Improving GPS RO Stratospheric Retrieval for Climate Benchmarking

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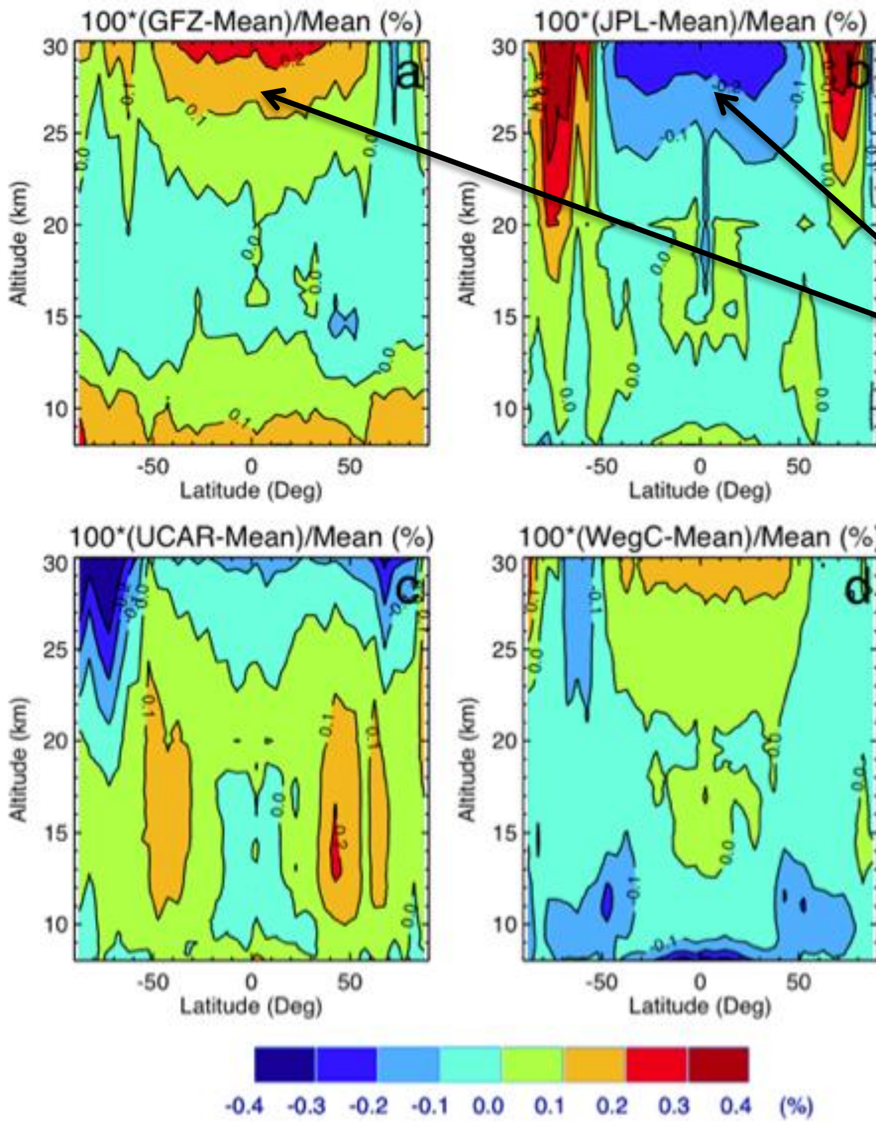
Introduction

