Comparison of GPS-RO Retrievals from Multiple Data Processing Centers

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RO as Anchor Measurements

- NWP data assimilation has demonstrated the value of RO data as an anchor dataset for bias correction of other data.

- Increasing interests in using RO data as a reference dataset for anchoring other climate observations
  - 3G (GRUAN, GSICS, GPS-RO) Workshop in May 2014
  - NPROVS from NOAA STAR (Tony Reale, Bomin Sun) interested in anchoring other satellite observations to RO instead of RAOB.

- Interests in using RO for climate model comparisons
  - obs4MIPs data from GPS-RO (NASA ROSES/NDOA).

- **Given the existence of RO retrieval data from multiple processing centers, which dataset should be used? How consistent or inconsistent are these datasets?**
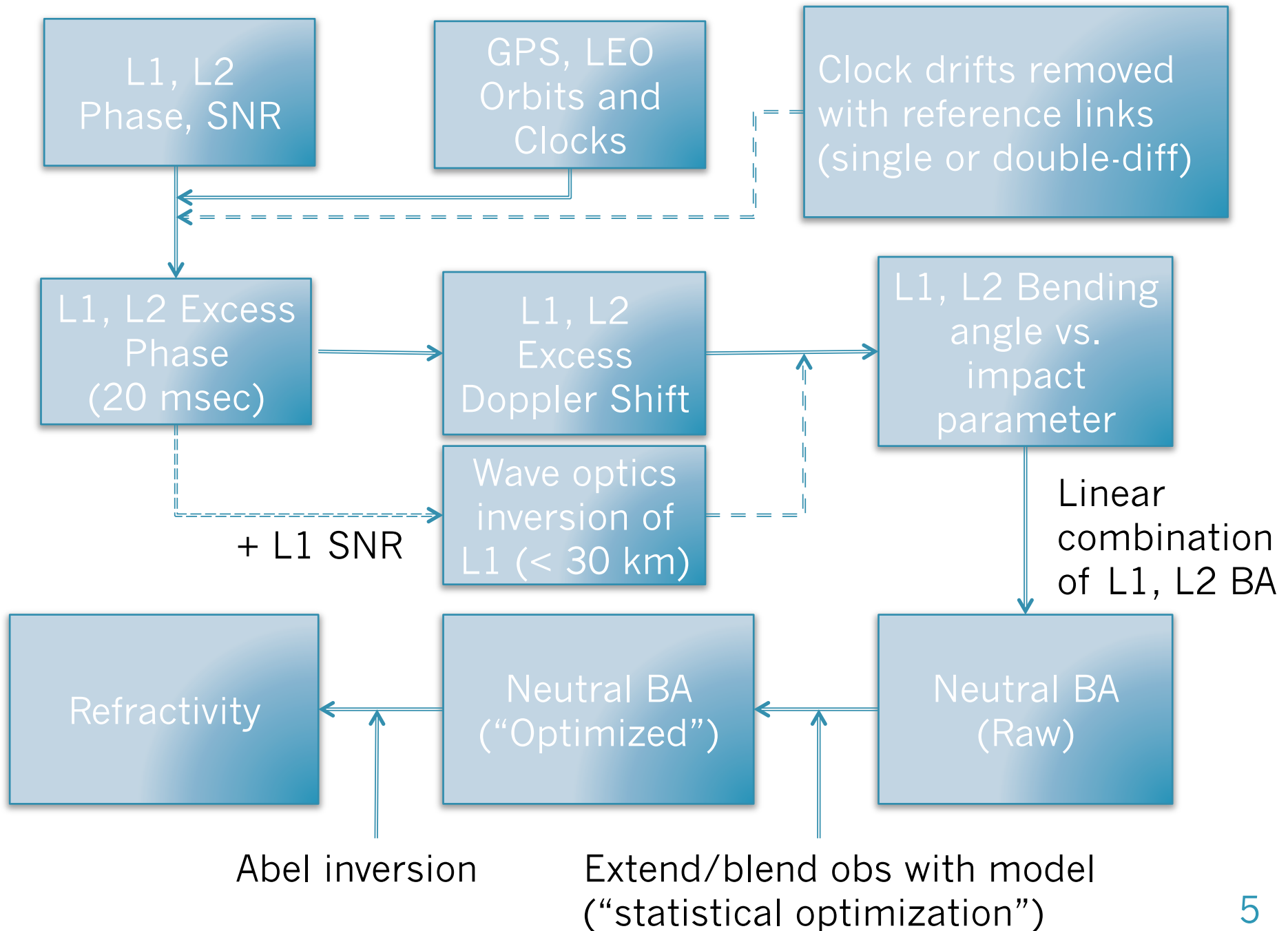
RO Comparison Project

- Joint effort from multiple GPS-RO processing centers from Europe and USA
  - Comparisons of retrievals based on multi-year CHAMP data [Ho et al. 2009, Ho et al. 2012, Steiner et al. 2013].
  - Follow on studies
    1. Understand where the reported CHAMP differences originate [led by JPL]
    2. Differences across different RO missions [led by WEGC]
    3. Differences in quality controls [led by UCAR]
  - "ROTrends" group, now formally, "RO-CLIM" project under SCOPE-CM (led by Hans Gleisner of DMI).
    http://irowg.org/projects/ro-clim-under-scope-cm/

- Participating processing centers
  - EUMETSAT (**EUM**)
  - Danish Meteorological Institute (**DMI**)
  - GeoForschungsZentrum (**GFZ**)
  - Jet Propulsion Laboratory (**JPL**)
  - COSMIC Data Analysis and Archive Center, UCAR (**UCAR**)
  - Wegener Center, U. Graz (**WEGC**)

Caveats

- **The dataset and methodologies are not fully independent among the processing centers, for example,**
  - UCAR excess phase/orbits were used by EUM, DMI, WEGC
  - Use of MSIS climatology by most for upper altitude initialization of bending angle, etc.
  - Same ionosphere correction algorithm means common ionospheric residual errors.
  - Thus a center being outlier doesn't necessarily mean it's wrong. When they all agree, it does not imply they are all correct.

