# Improved Radio Occultation Observations for a COSMIC Follow-on Mission

C. Rocken, S. Sokolovskiy, B. Schreiner UCAR / COSMIC
D. Ector NOAA

# Areas Of Improvement

- Data quantity / distribution
- Data latency
- Data quality
  - Reduce failure rate
  - Reduce biases
  - Extend useful height range upwards
  - Improve penetration to surface
- New type of RO observations
- Attitude control (related to antenna pattern)
- Next mission will be near solar maximum conditions - what do we need to do in preparation ?

# Data Quantity / Distribution

- Goal (NOAA requirement) is ~ 10,000 profiles / day
- This means ~5 soundings per 500x500 $km^2$ / day
- This would provide similar coverage globally as current radiosonde coverage over the US (~150 launches)
- Assuming launch of 12 LEO satellites this would require ~840 / soundings per LEO / day
  - Galileo and / or Compass must be available
  - Glonass CDMA signal must be available since no planned RO receiver can track the current Glonass FDMA
- Even distribution (within a factor of 2) shall be achieved with multiple orbit planes of different inclination

# Data Latency

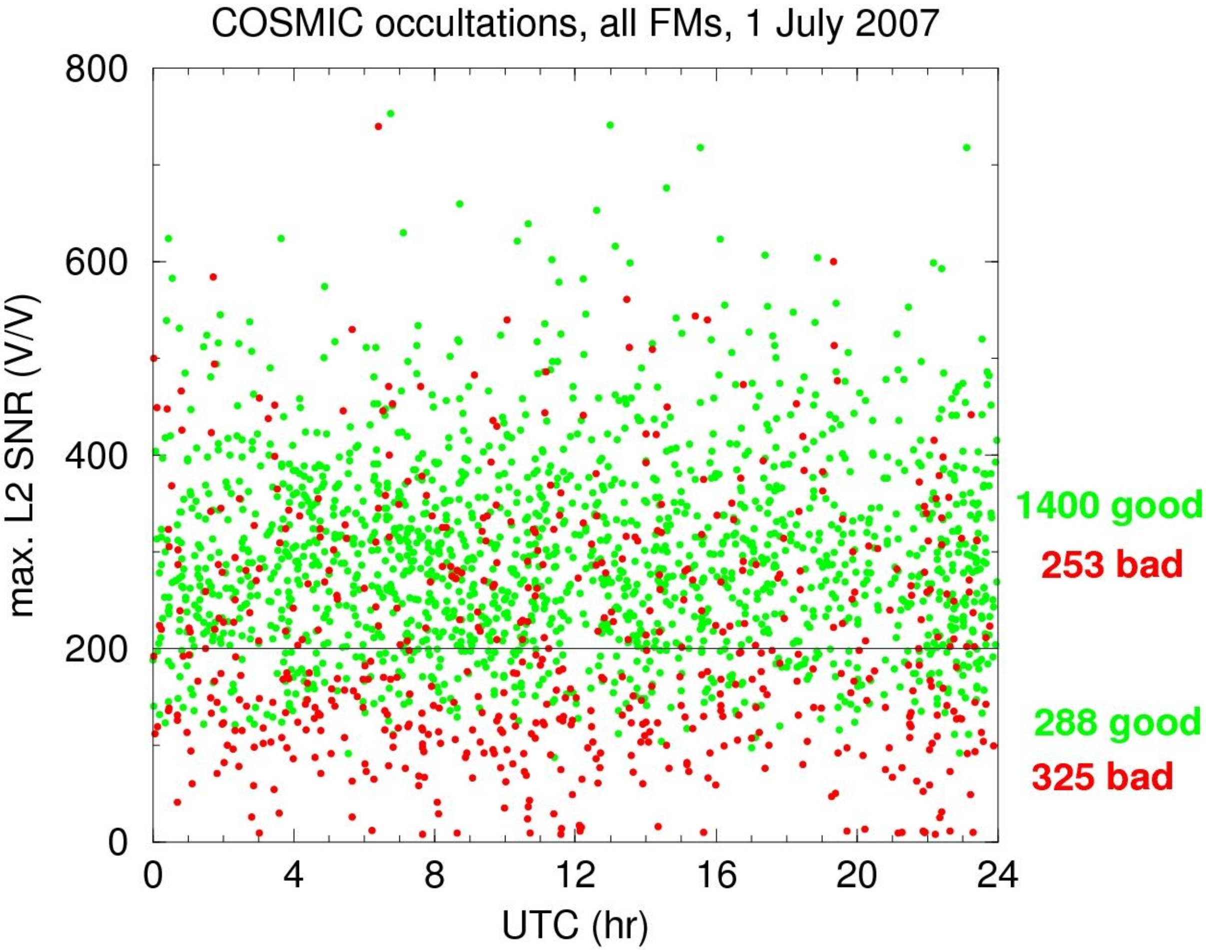
- Low data latency requirements (30 min or less) are driven by:
  - Space weather needs (TEC and especially Scintillation)
  - Operational weather models - more data included in rapid-rate update cycles
- Low latency can be achieved with
  - Large (~10) number of ground stations, or
  - Leo -> GEO (or Leo) -> Ground communications
- Latency requirements can be significant cost drivers

# Data Quality

- Improvements are desired because
  - “bad L2 data” still cause ~20 % failure rate
  - observation noise causes biases in RO
  - COSMIC phase data have higher phase noise than GRAS (affects atmospheric profiles) - so we know that lower noise observations can be achieved
  - Low SNR limits the height range of high quality profiles observation

