

# Systematic Error Analysis for GPS RO Refractivity in the Lower Troposphere

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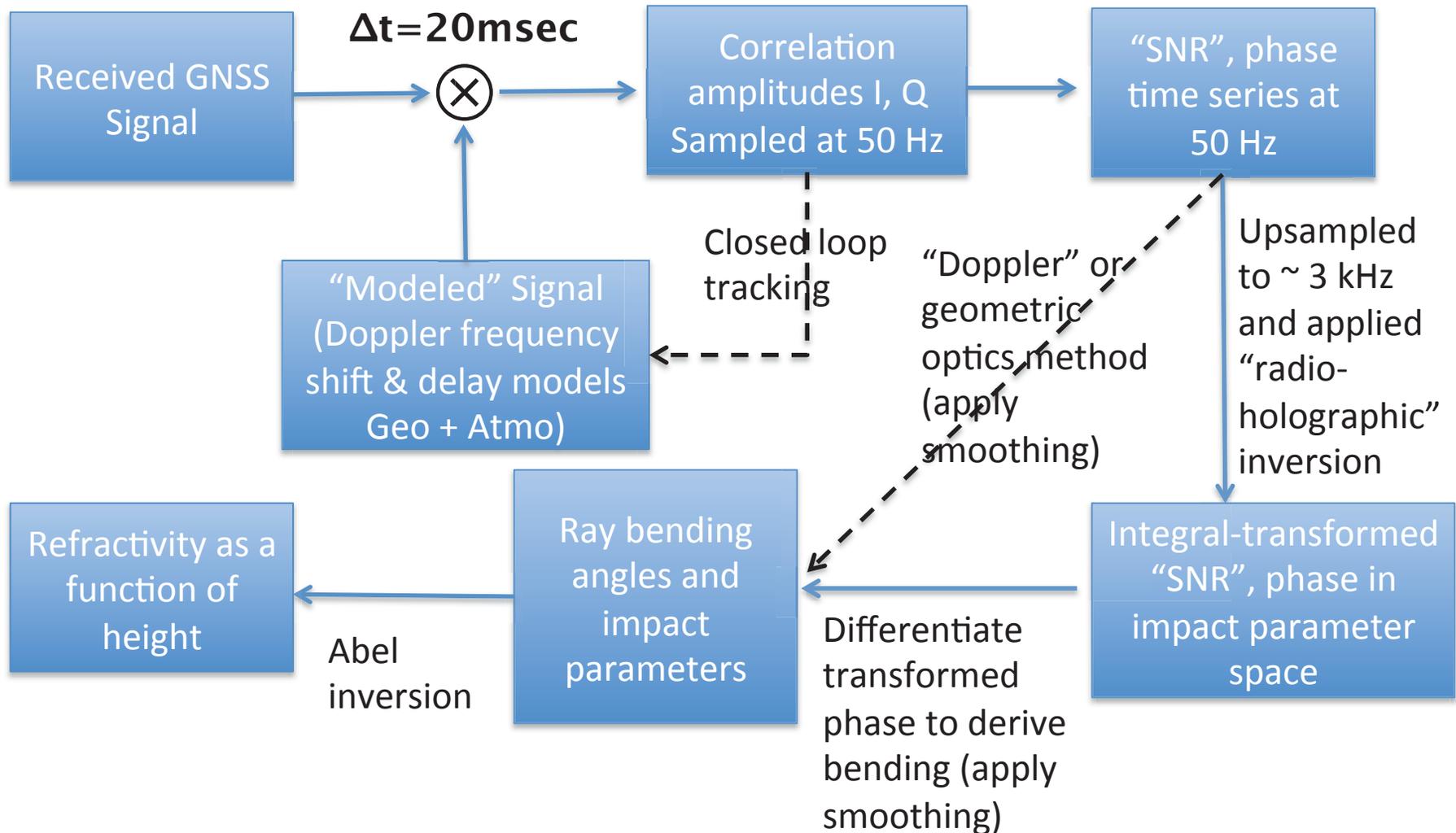
Oct 12-14, 2011  
CLARREO Science Team Meeting  
Madison, WI

# Objectives

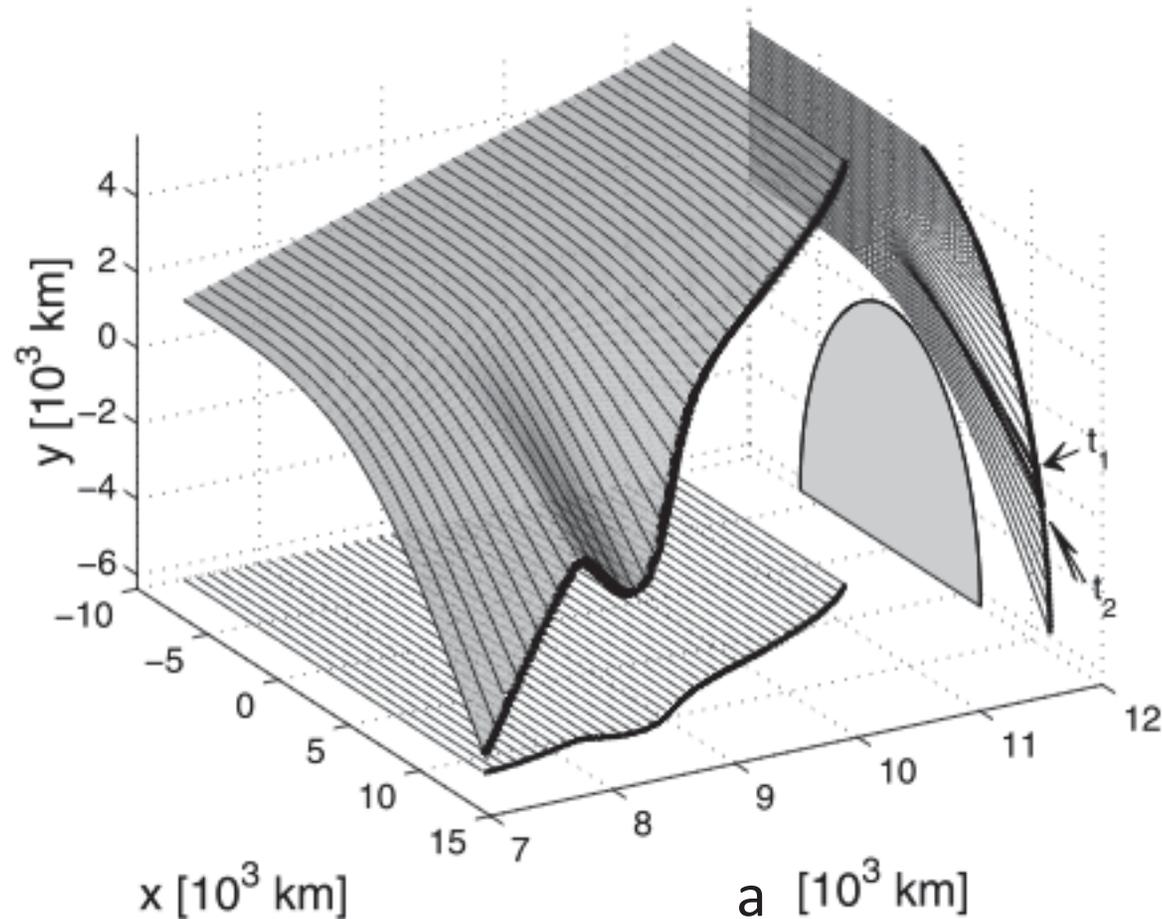
**Identify, Evaluate, and Mitigate**  
systematic errors in GPS RO refractivity