- **The comparisons were limited in altitudes and higher-level products.**

- For better understanding, needs a deeper look at lower level data and at higher altitudes.

Retrieval Chain

```
L1, L2
Phase, SNR
```

```
GPS, LEO
Orbits and
Clocks
```

```
Clock drifts removed
with reference links
(single or double-diff)
```

```
L1, L2 Excess
Phase
(20 msec)
```

```
L1, L2
Excess
Doppler Shift
```

```
L1, L2 Bending
angle vs.
impact
parameter
```

+ L1 SNR

```
Wave optics
inversion of
L1 (< 30 km)
```

Linear
combination
of L1, L2 BA

```
Refractivity
```

```
Neutral BA
("Optimized")
```

```
Neutral BA
(Raw)
```

Abel inversion

Extend/blend obs with model
("statistical optimization")

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Comparison Results

- Two months of CHAMP data were chosen (Dec 2006 & July 2008).

- Extended altitudes and data types (L1, L2, Raw and Optimized BA) were requested.

- Unfortunately not all centers stored all data types and to altitudes > 60 km.

- Results shown here based on profiles that pass QC for all processing centers (~ 3000 profiles per month).

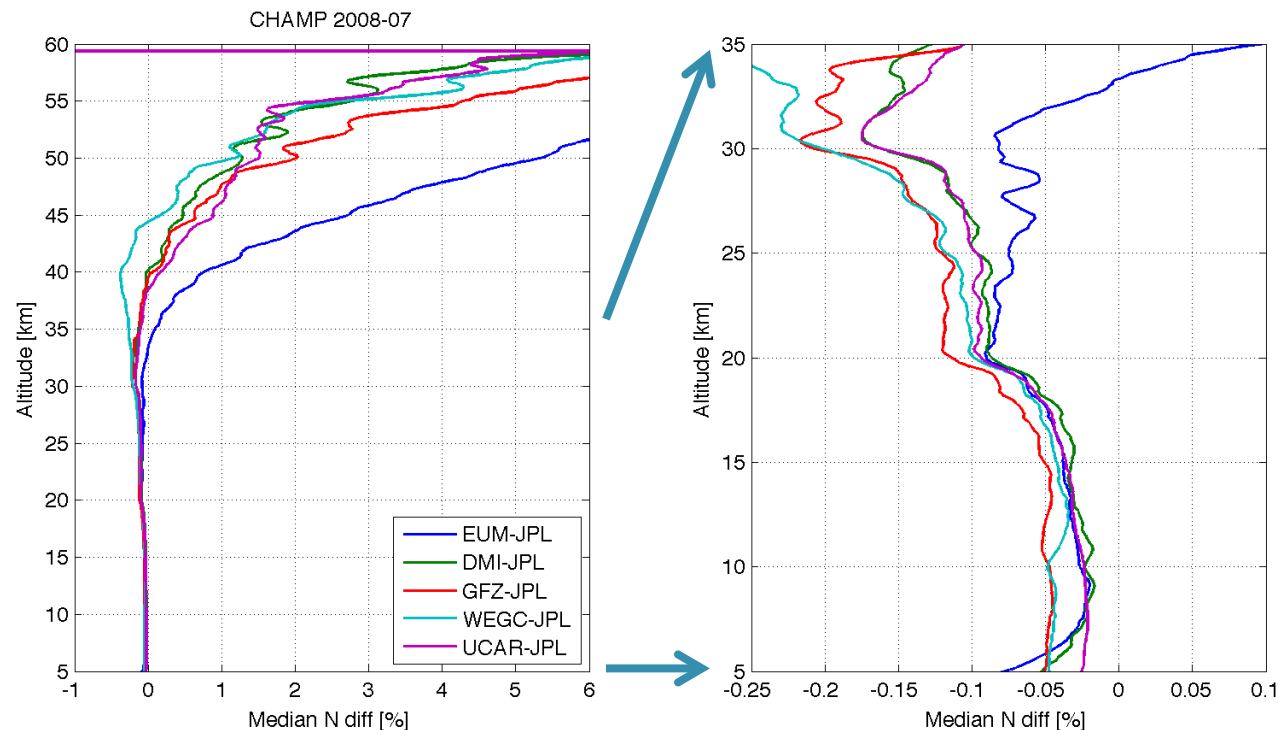- Results presented in median fractional difference relative to JPL.
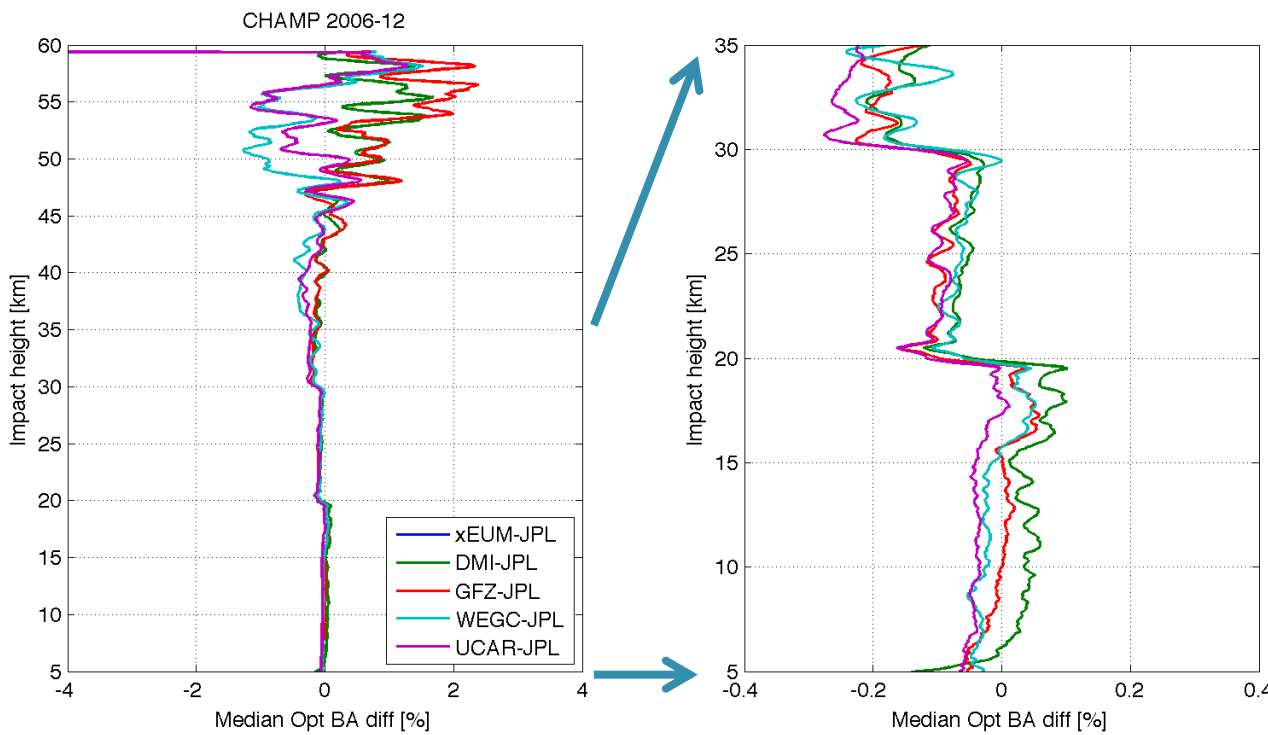
Refractivity (N)