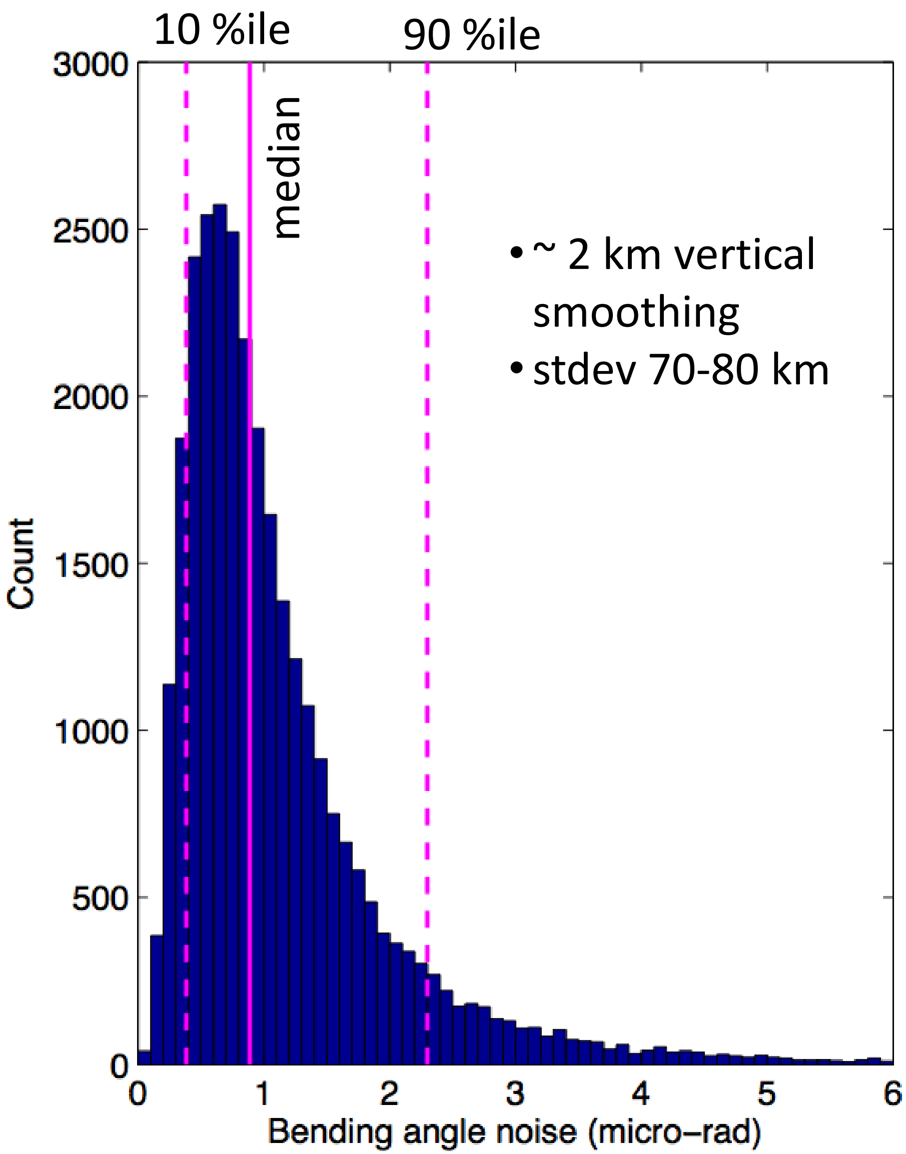
- GPS RO refractivity (N) has been shown to be useful for long-term climate monitoring [CLARREO; Leroy et al., 2006; Huang et al. 2010].
- Accuracy is well proven in the “sweet spot” of 5-20 km alt, but considerable uncertainty in the lower troposphere (< 5 km) and stratosphere (> 20 km).
- **We present a new method to reduce the stratospheric bias in the mean N due to the Abel upper boundary initialization.**