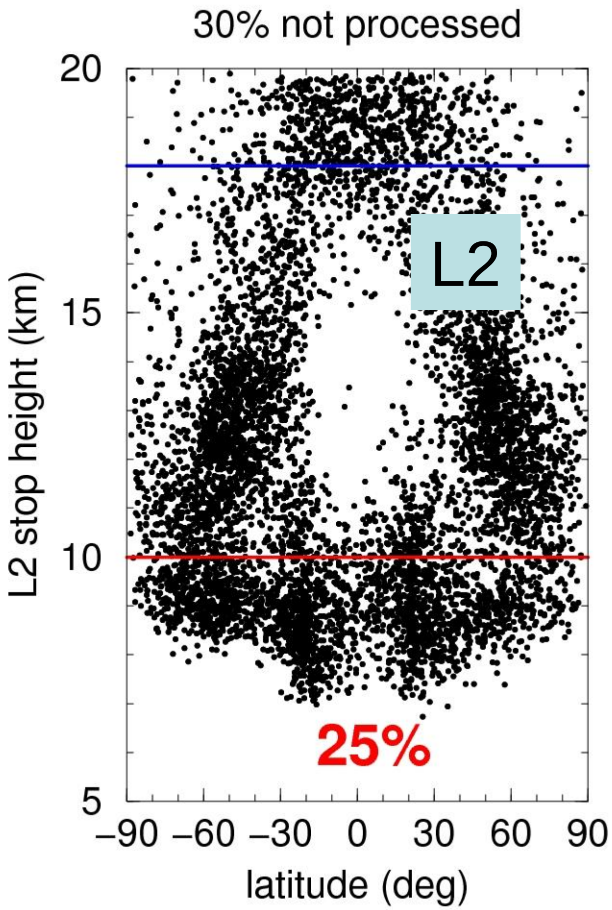
Reduction of Failure Rate (for COSMIC ~ 20%)

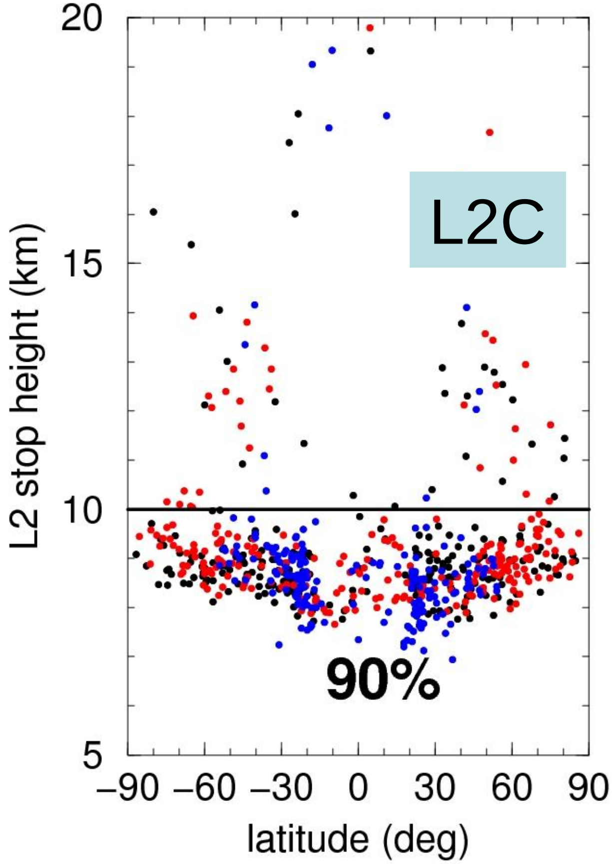
# How do “bad” RO profiles relate to SNR ?




Clearly most soundings that fail are related to poor L2 SNR > 20 km

# Tracking the new L2C GPS signal (height where L2 data stop)




- Only 25% of L2 is tracked < 10 km - compared to 90% of L2C.
- 30% of L2 tracking data cannot be processed compared to ~1% of L2C.

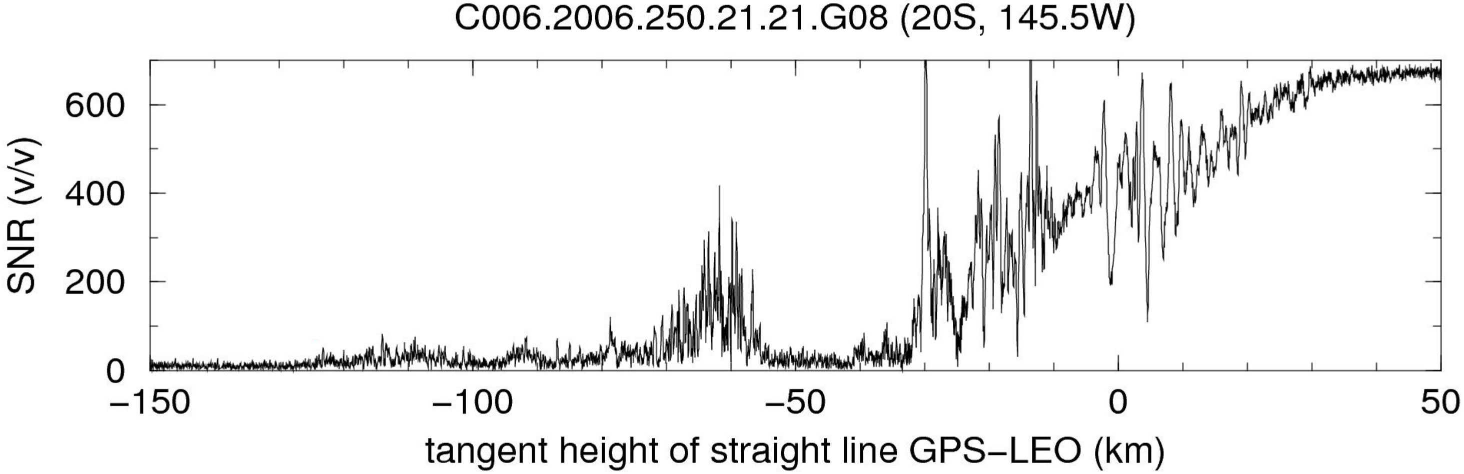
# Noise introduces biases in Radio Occultation