Dec 2006
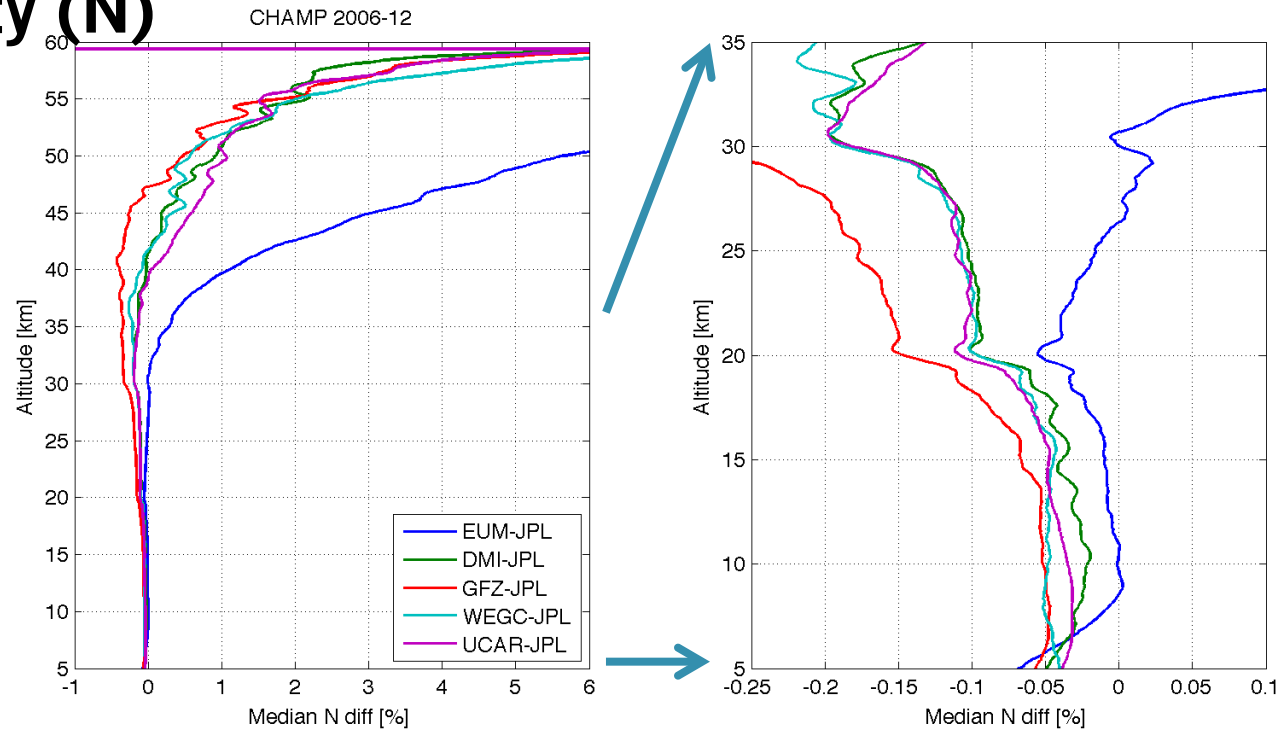
Jul 2008

- At larger altitudes, JPL small relative to all other centers; EUM larger.

- Shifts at 20 and 30 km.

- At lower altitudes, JPL tends to be larger (~ 0.1 % between 20-30 km, 0.05% below 20 km).

