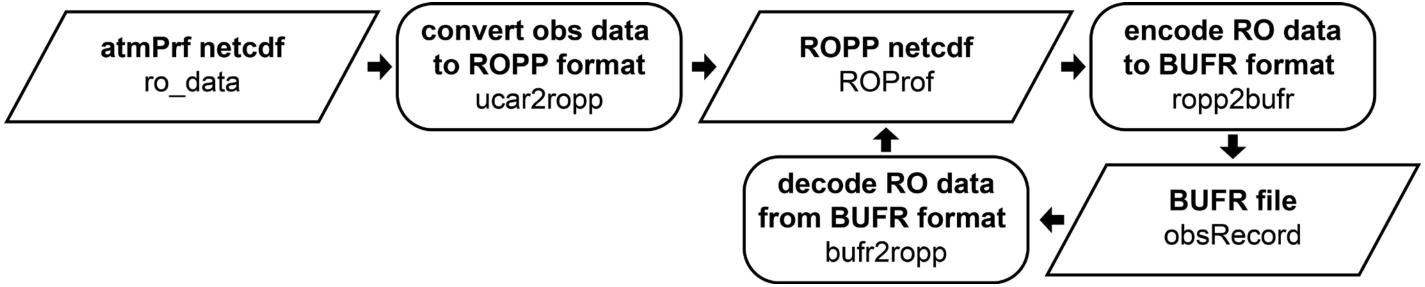
Additional ARO-specific variables (function of time):
- in-situ refractivity at the aircraft
- aircraft height

ARO BUFR

In process…

Currently, ARO BUFR has the same structure and variables as spaceborne RO:

- bending angles starts at the aircraft location
- both partial and full bending angles will be included
- refractivity structure as in spaceborne RO



Modifications to the 2D ray-tracer

Key features:

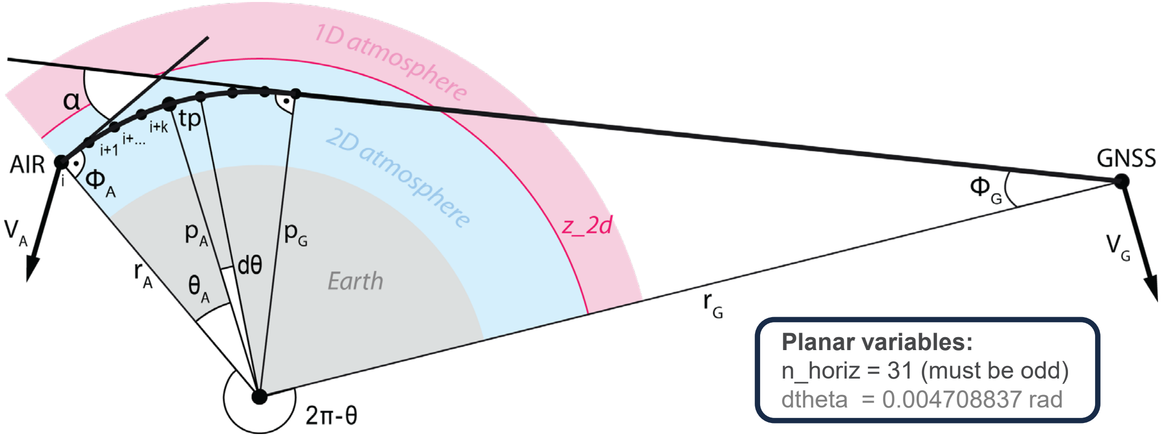
- integration starts at the obs tangent point outwards,
- based on Runge-Kutta method,
- can account for **tangent point drift** (individual runs for each TP).