The largest uncertainties of RO inversions are:

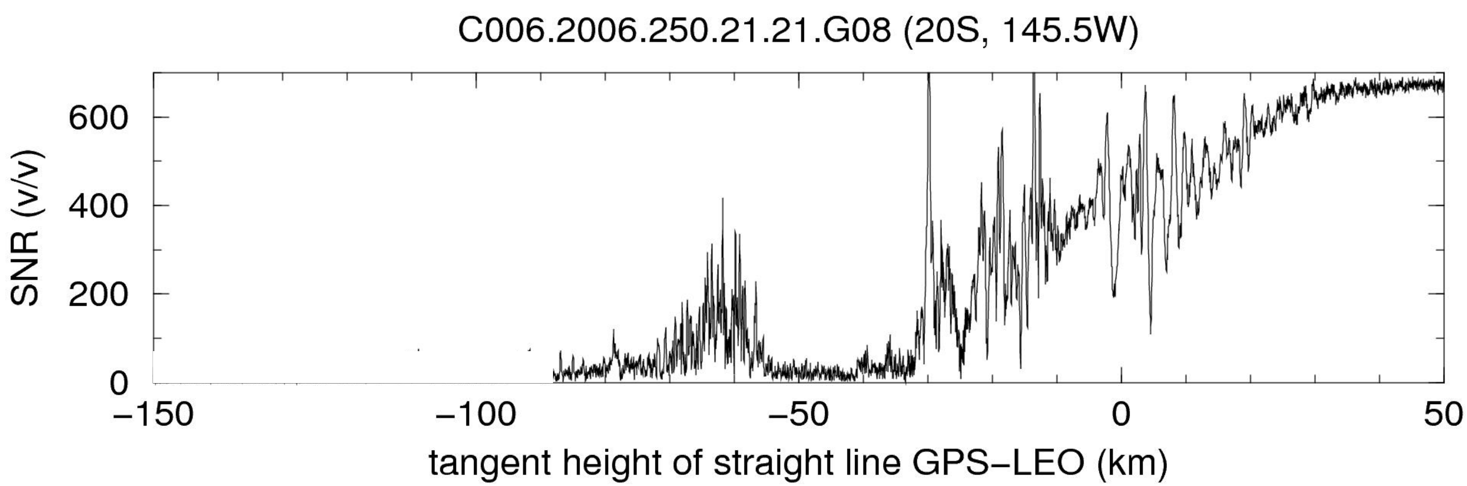
in the upper stratosphere - the signal drops below the noise level in terms of the phase

in the lower troposphere - the signal drops below the noise level in terms of the amplitude

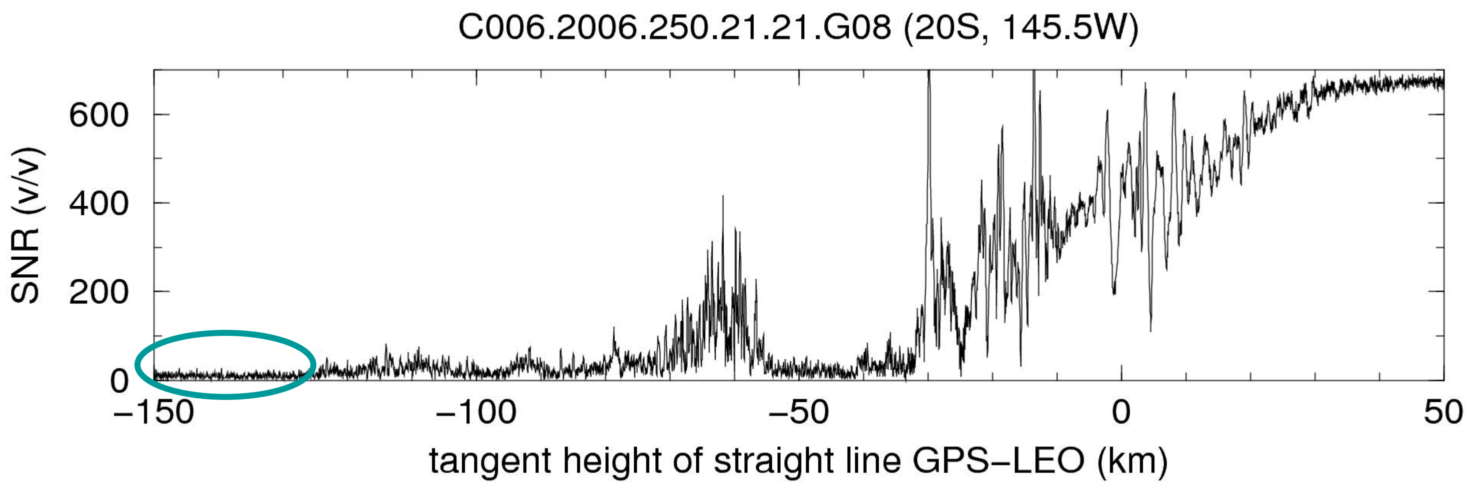
# Amplitude of a tropical COSMIC Radio Occultation