- Refractivity (“N”) most accurate over 5-20 km altitude (CLARREO baseline, < 0.03%)
- > 20 km (Stratosphere): AGU Fall Meeting
- < 5 km (Lower Tropo): this talk

# GPS RO tracking and retrieval



# Transformation to a-space



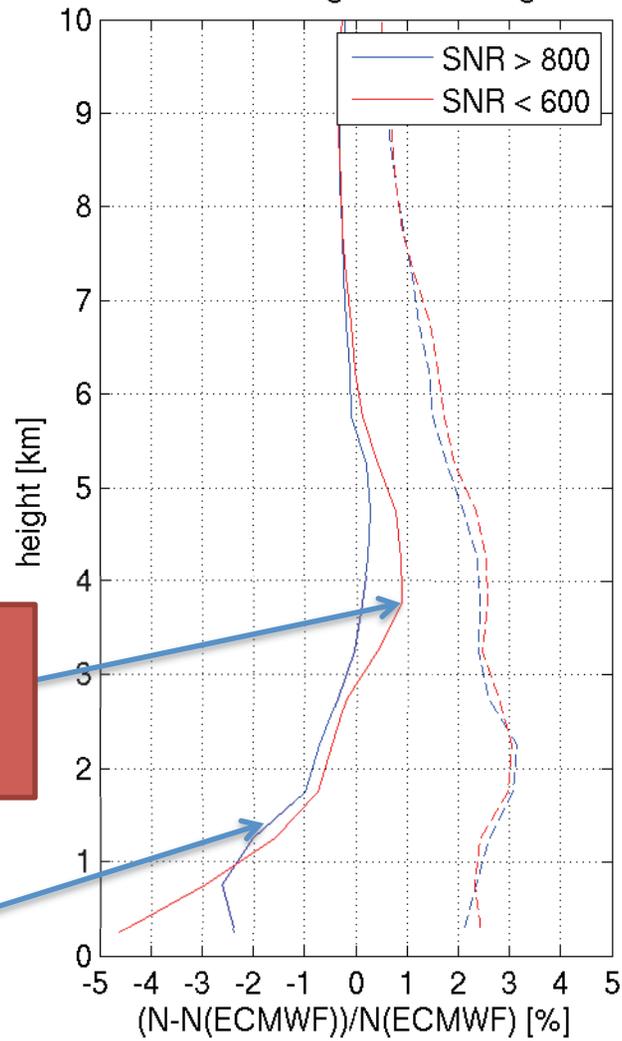
Beyerle, Gorbunov, Ao,  
RS [2003]

Ray manifold is single-valued  
in impact parameter

# What make LT so tough

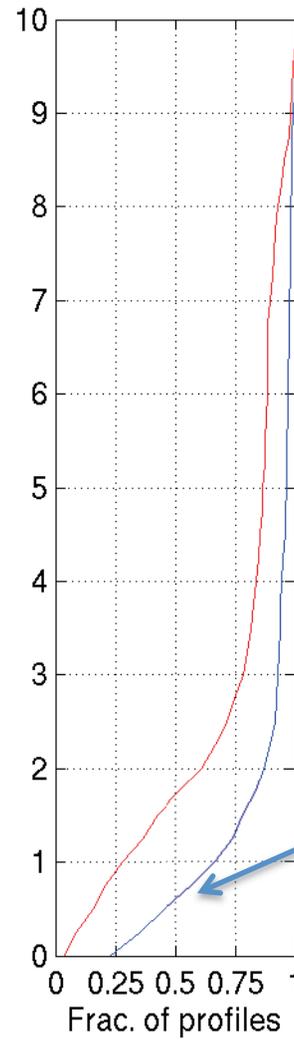
- **Fine-scale water vapor structure** creates challenging conditions for signal tracking and retrieval.
  - Large vertical gradient causes strong differential bending leading to atmospheric multipath (caustics).
  - Very large vertical gradient (“ducting condition”) makes inversion ill-posed.
  - 3D atmospheric turbulence causes strong signal dynamics (scintillations).

COSMIC4 setting 30S-30N Aug.2007



Positive bias when SNR is low?