Variables:

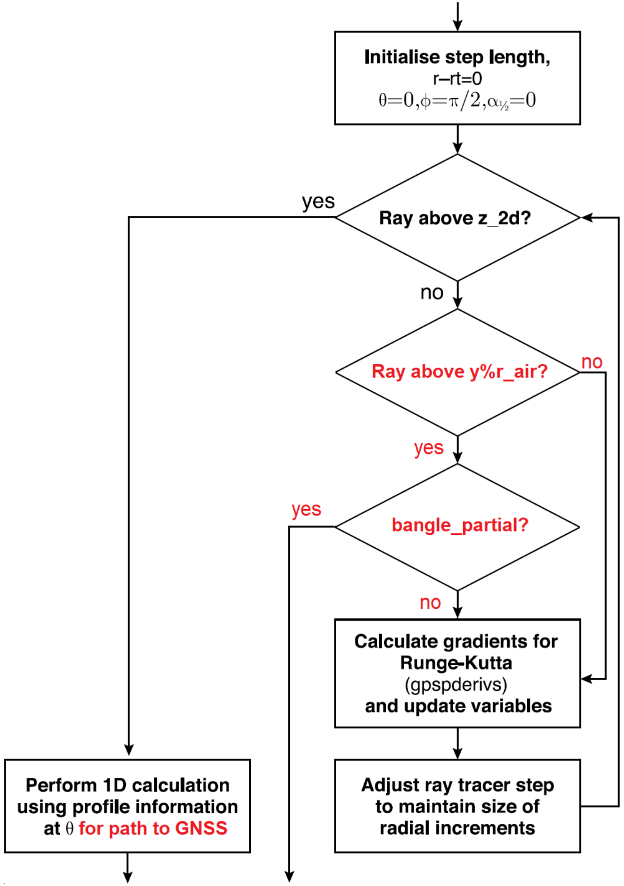
z_2d: hard-coded, **upper limit for 2D ray-tracer**, currently set to 20 km (technically impact height / nr product)

y%r_air (new): radius of the aircraft to terminate integration on aircraft side.

Currently invariant during occultation due to BUFR limitations
top impact height = aircraft impact height



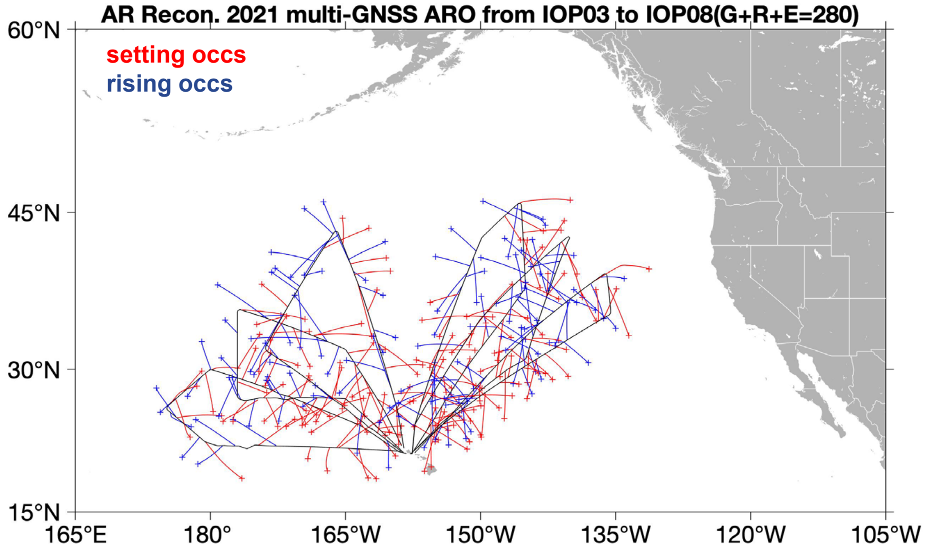
Planar variables:
n_horiz = 31 (must be odd)
dtheta = 0.004708837 rad