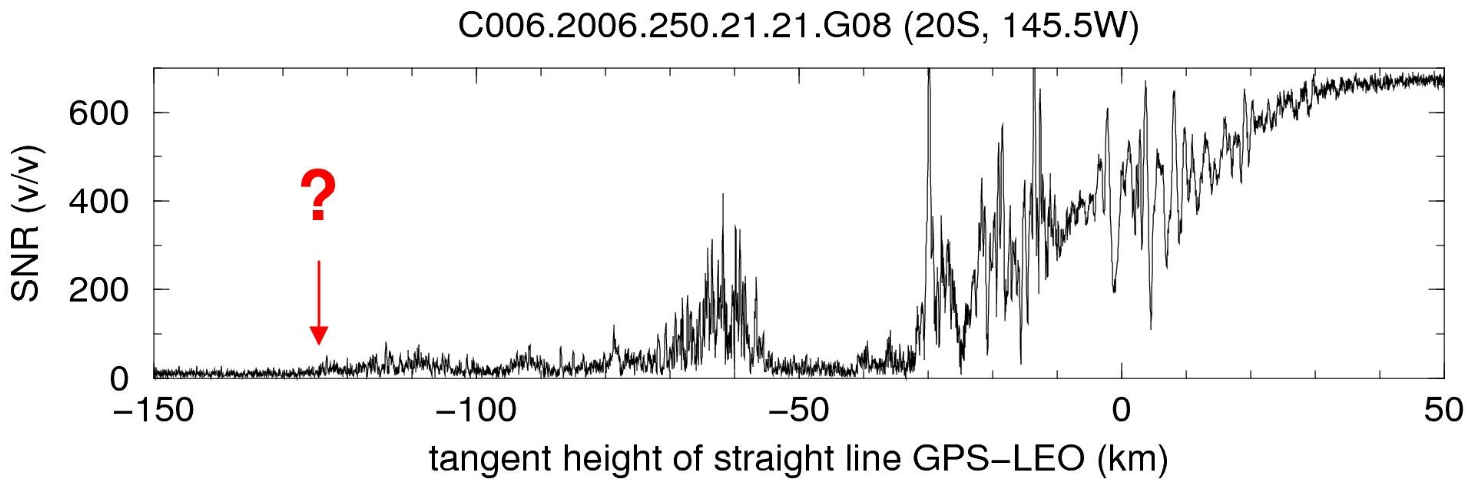

Determination of the minimal height where RO signal is used for inversion introduces an uncertainty in inversion results




If we stop using the signal too high - we get a negative bias a main reason for the “famous” negative N-bias