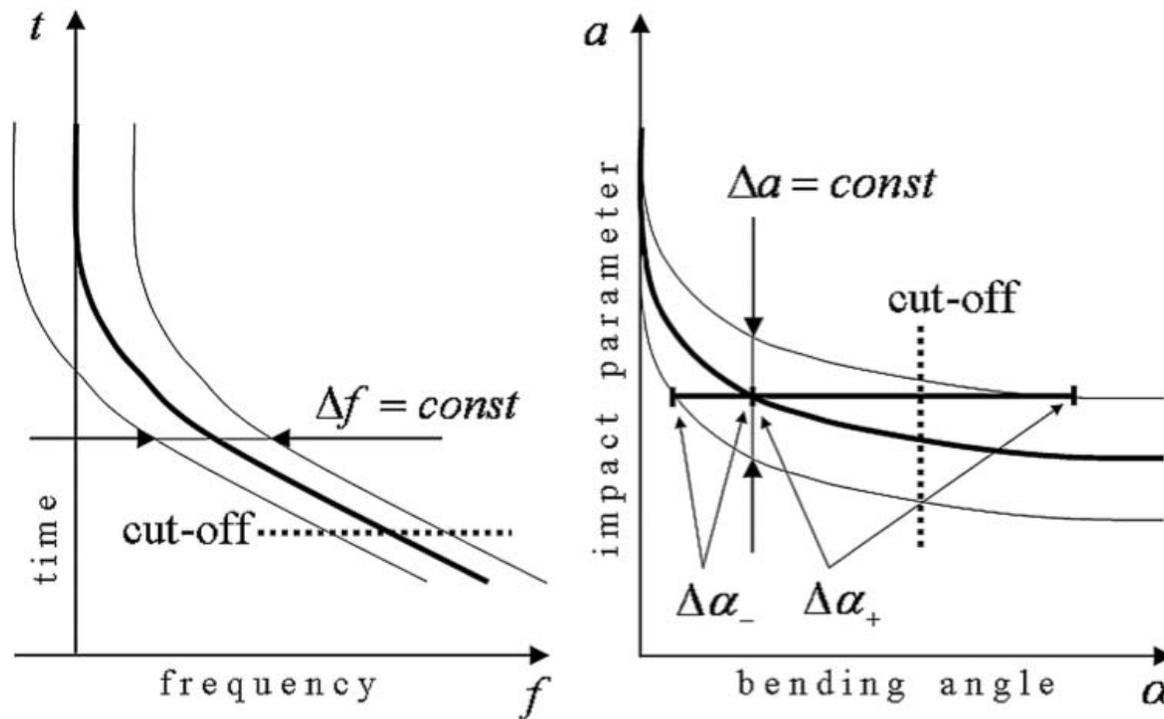
Negative bias below ~ 2 km



Not all profiles reach surface due to ret/qc (worse for low SNR)

# Noise-related bias

Sokolovskiy et al., JGR, 2010 [sok10] argued that a positive bias in  $\alpha$  (N) can result from random phase noise in the tropical lower troposphere.



**Figure 4.** The noise band of RO signal in time-frequency and impact parameter-bending angle representations (for details, see text).

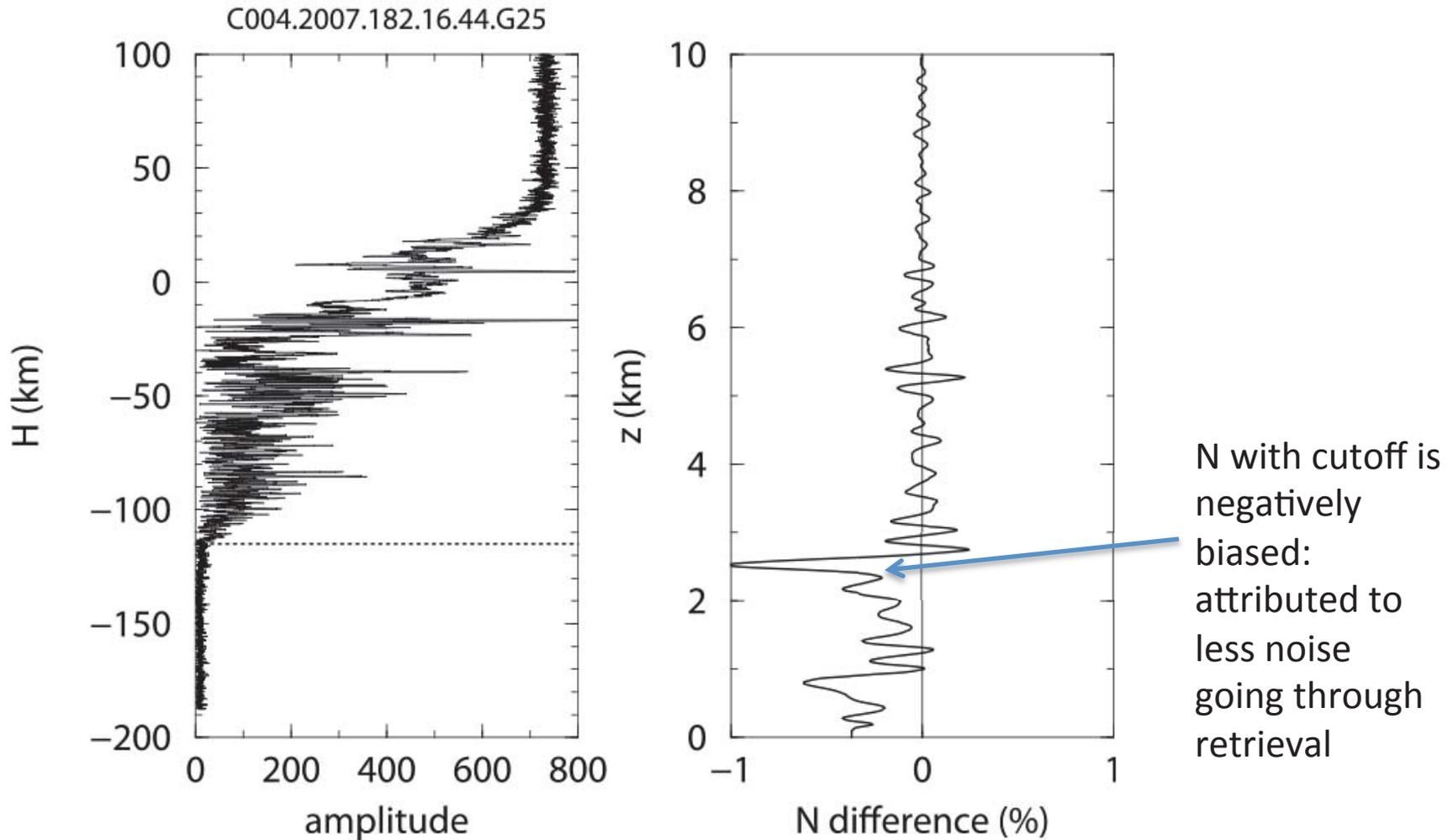
# Main Results from Sok10

1. The bias affected tropical occultations.
2. The bias was demonstrated in 3 ways:
  - i. Truncating noisy part of the data results in a negative bias.
  - ii. Adding random noise results in a positive bias.
  - iii. Average refractivity for low SNR is larger than for high SNR in the tropics (cf earlier slide).
3. The bias is highly sensitive to filtering/smoothing method used in calculating bending.