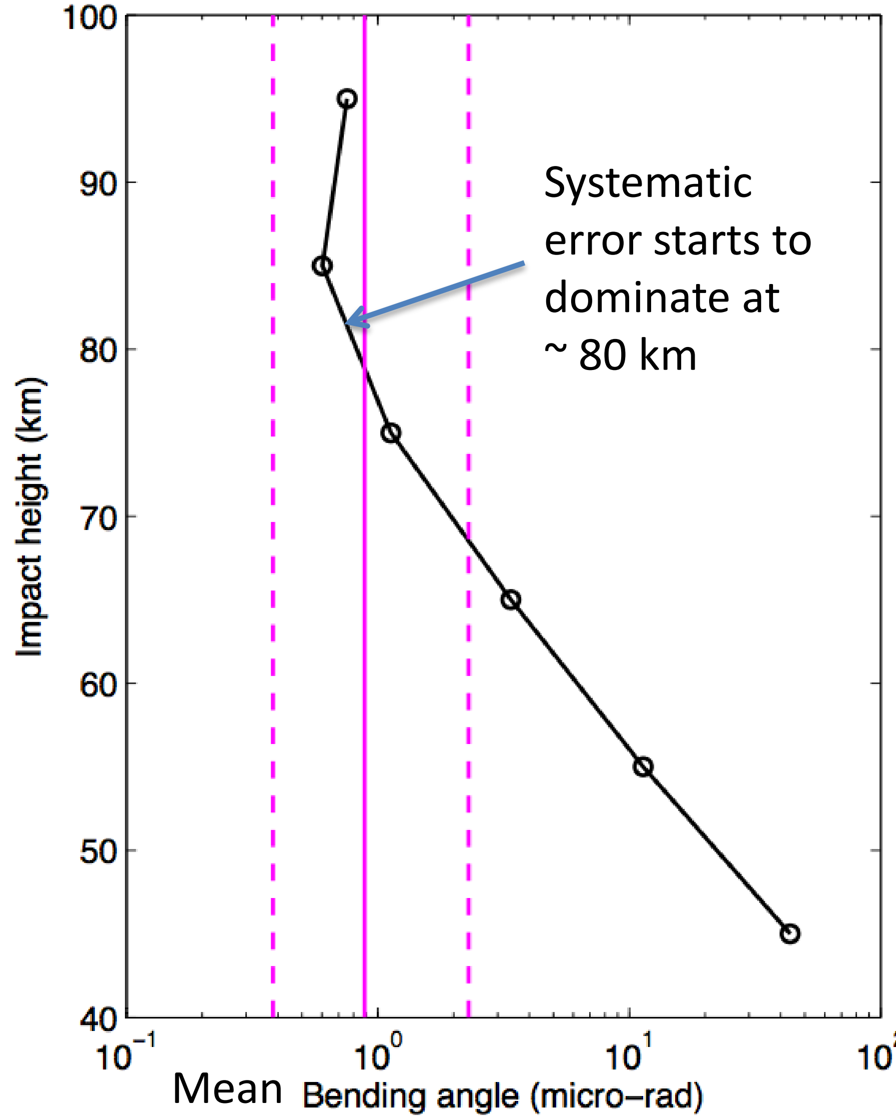
Intercomparison of CHAMP RO refractivity [Ho et al., JGR, 2009]



Disagreement over 25 km is largely due to different ways of dealing with noisy bending angles at high altitudes

Iono-corrected bending angle from COSMIC Jan 2008





Bending Angle Noise

- Random
  - Thermal noise (occ + cal links)
  - Ionosphere (small scale)?
- Systematic
  - Ionospheric residual error (< 0.5 micro-rad for solar max daytime)
  - Local Multipath, Orbit, Antenna phase center offset

Abel Upper Boundary Condition: High altitude noisy bending angles are replaced by a "model".

$$n(a) = \exp\left[\frac{1}{\pi}\int_a^\infty \frac{da'}{\sqrt{a'^2 - a^2}}\alpha(a')\right]$$

Refractive index

Impact parameter
a = n(r) r

Bending angle

Fixed height transition from obs to model:

$$\alpha(a) = \alpha_{\mathrm{mod}}(a) \qquad \text{if} \qquad a - R > h_m$$

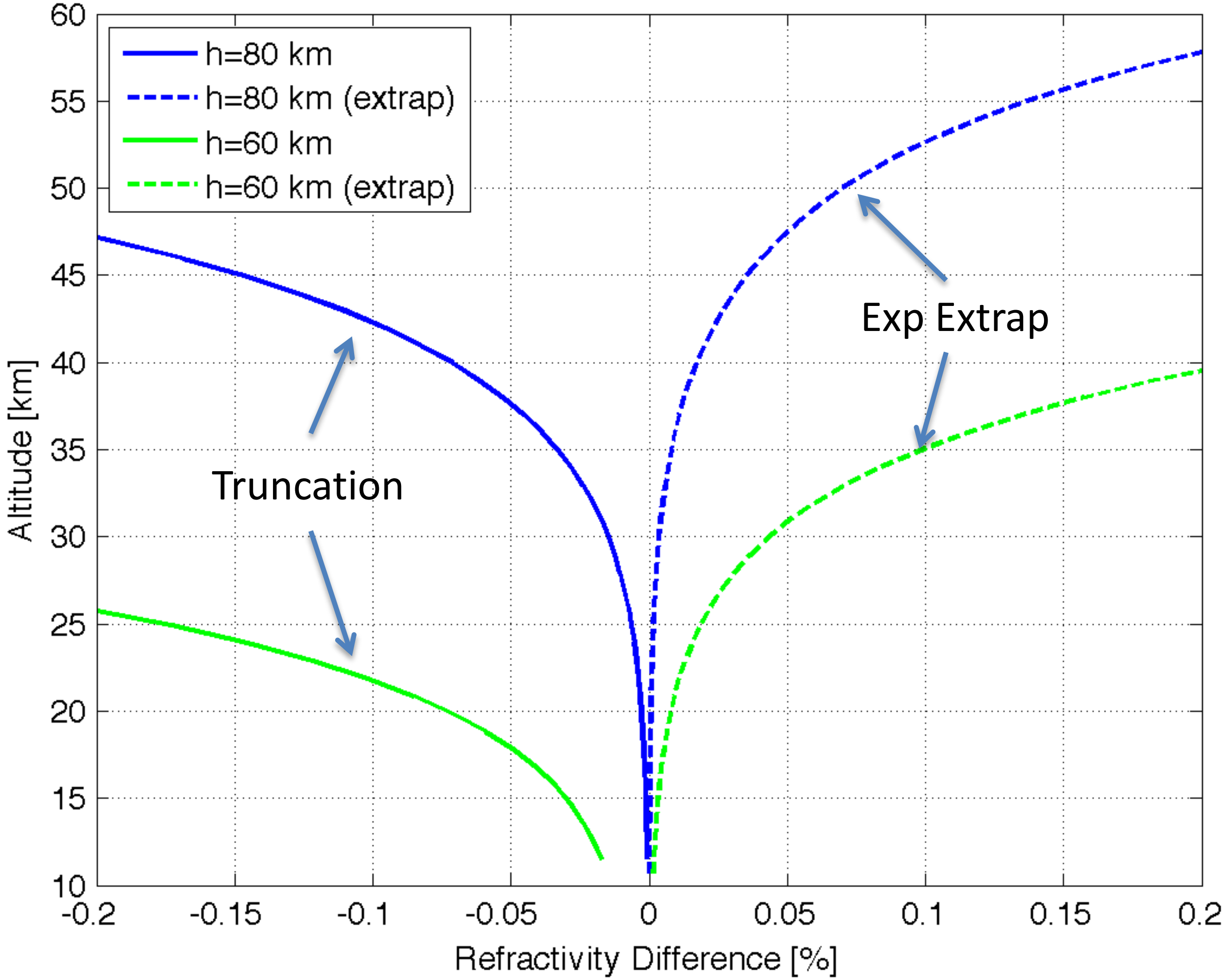
Blending of obs and model (Statistical Optimization):

$$\alpha(a) = w(a)\alpha_{\mathrm{obs}}(a) + [1 - w(a)]\alpha_{\mathrm{mod}}(a), \quad 0 < w(a) < 1$$

Which "Model"?

- MSIS Climatology
- NCAR Climatology (exponentially extrapolated)
- Climatology model with bias adjustment
- Our preference for climate dataset:
  - Exponential extrapolation based on measurements: No dependence on climatology models.
  - Fixed height transition: "model" influence more transparent.
- **All "models" will introduce systematic bias at lower altitudes if the max obs height (h_m) is too low.**

To reduce the bias, the cutoff height h_m should be set as high as possible.



Strategies for Reducing Random Noise

- Better antenna gain (increase SNR);
- Less calibrating links (zero differencing);
- More vertical smoothing (decrease vertical resolution);
- **Averaging over large number of bending angle profiles (e.g., monthly zonal means)**

Can we compute the mean refractivity profile by Abel inversion of the mean bending angle profile?

$$\langle n(a)\rangle = \frac{1}{M}\sum_{i=1}^{M}\exp\left(\frac{1}{\pi}\int_a^\infty \frac{da'}{\sqrt{a'^2-a^2}}\alpha_i(a')\right)$$