If we use the signal too low - this introduces a positive N bias

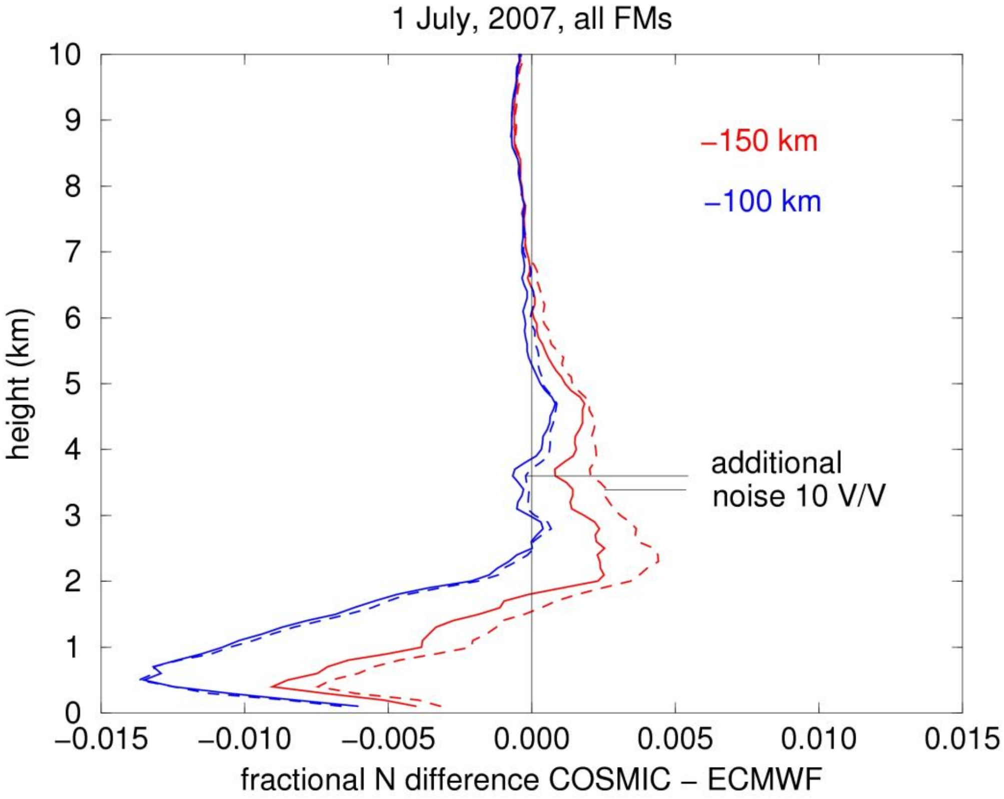



The “trick” is to stop using the signal at the correct height

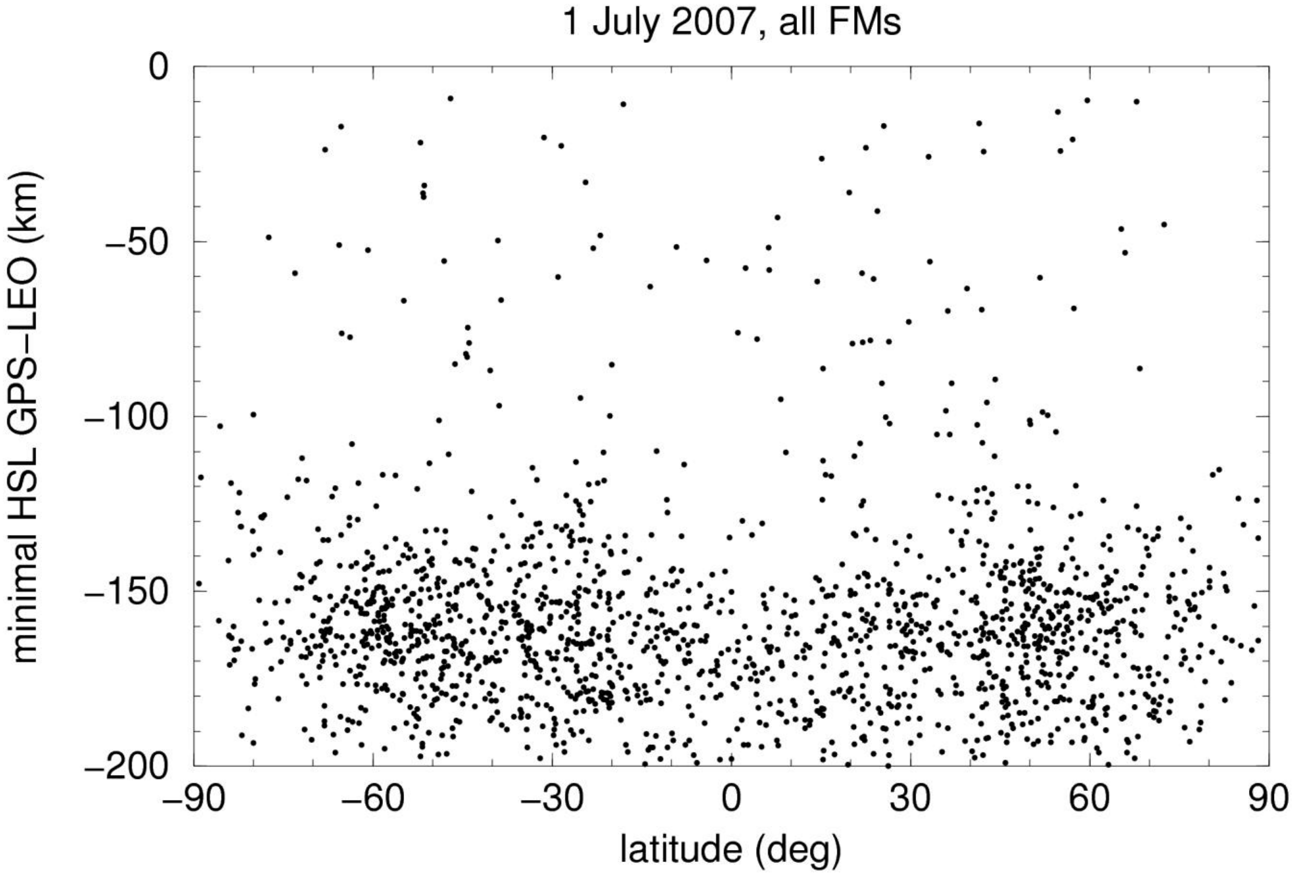
Truncation of RO signals too high results in the negative N-bias (due to missing sub-signals with large BA)

Truncation of RO signals too low makes inversion results sensitive to noise (positive N-bias)

Dynamic truncation has to be applied



COSMIC is tracking RO signals on average < -150 km
Is this sufficient depth?



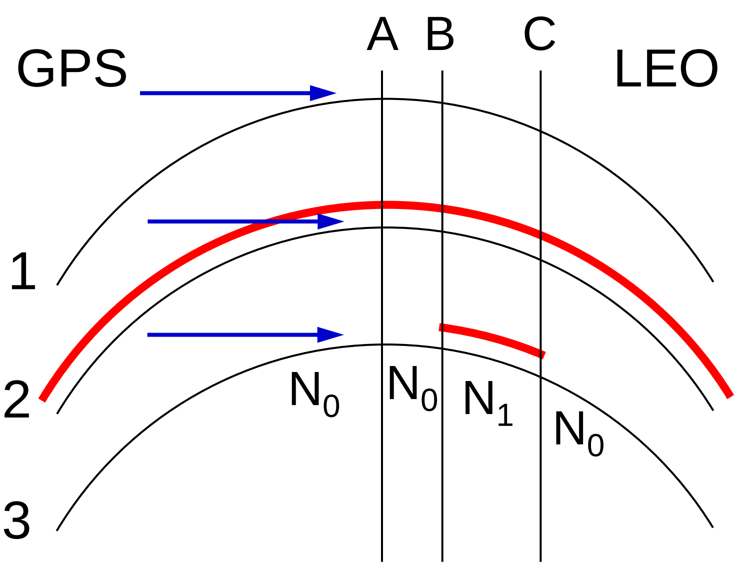

In general it would be better if we could track even lower
- as long as the noise level of the low observations is small

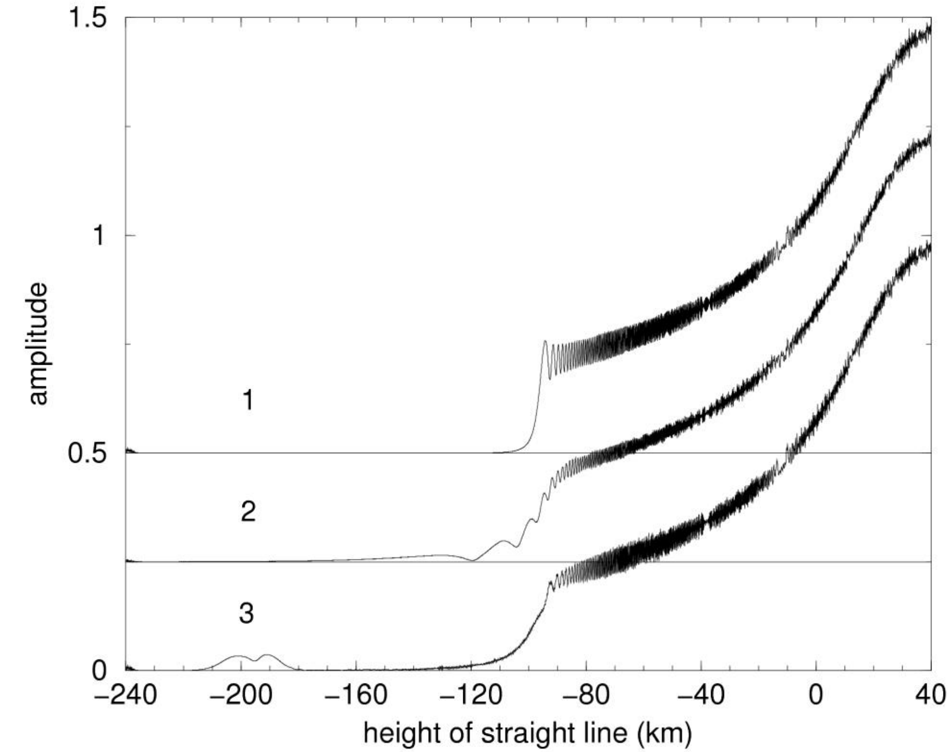
# Very deep RO signals can be explained by surface ducts with limited horizontal extension