# Key Questions

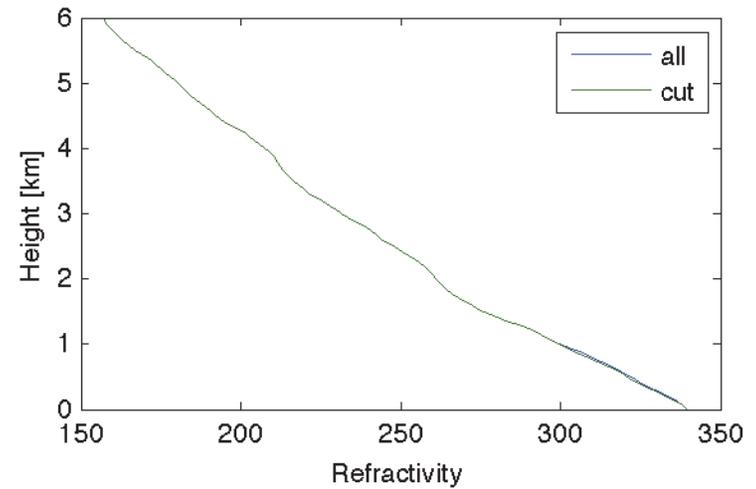
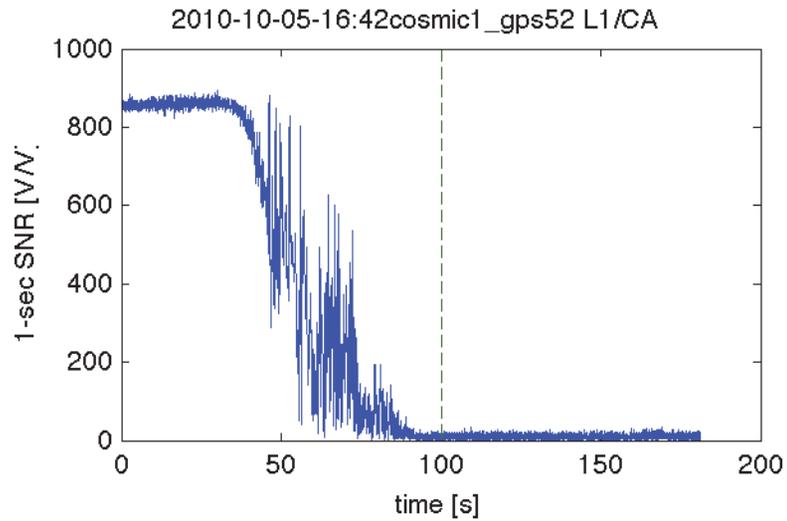
- Can these results be reproduced using JPL retrieval system?
- How does the bias vary with latitude (or longitude)?
- Given an accuracy requirement for  $N$ , what is the required SNR?
- What filtering/smoothing method (if any) works best in reducing the bias?
- Can we simulate this effect with end-to-end simulations?