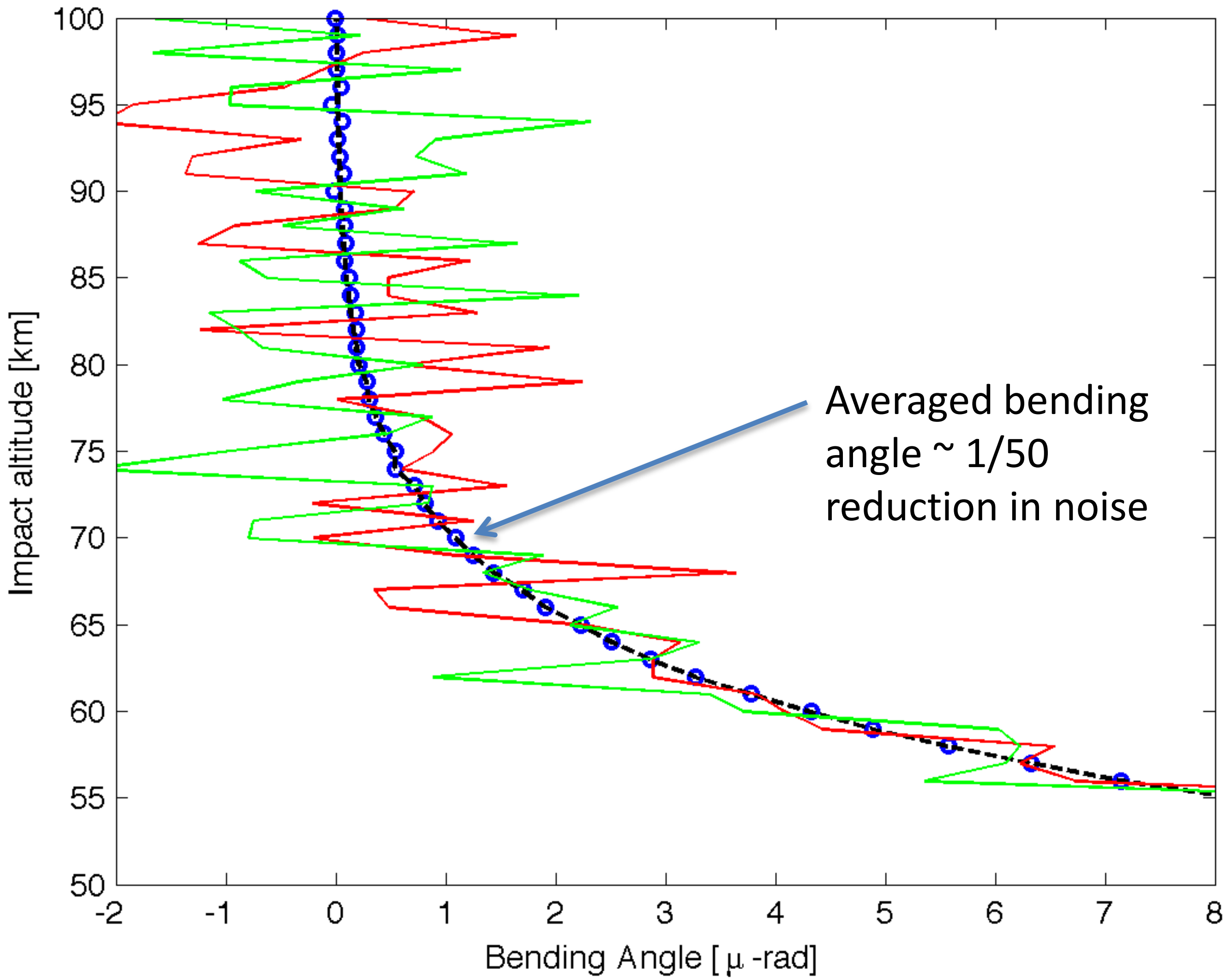
$$\stackrel{?}{=}$$

$$n_m(a) = \exp\left(\frac{1}{\pi}\int_a^\infty \frac{da'}{\sqrt{a'^2-a^2}}\langle\alpha(a')\rangle\right)$$