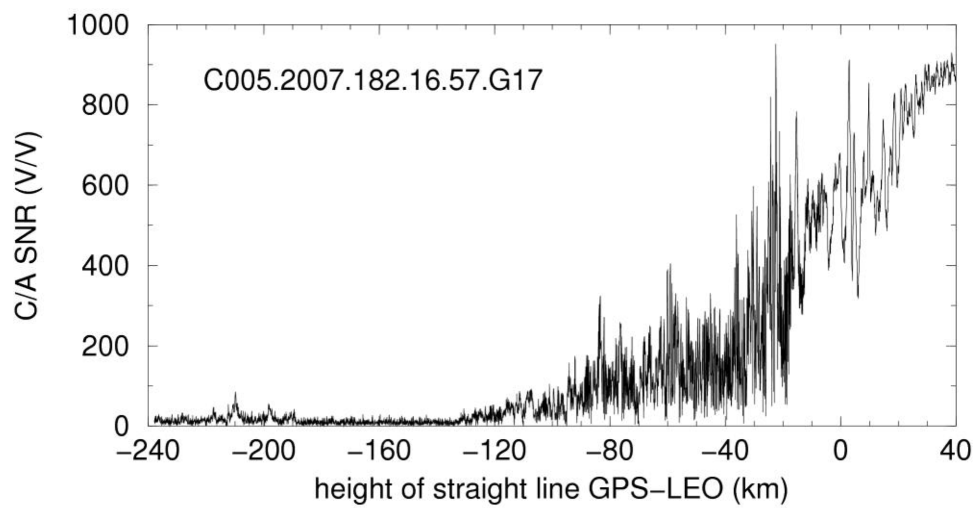
$$N_0(z) = 400\exp(-z/7.5km)$$

$$N_1(z) = N_0(z) \times$$
$$\times \left\{ 1 + 0.03 \left[ \frac{\pi}{2} - \arctan\left( \frac{z - 0.1km}{0.03km} \right) \right] \right\}$$