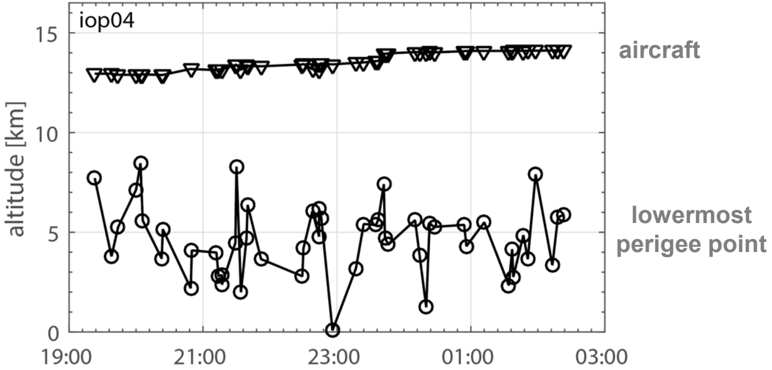


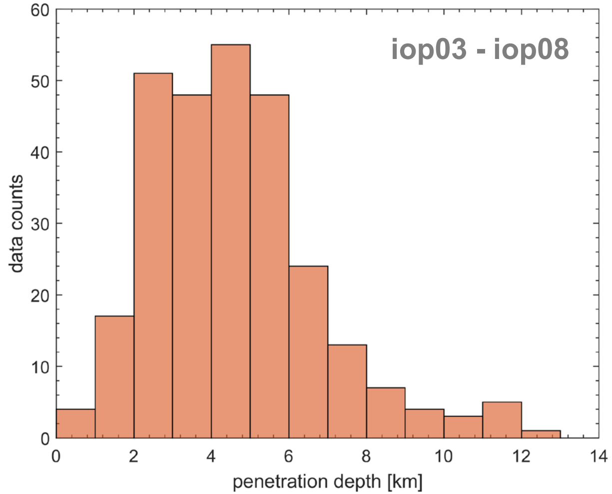
ARO data from AR Recon 2021

2021 Atmospheric River Reconnaissance (AR Recon) campaign:

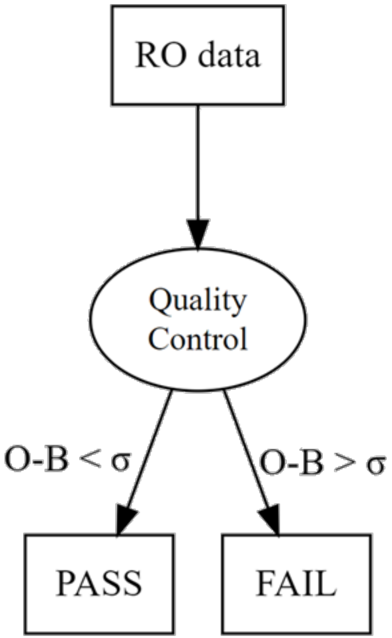
- six intensive operating periods (IOPs)
- ARO data for 2021.022 – 2021.027
- 280 occultations in total (~40 per flight)







OmB statistics



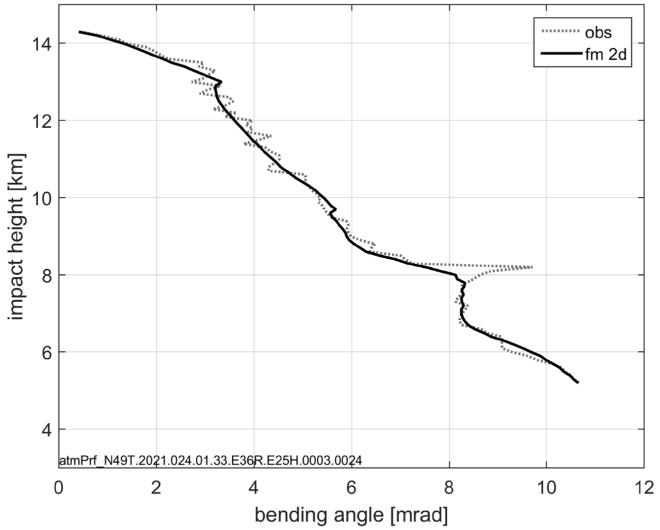
Obs errors based on OmB statistics for spaceborne RO:

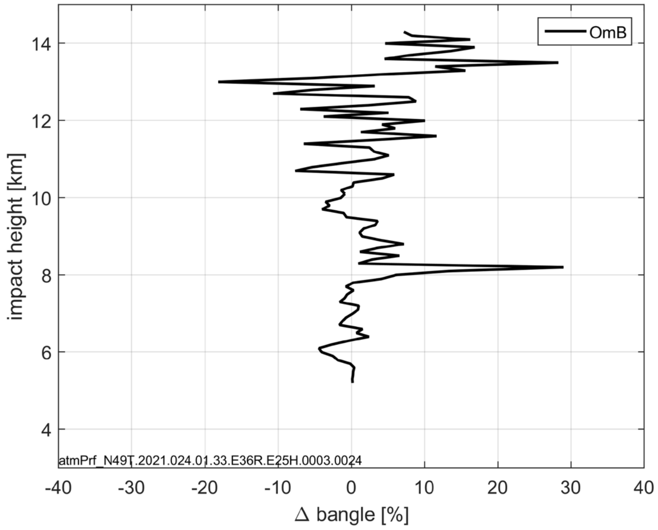
Bending angle*: 10% at surface to 1% at 10 km*

Refractivity*: 1.1% at 4 km to 0.25% at 10 km*

Sigma needs to be estimated for airborne RO

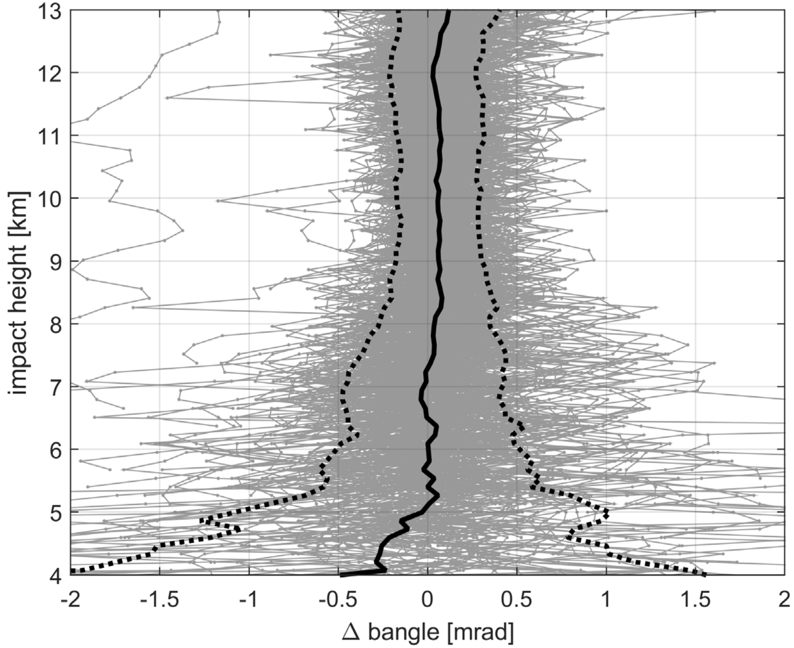
Typical threshold for rejection: ***5 x sigma*** *(standard deviation)*