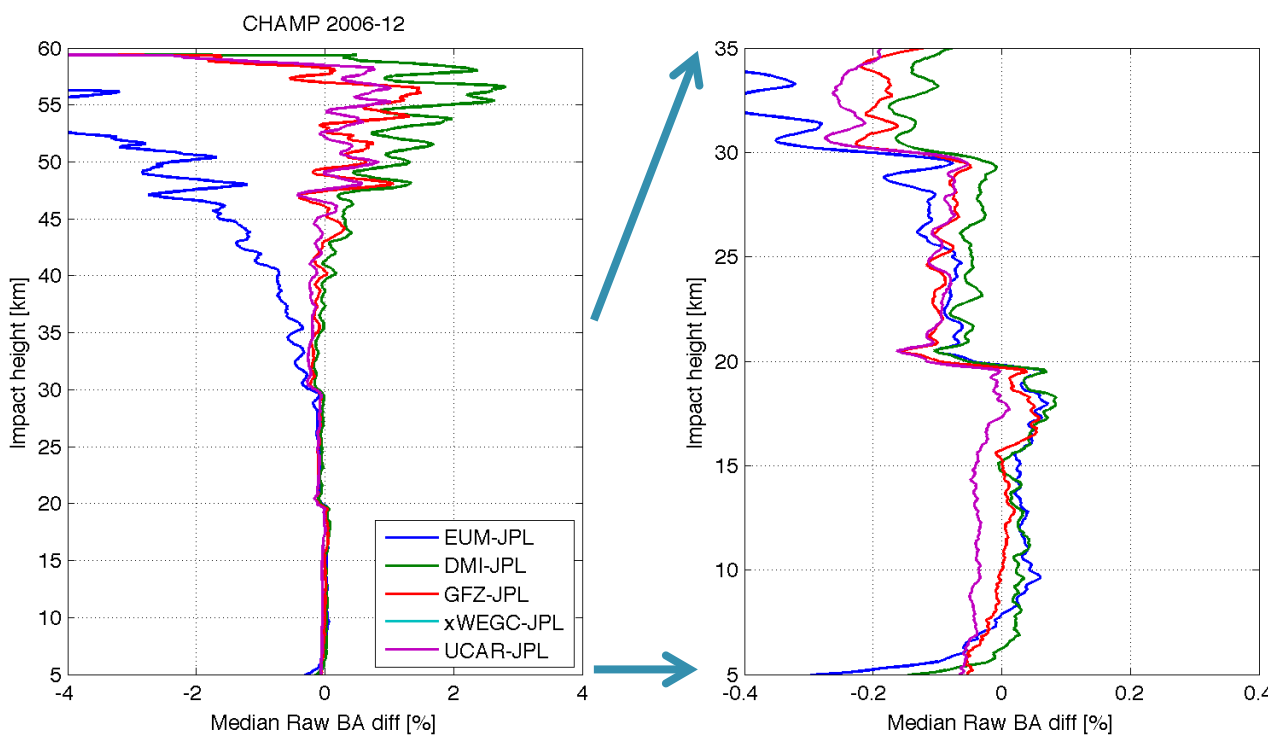- Similar between the two months, but some centers show larger diff.

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Neutral BA

"Optimized"

(No EUM)

"Raw"

(No WEGC)

CHAMP 2006-12

- Better agreement than N.