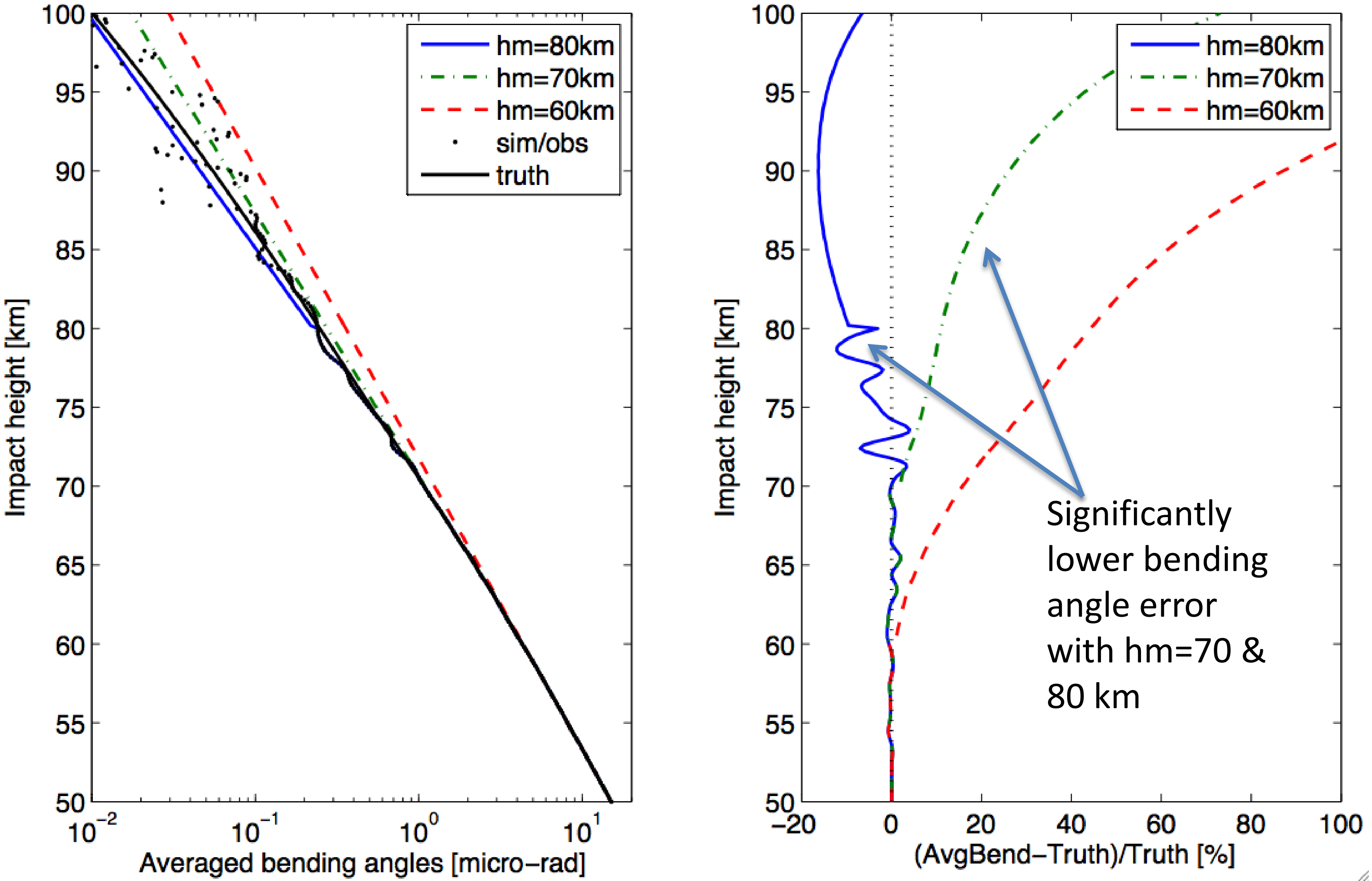
In general, they are not the same. However, for n ~ 1, the difference can be neglected.

The neglected higher order term has relative error ~ 0.5 N 10^{-6}, which at 10 km (N~100), is only 0.005%.