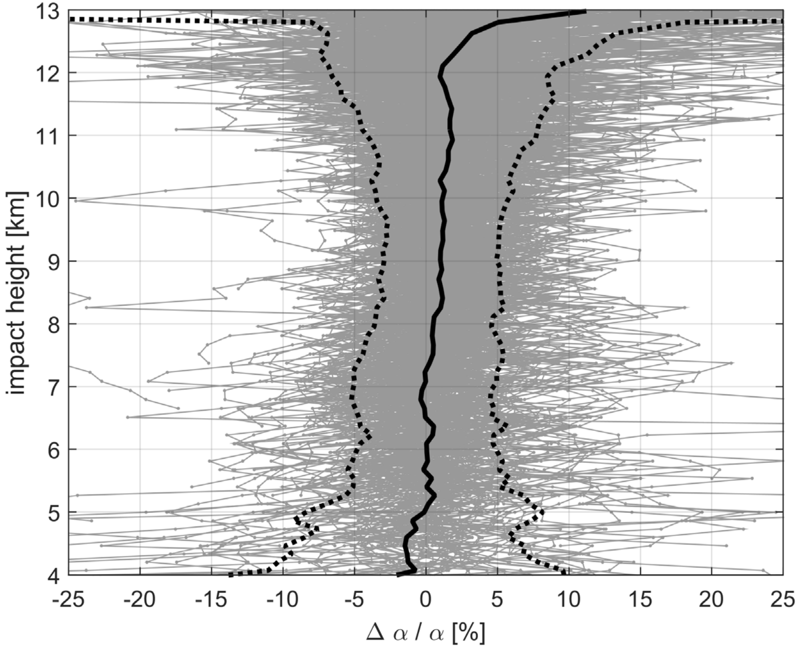




Overall statistics: iop03 – iop08 (280 occs)

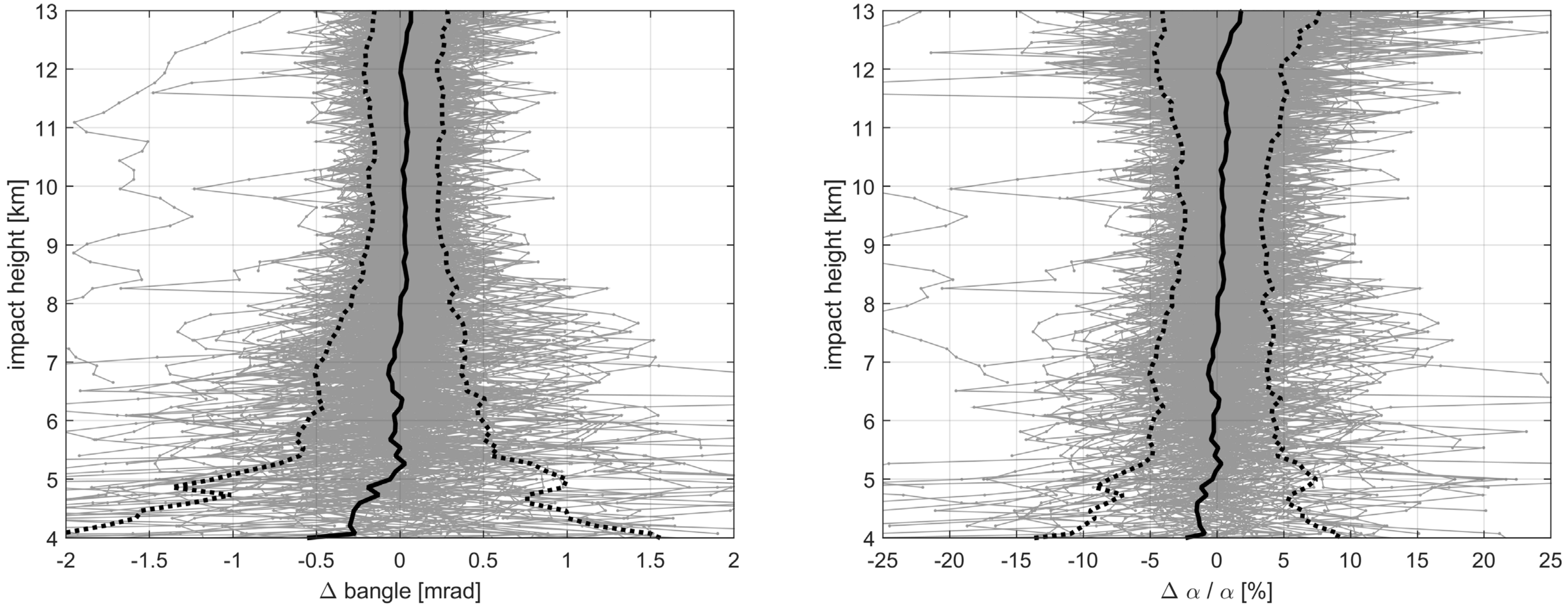
Partial bending angle with tangent point drift