- Shifts at 20 and 30 km.
- BA optimization has some effects even at lower altitudes but mainly above 50 km and especially above 60 km (based on large N diff).
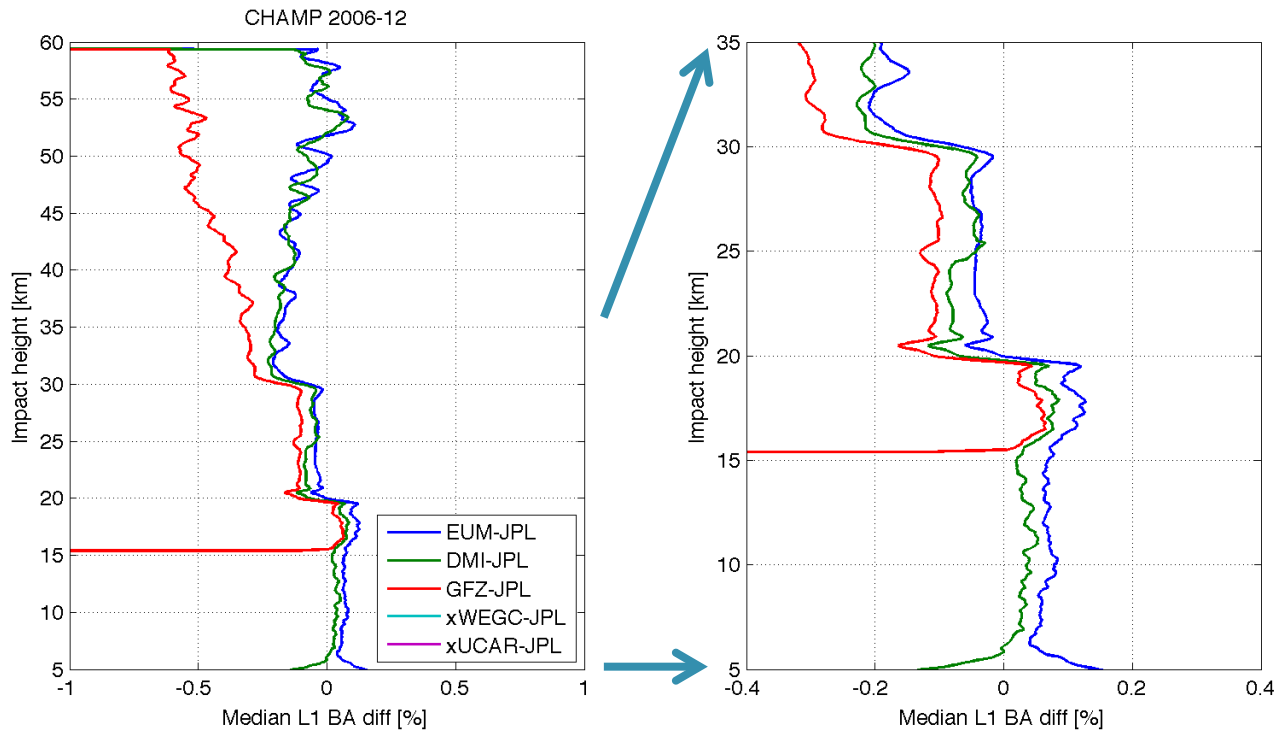
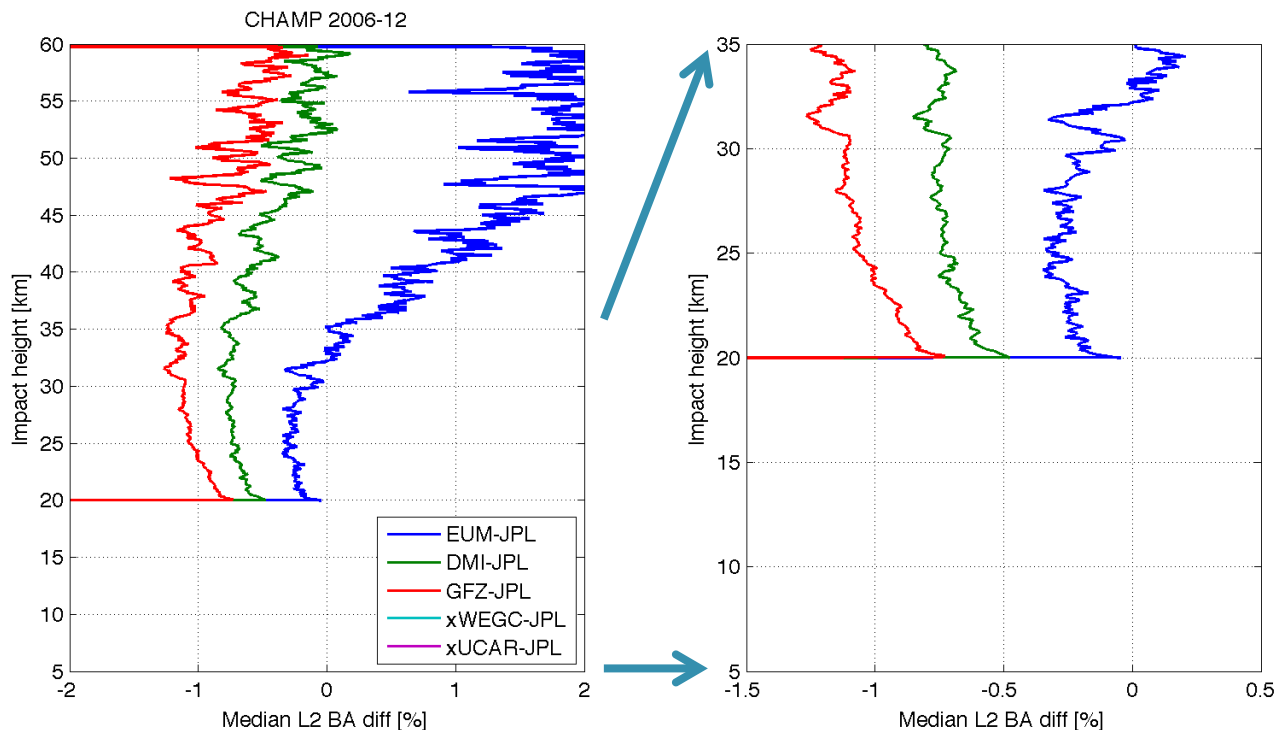# L1, L2 BA