AB = 125km, BC = 225km



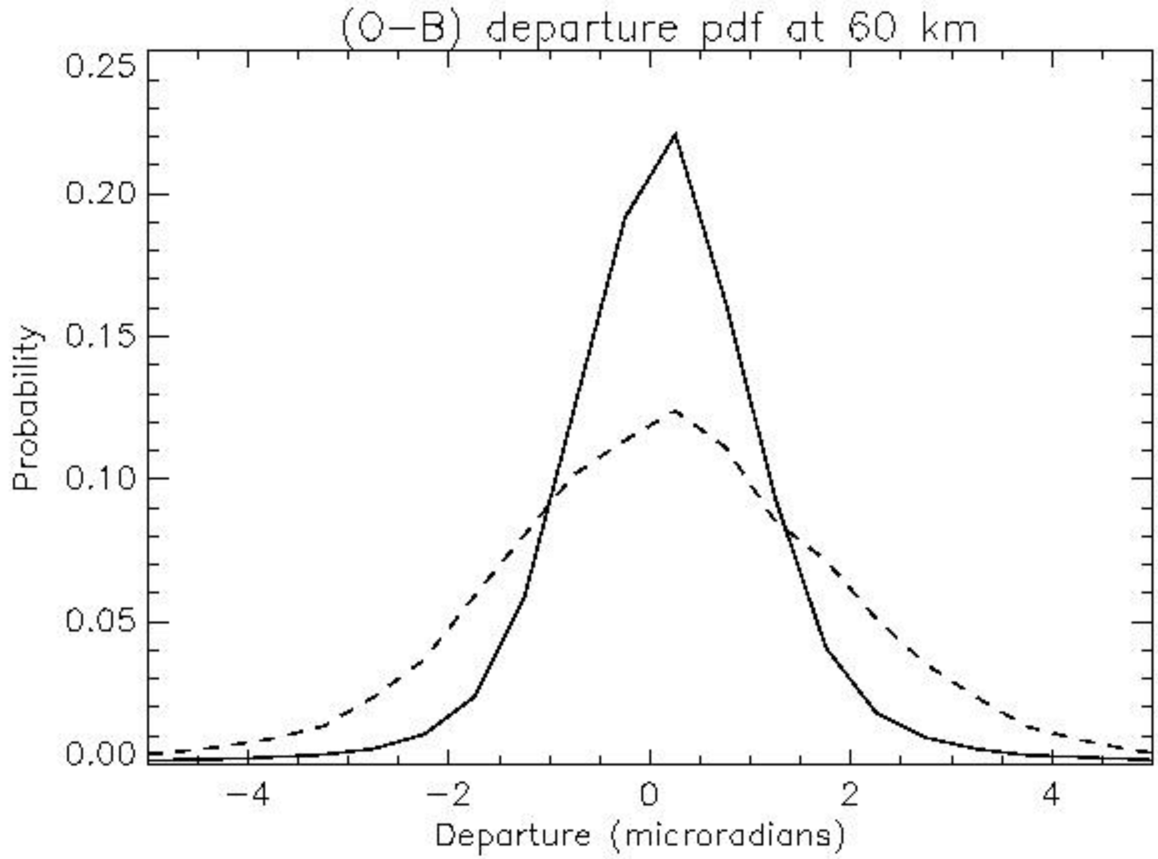



# Noise levels from COSMIC and Metop/GRAS

# Comparison of GRAS and COSMIC-4 bending angle departures

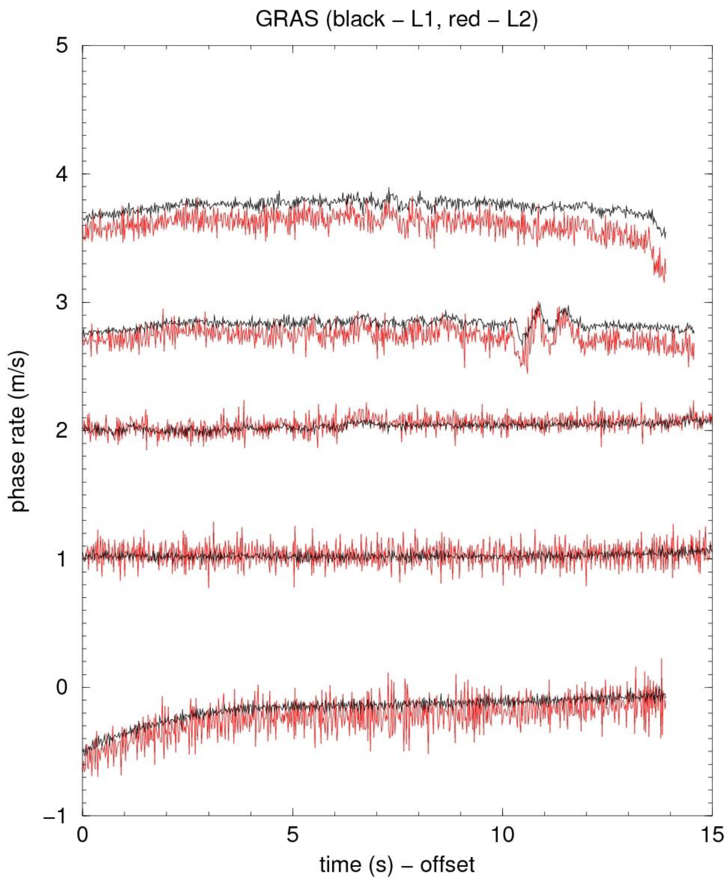
- Both COSMIC and GRAS are now being assimilated operationally. Noise characteristics of GRAS measurements are slightly better.



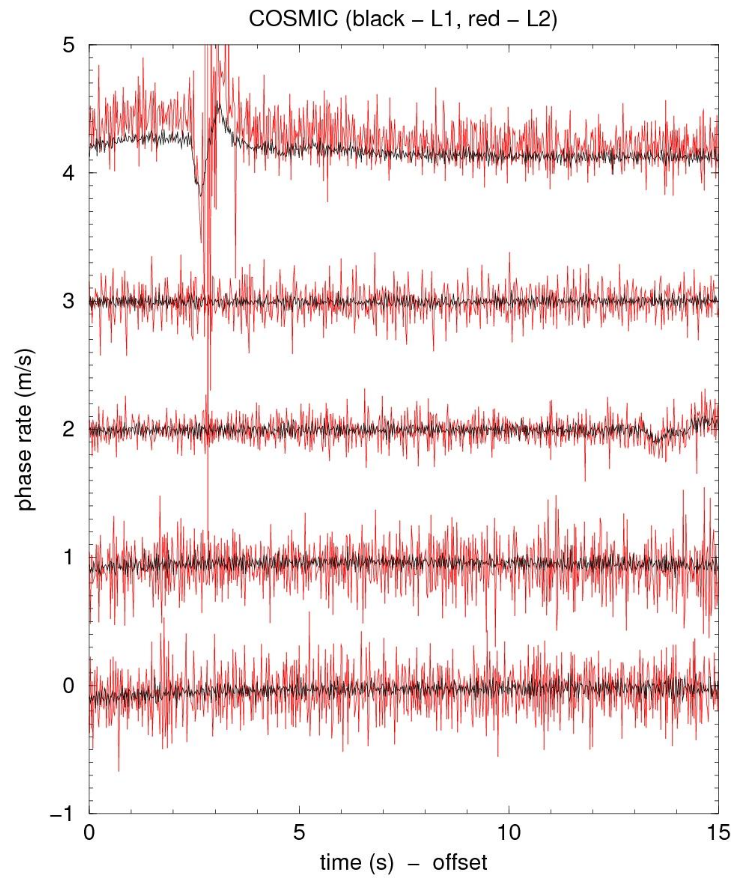

(Jan 2009 Global, from operations )