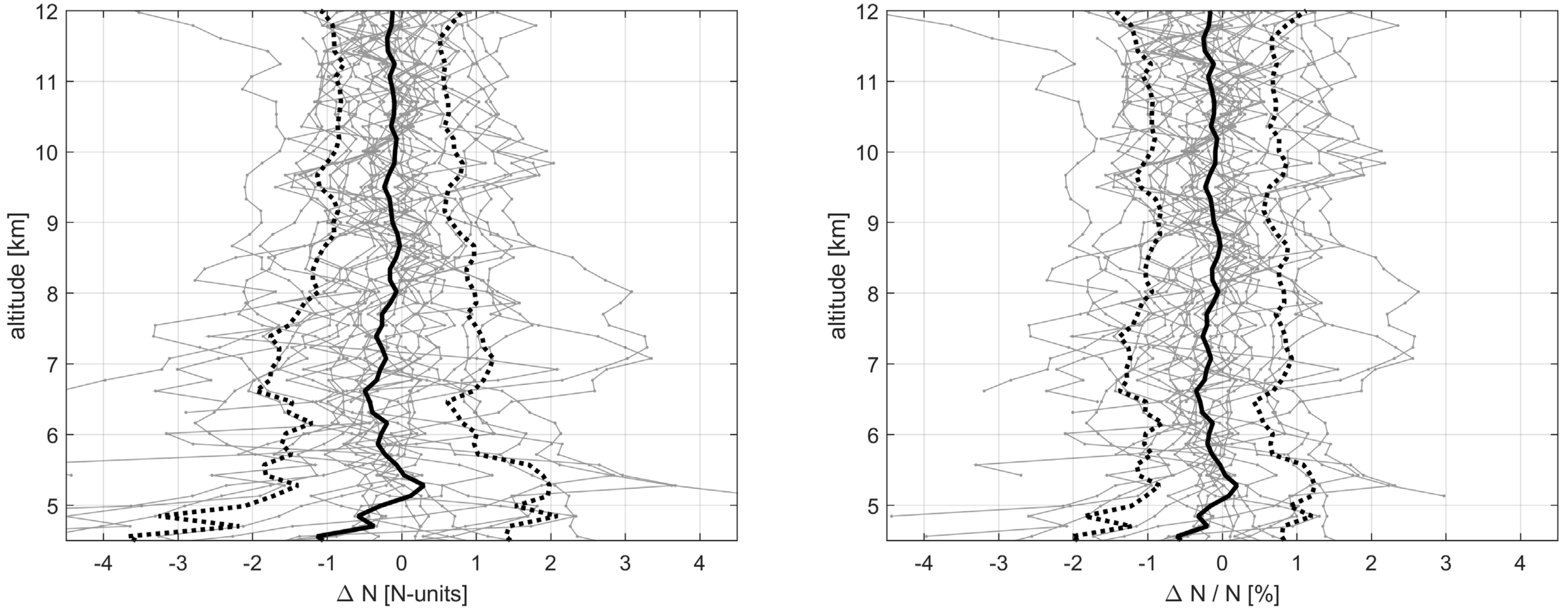
Overall statistics: iop03 – iop08 (280 occs)

Full bending angle with tangent point drift



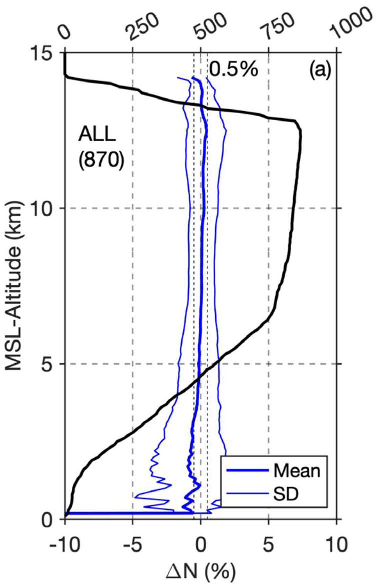
Overall statistics: iop03 – iop08 (37 occs)