# “Noise” Cutoff Experiment

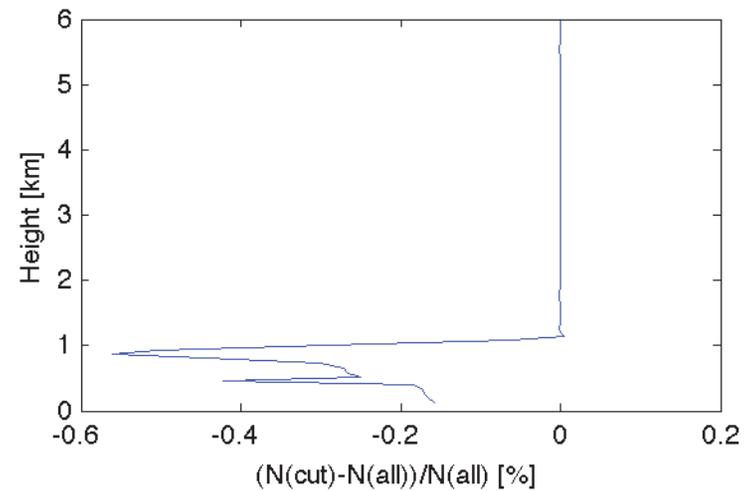


Sok10

**Figure 6.** Same as Figure 5 but for a tropical occultation.

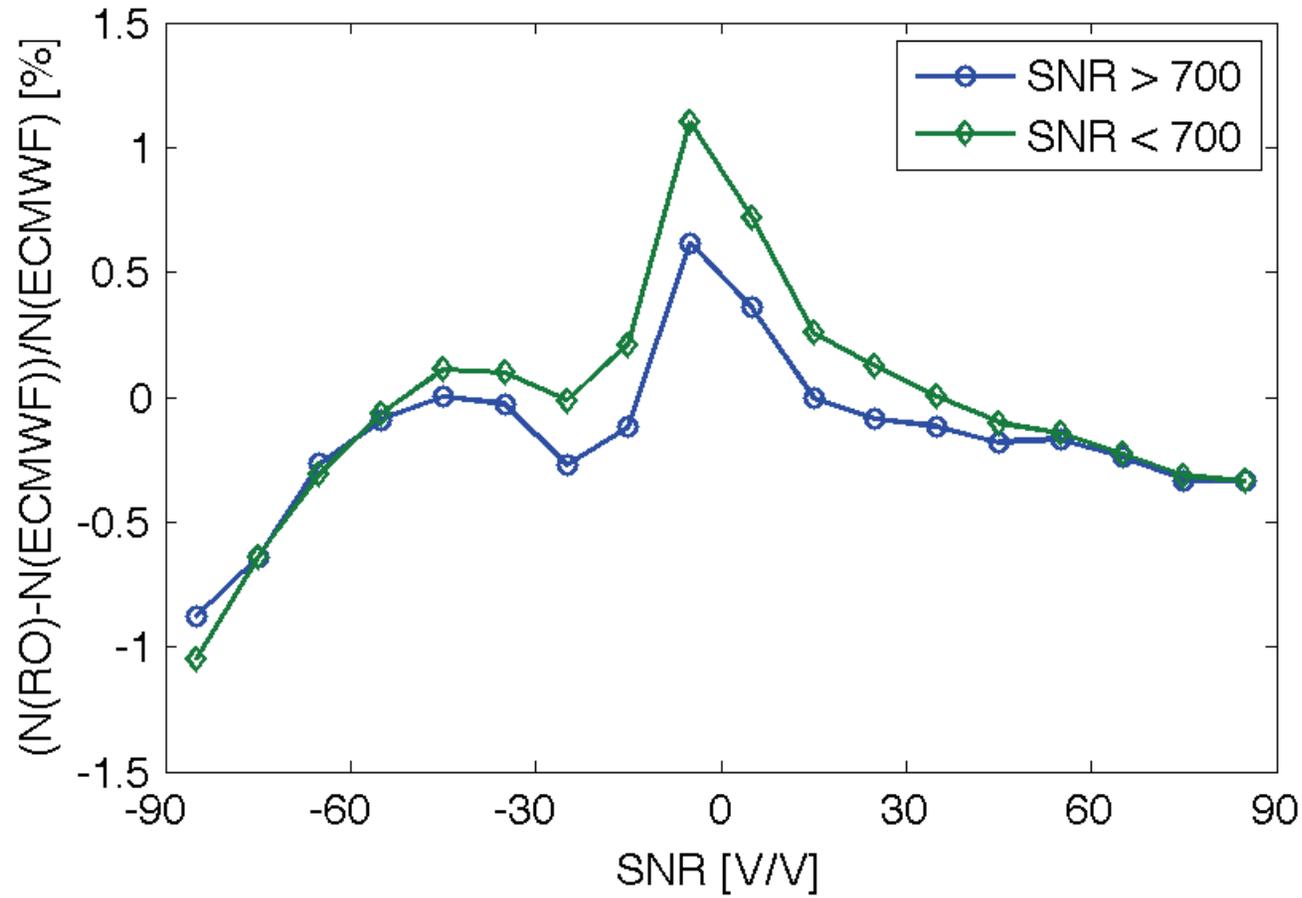


- Similar bias below  $\sim 1$  km but none above 2 km.
- Are we throwing away noise or data?