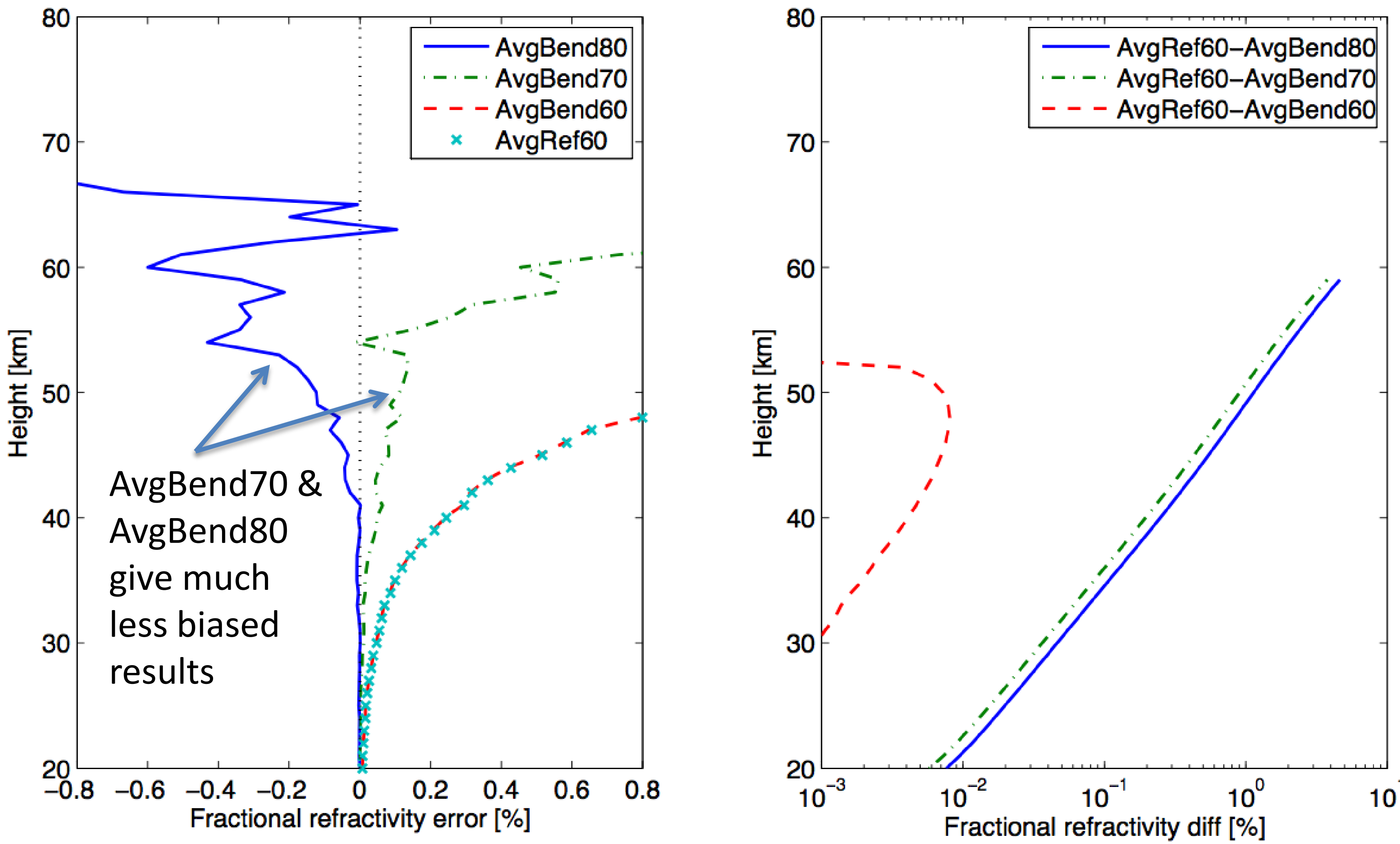
Simulations using MSIS profiles with COSMIC sampling for one zonal band (45-50 deg latitude, Jan 2008, ~ 2000 profiles). Random Gaussian noise of 1 μ-rad sigma and zero mean were added.



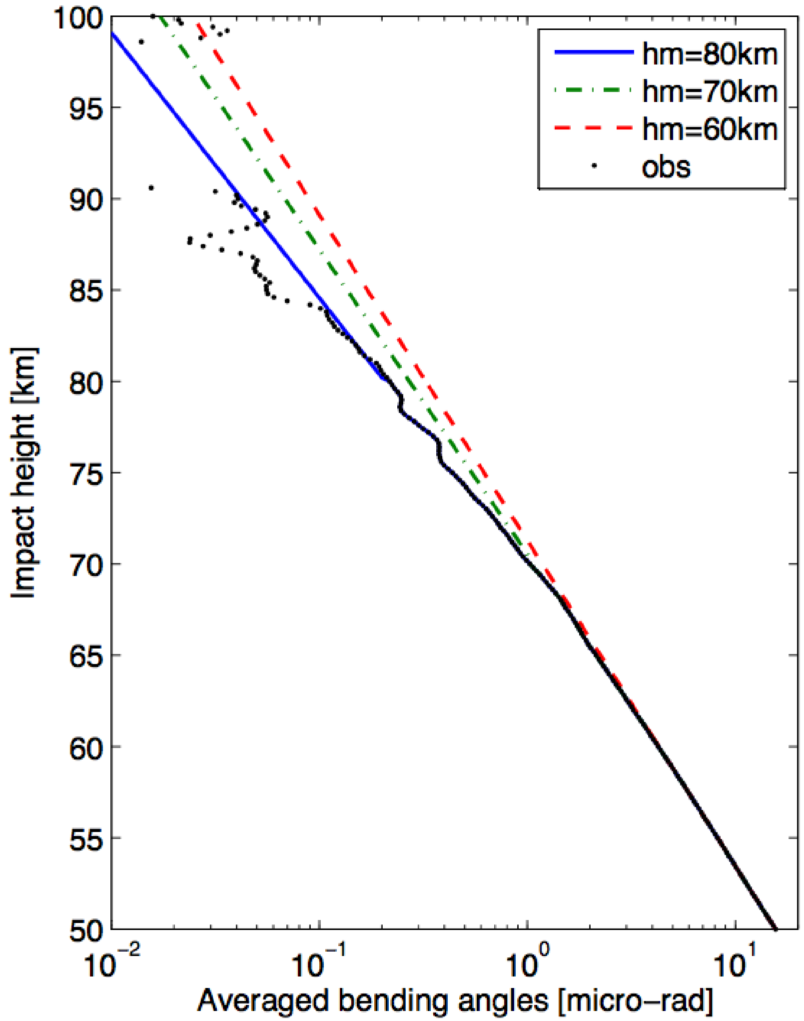
Averaged bending angle with exponential extrapolation at different h_m