Refractivity: ARO minus dropsonde
collocation: *+/- 1h, < 300 km*

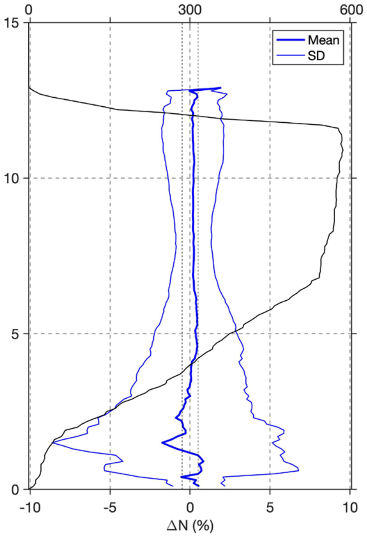


More N statistics: for 2021 (>750 occs)

ARO – ERA5

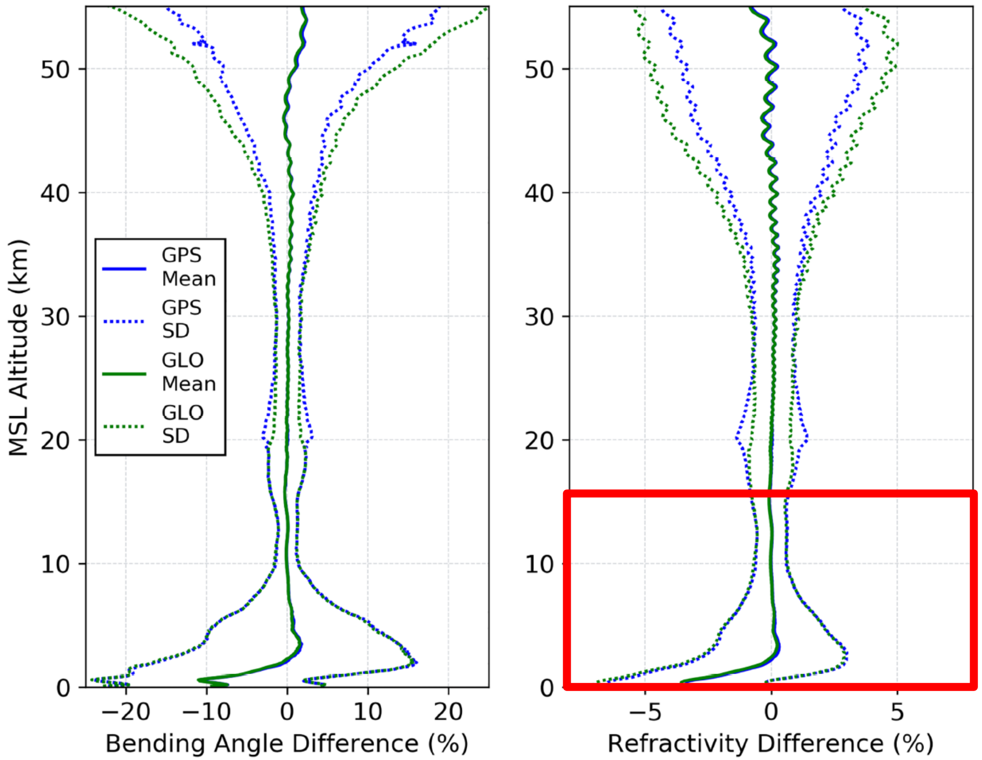


ARO – dropsonde



COSMIC-2 for reference

source: Schreiner et al. (2019)



Summary

1. **ARO 2D bending angle operator:**
   - can account for tangent point drift (significant for ARO),
   - ARO is good 1.5 km below flight level,
   - error properties in the midtroposphere comparable to spaceborne RO,
   - penetration depth limited by closed-loop data: down to approx. 4 km.

2. **Future plans:**
   - incorporate 2D ARO operator into JEDI (spaceborne operators already available),
   - ARO obs data: atmPrf and BUFR expected before the end of 2022 (endorsed by IROWG working group),
   - AR Recon 2022 raw data transmitted in real time, plans for AR Recon 2023 to develop NRT capability.

Thank you for your attention