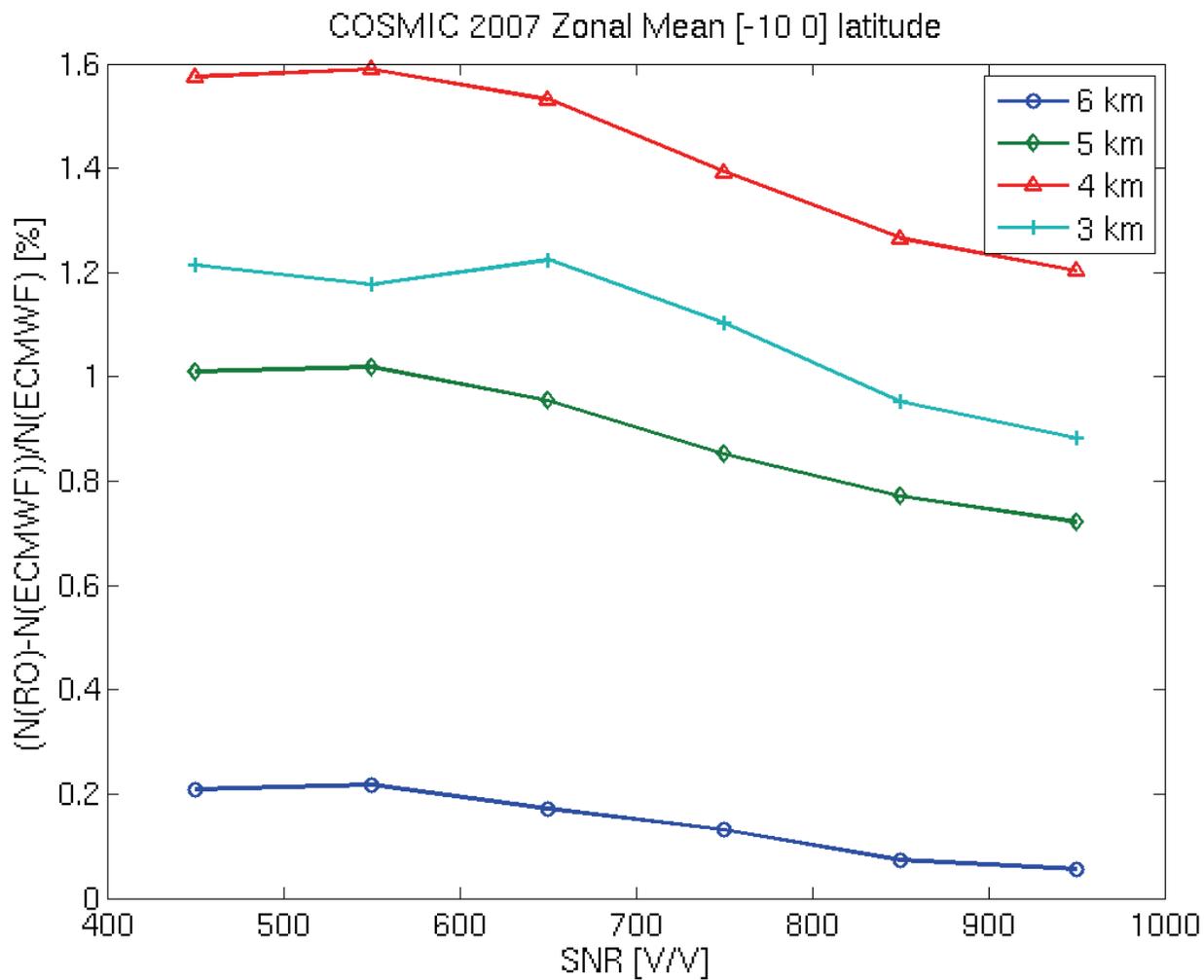


# Zonal N vs Lat

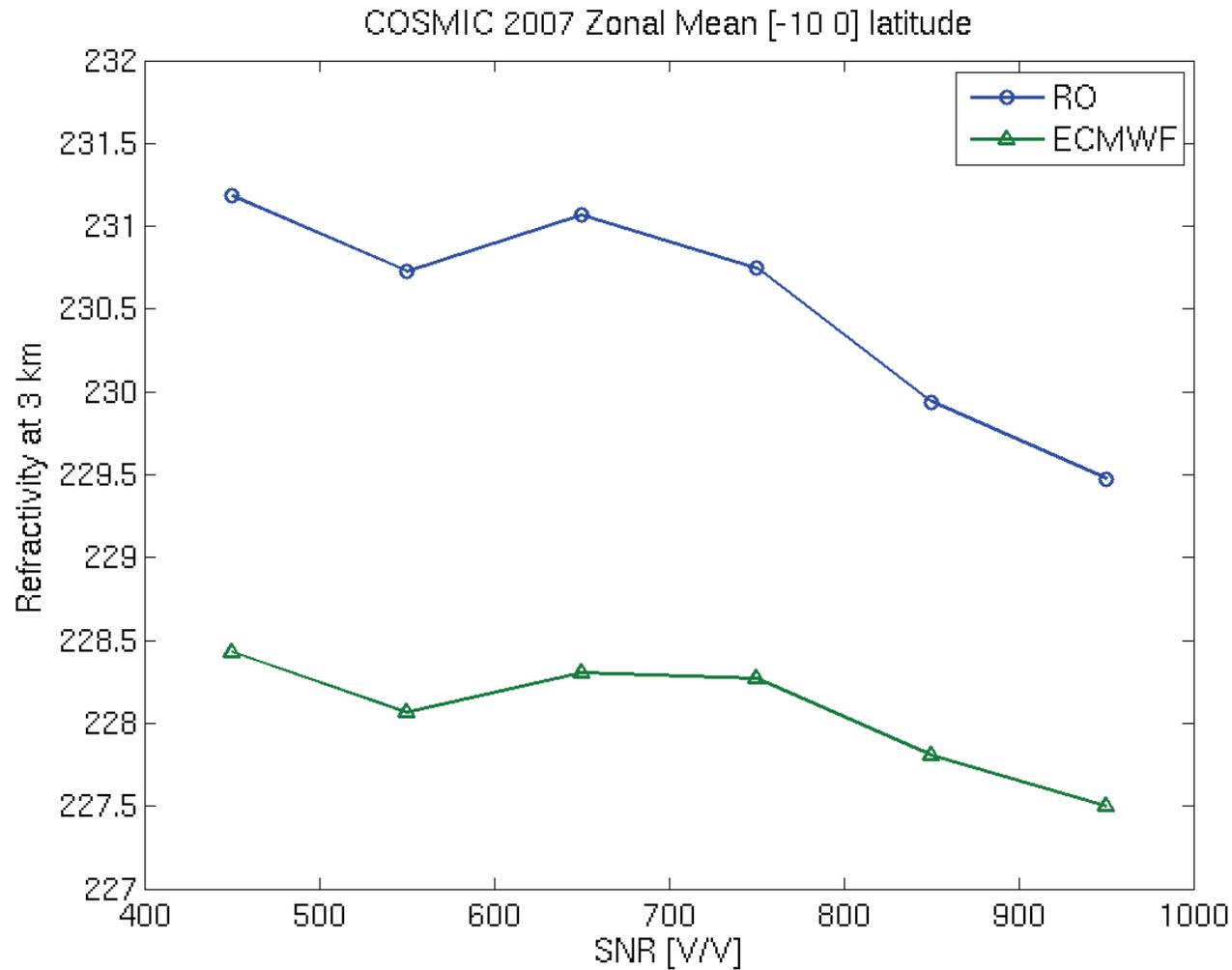
COSMIC 2007 Zonal Mean at 3 km



# Zonal N vs SNR

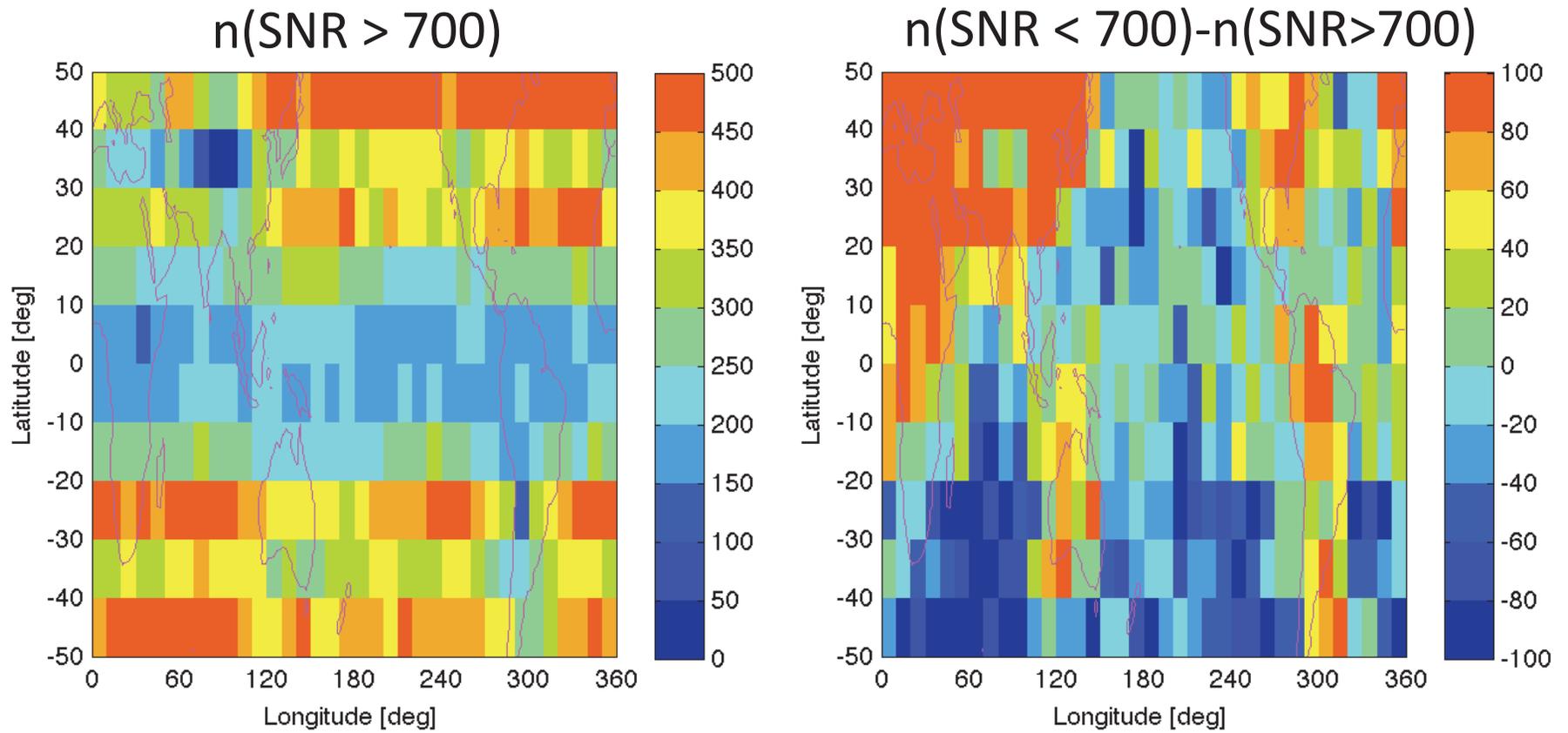


Clear dependence on SNR, consistent with earlier slide and also Sok10.