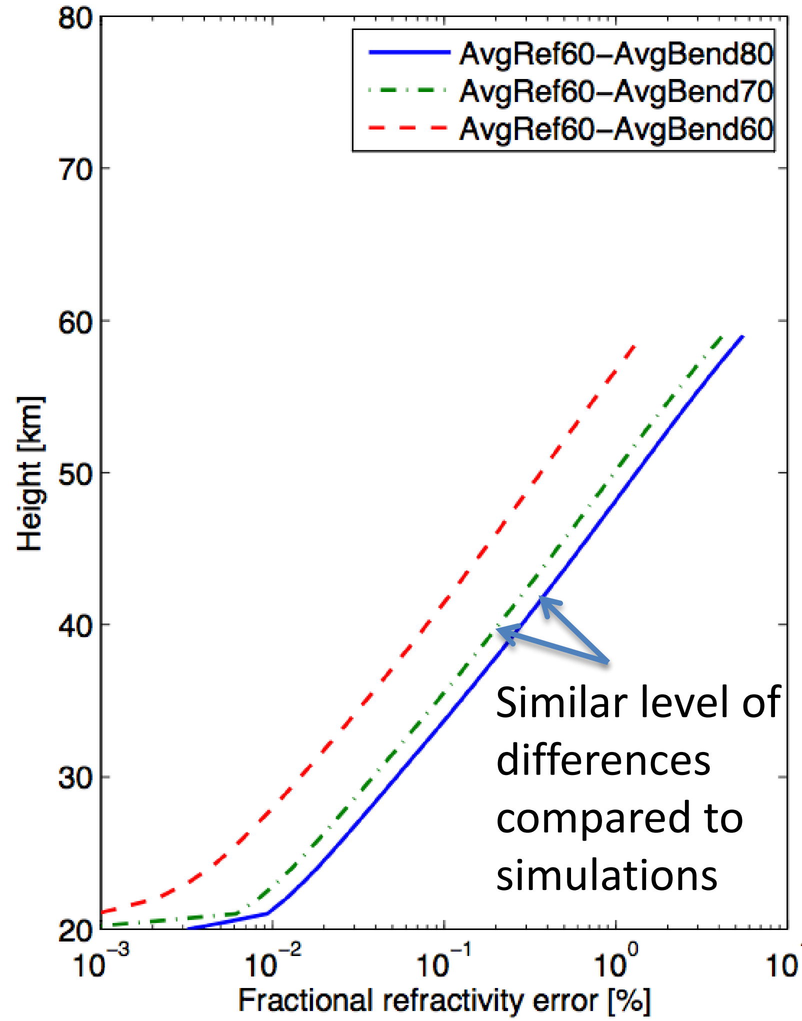


Averaged refractivity retrieved from inversion of averaged bending angle (AvgBend) VS averaging individually retrieved refractivity profiles (AvgRef)



Results from actual COSMIC data





Iono Residual Error & New GNSS Signal

- The AvgBend method does not reduce systematic bias from ionospheric residual.
- The availability of the third GNSS signals (L5) could be used to remove $1/f^4$ term

$$\frac{f_2^2}{f_2^2 - f_5^2}\alpha_{12}(a) - \frac{f_5^2}{f_2^2 - f_5^2}\alpha_{15}(a)$$

- But this comes the expense of amplifying random noise by a factor of ~20 due to small separation between L2 and L5 frequencies.
- The AvgBend can be used to mitigate the increase in noise.

Conclusions

- For climate averaging, stratospheric refractivity can be improved by averaging the bending angles first before Abel inversion. (It’s also more computationally efficient.)
- By reducing the random noise, the bending angle measurements are useful up to higher altitudes, leading to substantial improvement in the Abel upper boundary condition and strato retrieval (esp. above 30 km).
- Even though exponential extrapolation is used to illustrate the results, similar improvement can be expected with a different kind of Abel upper boundary model (e.g., MSIS climatology).