L1

(No WEGC, UCAR)

CHAMP 2006-12

L2

(No WEGC, UCAR)

- Good agreement in L1 BA at higher altitudes.
- Large differences in L2 BA. (L2 phase is much noisier than L1.)
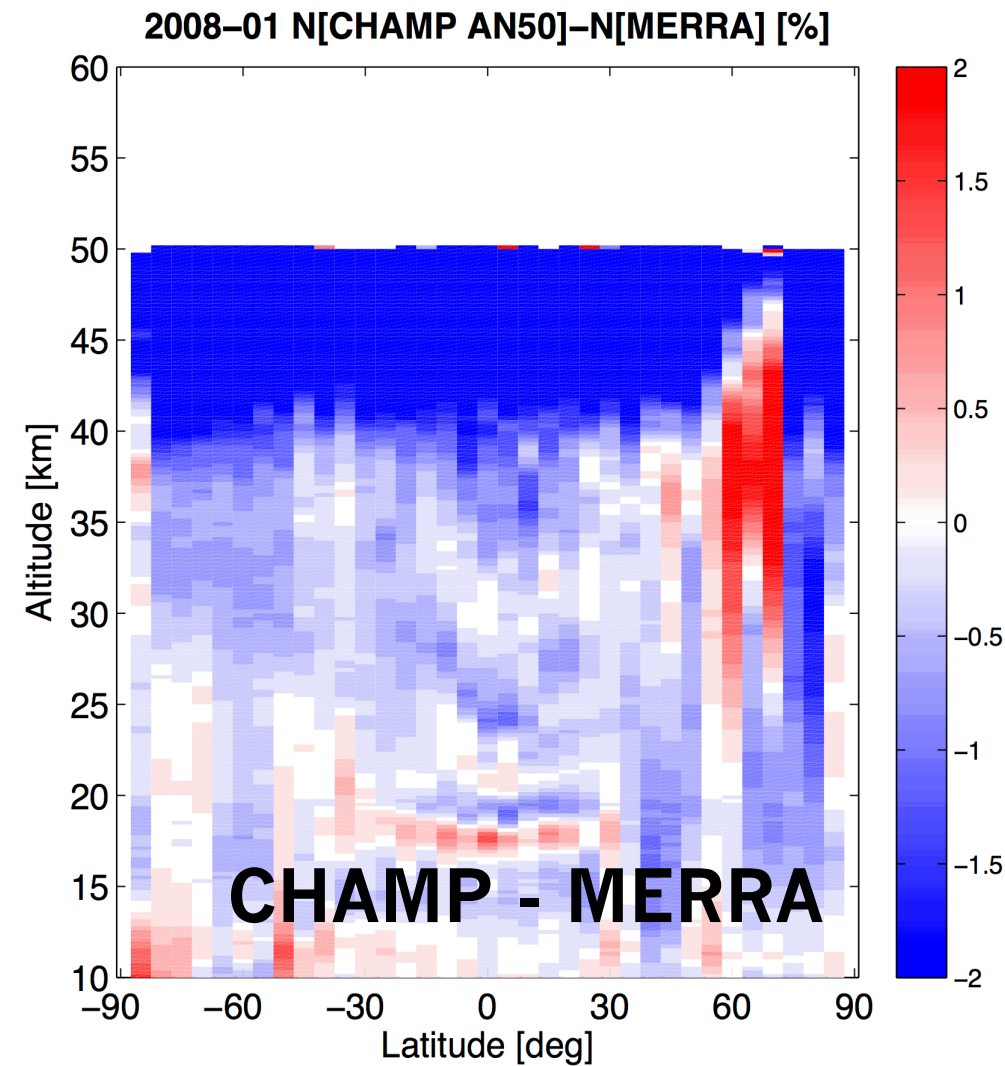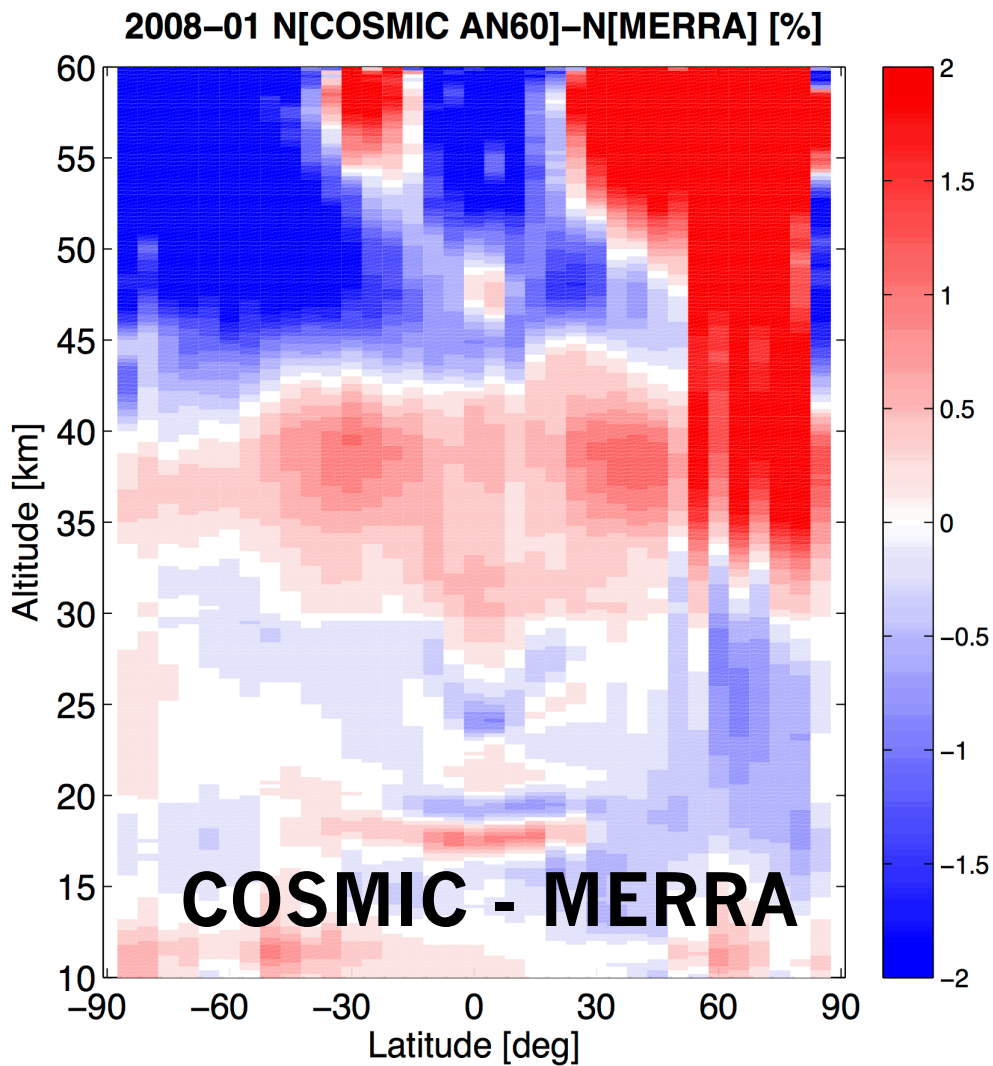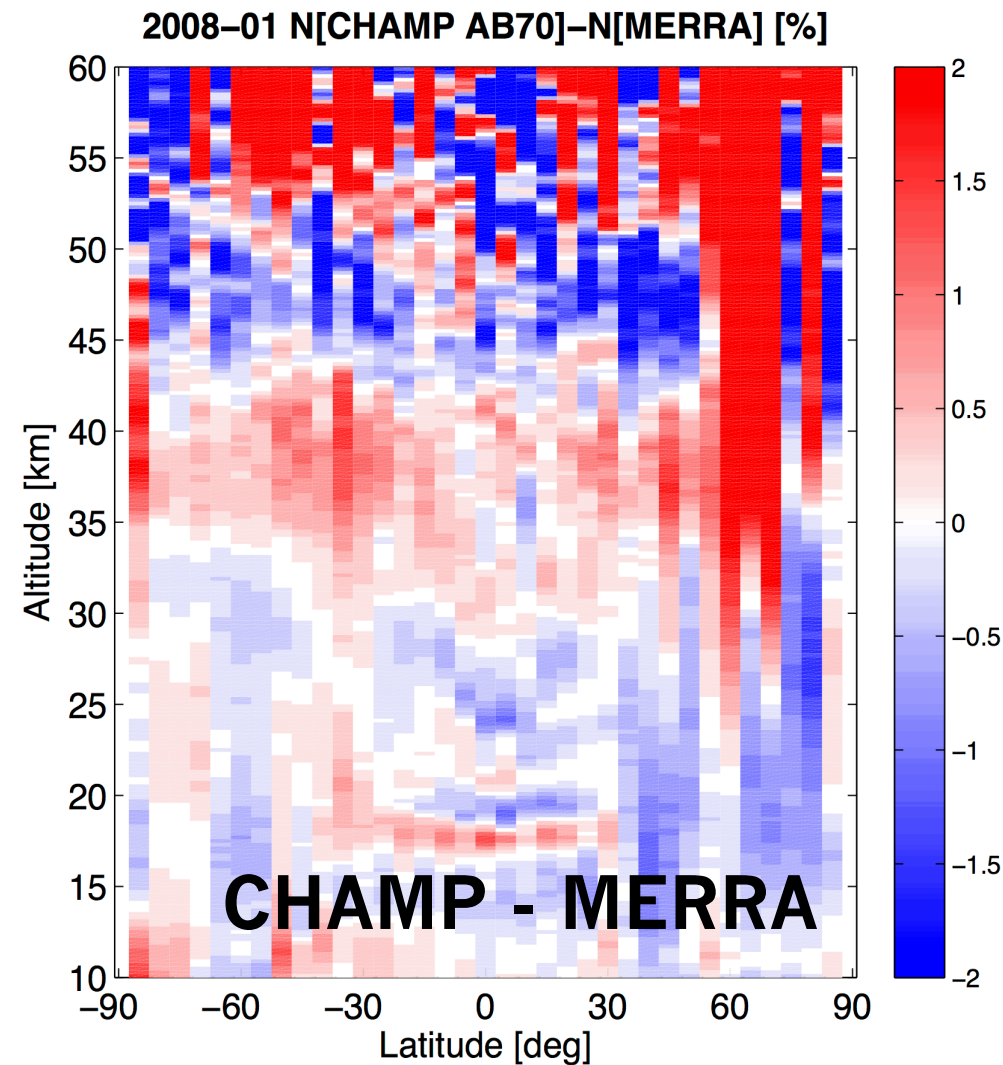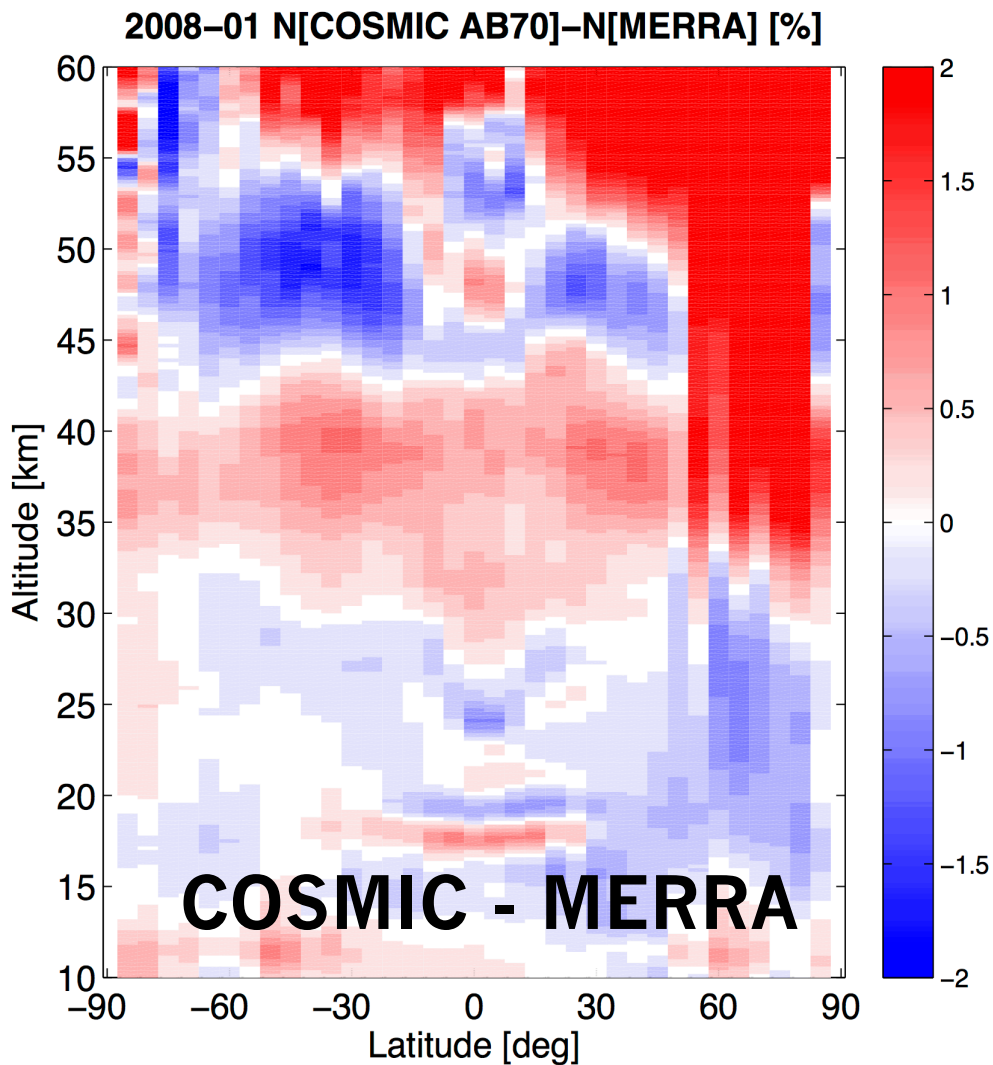- Large L2 BA differences did not get carried over to Neutral BA.