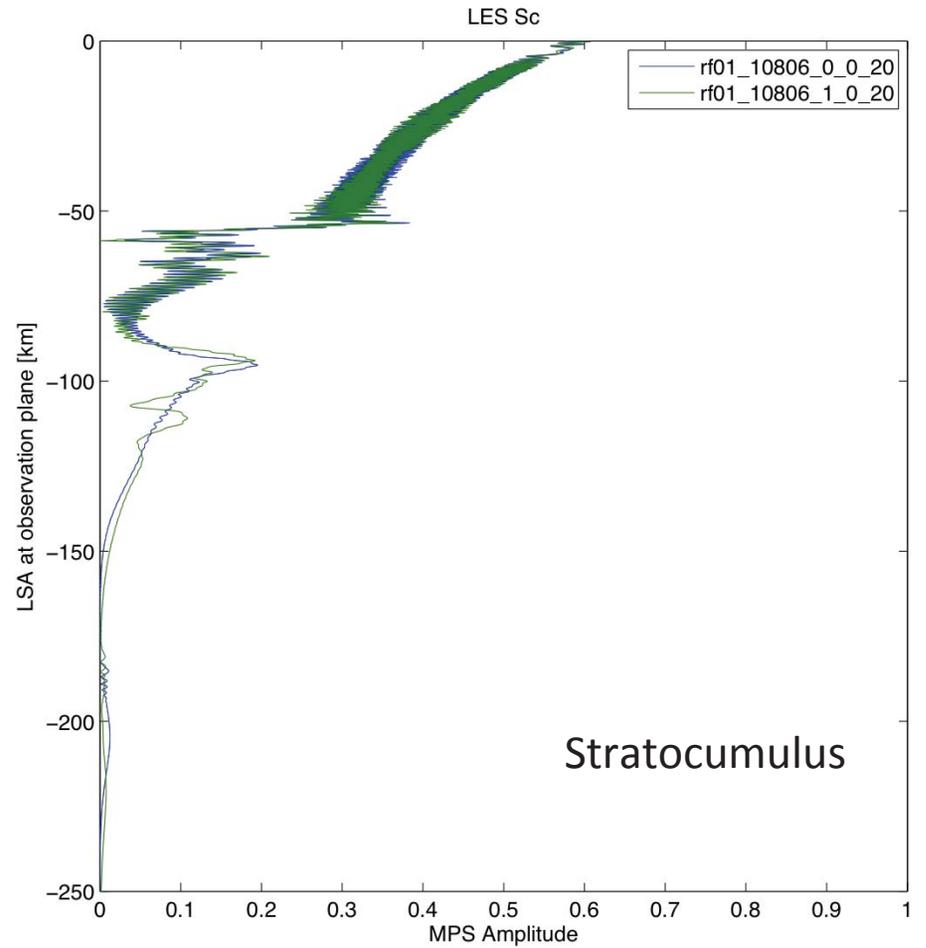
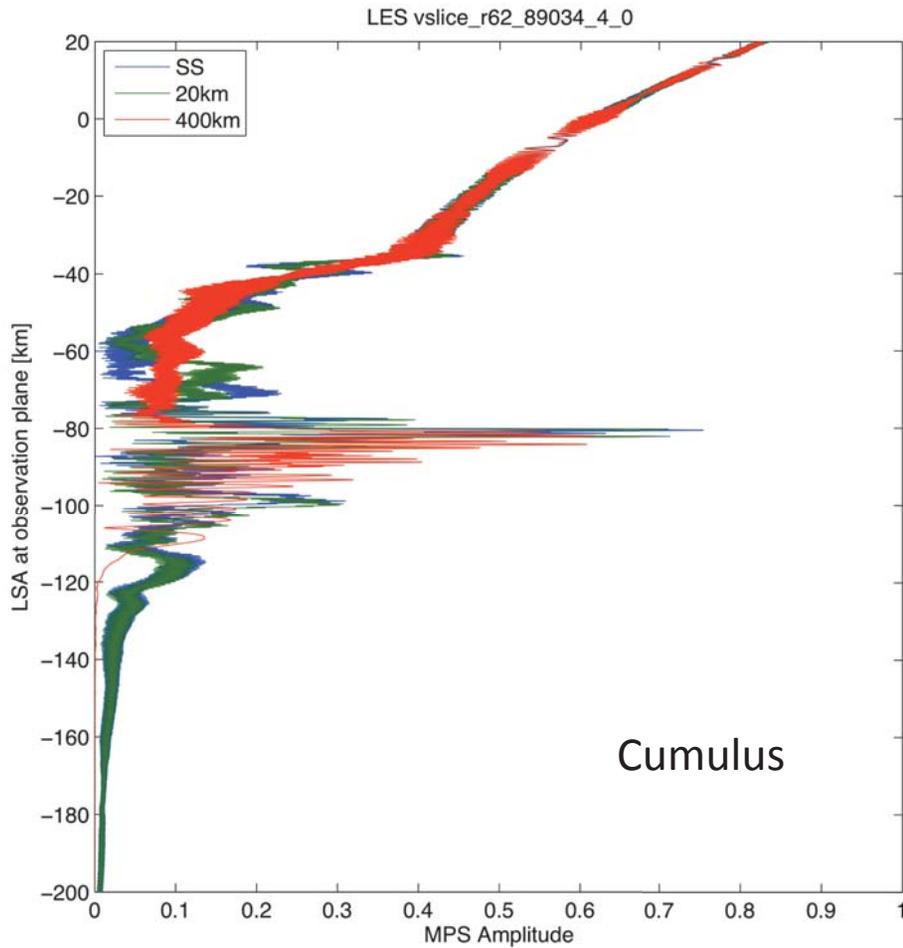
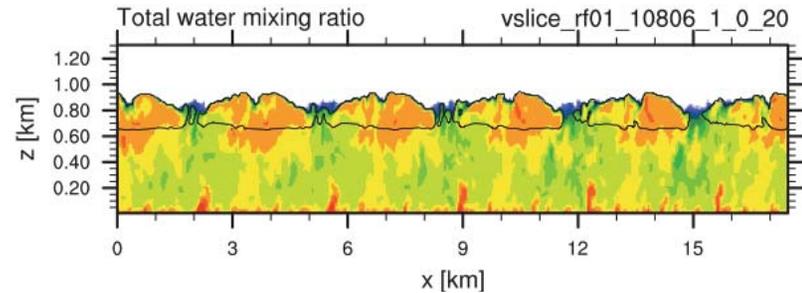
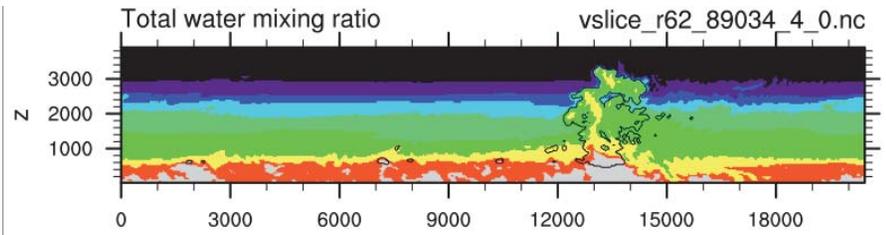


- ECMWF (interpolated to COSMIC loc) shows similar SNR dependence to COSMIC!
- This is presumably due to sampling differences between high and low SNR occultations.
- Could sampling bias account for the observed low SNR bias in COSMIC?

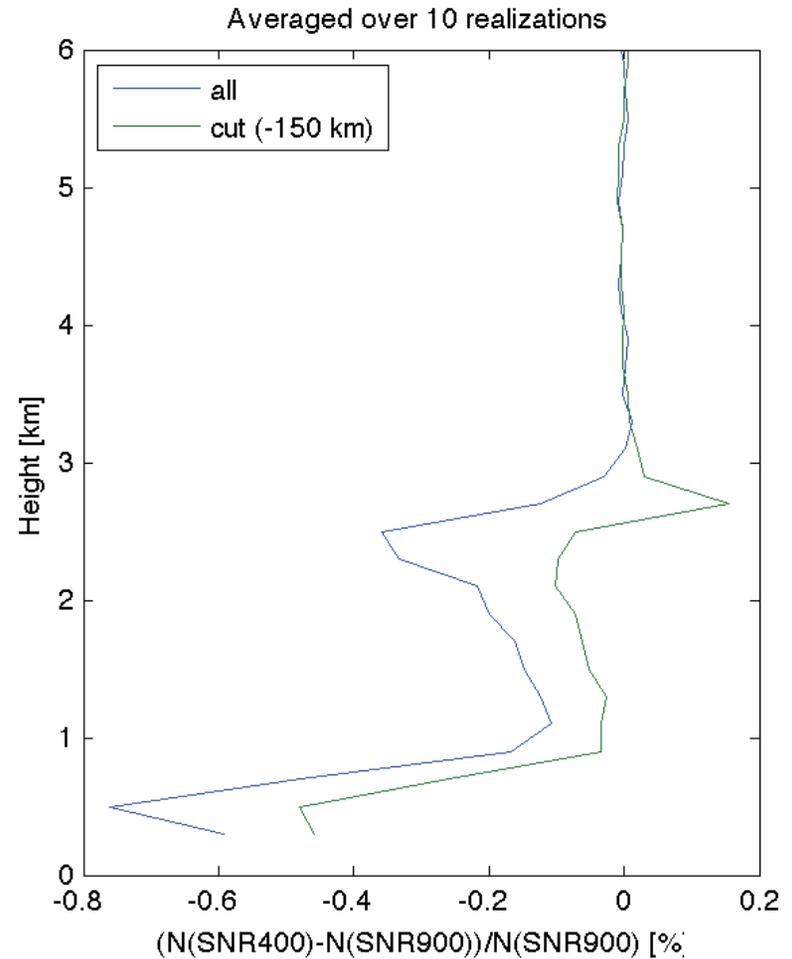
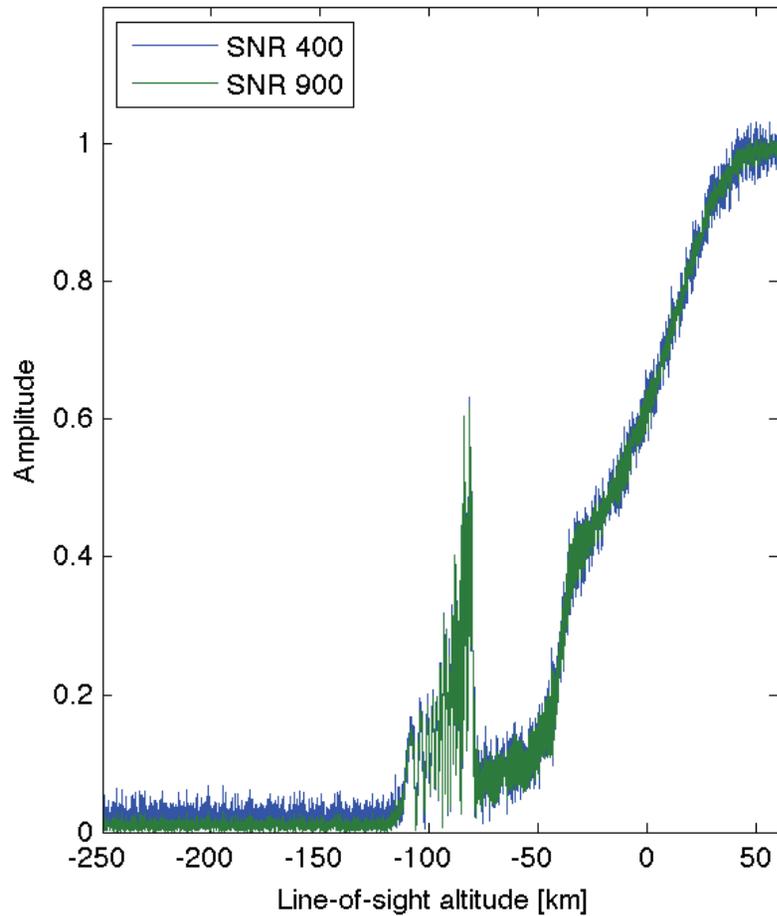
# Sampling vs. SNR



# RO Simulations with LES Atmosphere (From George Matheou, JPL)



# 2D Simulations with Noise Added



# Summary

- We examined the recent finding by Sok10 that random additive phase noise caused a large positive N bias at 3-4 km in the tropical LT.
- Our data analysis and simulations did not show conclusive evidence of this effect (due to different smoothing methods?).
- Observed positive bias  $> 3$  km might be a result of sampling bias.
- More work (esp. simulations) needed to fully characterize the effects of SNR and data length on retrieval biases.