Discussion

- Upper altitude initialization
  - This is a known issue mainly affecting N mainly at z > 30 km.
  - There are ways to improve monthly zonal means by averaging BA first [Ao et al. 2012; Gleisner and Healy 2013].
  - Also possible to improve single profile retrieval using RO-based BA climatology [Ao et al. 2013; Scherlin-Pirscher et al. 2013].

- Effect of vertical smoothing
  - JPL vertical smoothing changes at 20 km and 30 km correspond to shifts wrt other centers.
  - Can smoothing introduce a bias?

- Effect of "geometric optics" vs. "wave optics" transition (JPL transition at 30 km, DMI at 25 km, GFZ at 15 km, UCAR at 20 km).

- Nearly constant fractional N difference means ΔN must be increasing as N. One possible cause is a height difference (1 m in height can lead to ~0.01% in N). Can this be due to a difference in the reference geoid?

Upper Altitude Initialization (Avg N)

2008–01 N[COSMIC AN60]–N[MERRA] [%]

2008–01 N[CHAMP AN50]–N[MERRA] [%]

COSMIC - MERRA

CHAMP - MERRA

Upper Altitude Initialization (Avg BA)

2008−01 N[COSMIC AB70]−N[MERRA] [%]

COSMIC - MERRA

2008−01 N[CHAMP AB70]−N[MERRA] [%]

CHAMP - MERRA

Vertical Smoothing

CHAMP 2006-12

GO with 1-sec (2 km) smoothing

WO with 1 km smoothing

WO with 200 m smoothing

Legend: (200 m, 2.0 sec) — blue; (200 m, 0.4 sec) — green

X-axis: Median L1 BA diff wrt (1 km, 1 sec) [%]

Y-axis: Impact height [km]
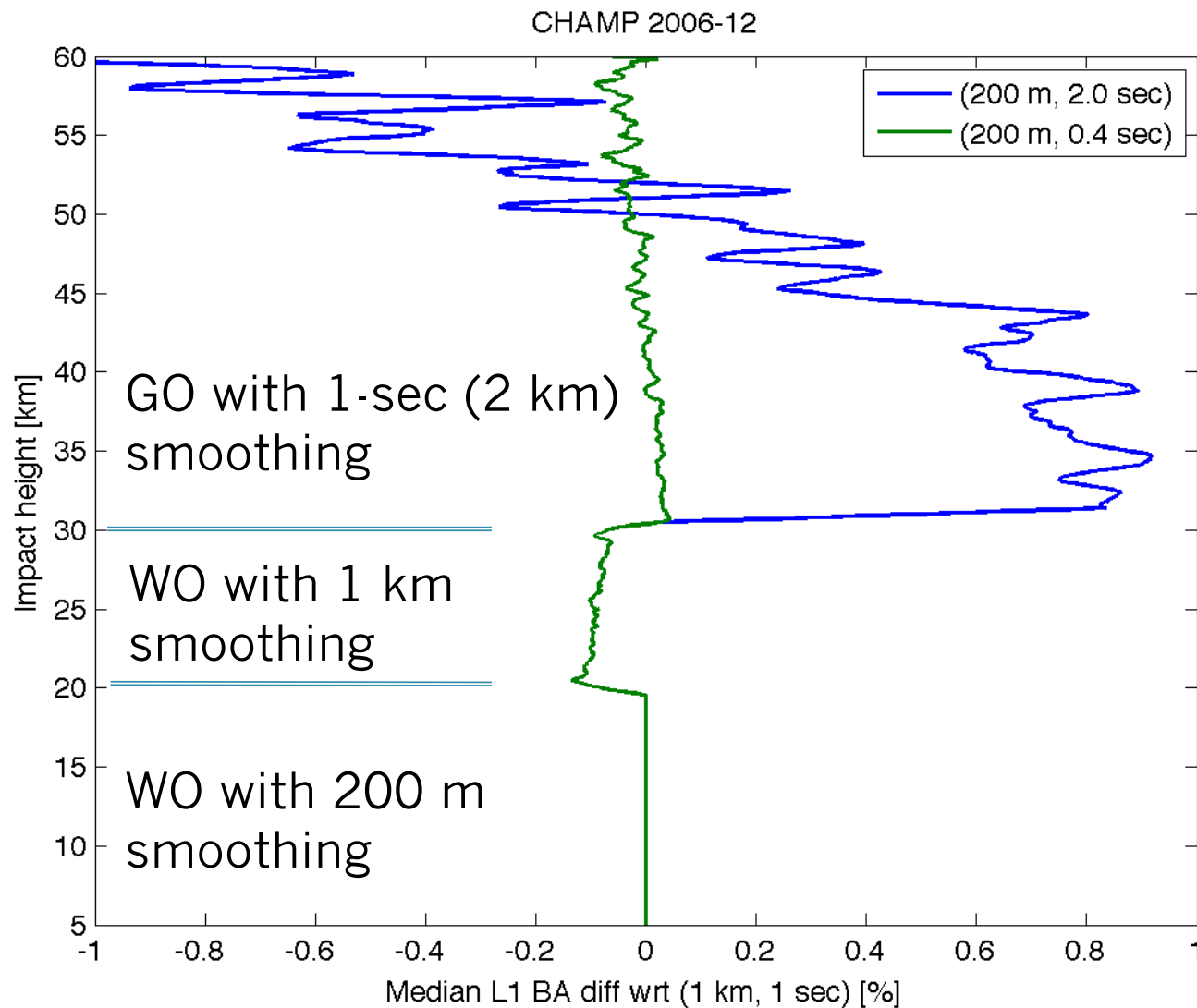
Summary

- Recognizing the increasing interest in using RO as an climate anchor measurement, the RO community is working jointly to better character retrieval **bias** and uncertainty.

- An in-depth look of the CHAMP retrievals reveals some intriguing differences not fully understood.
  - We confirmed differences arising from upper altitude initialization.
  - We found that vertical smoothing can have an impact on retrieval bias.
  - Refractivity and bending angle differences in the core altitudes of 5-20 km are too large!

- Simulations could provide a more definite approach to address some of these issues.