S. Healey
ECMWF

# GRAS vs. COSMIC Phase Noise

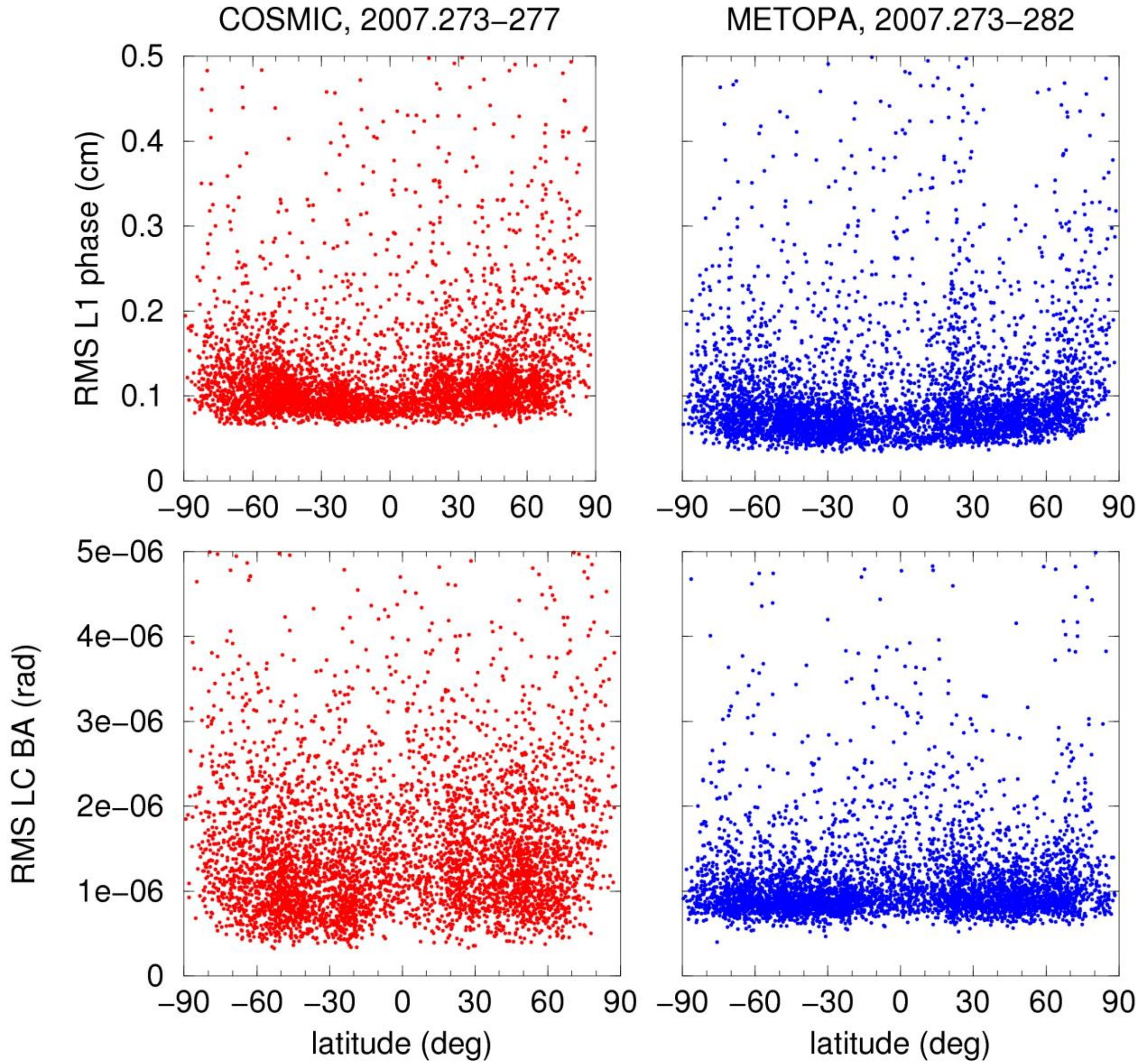



GRAS




COSMIC

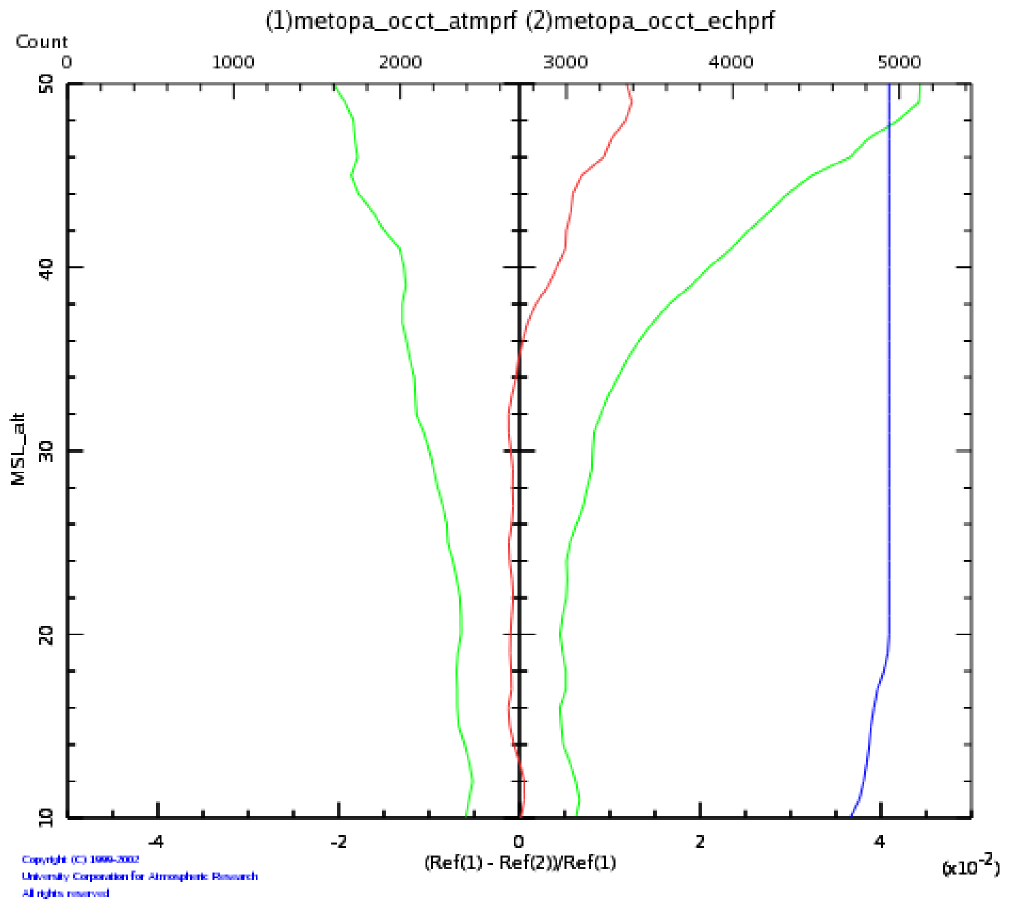
# Phase and Bending angle comparisons COSMIC and Metop




L1 Phase

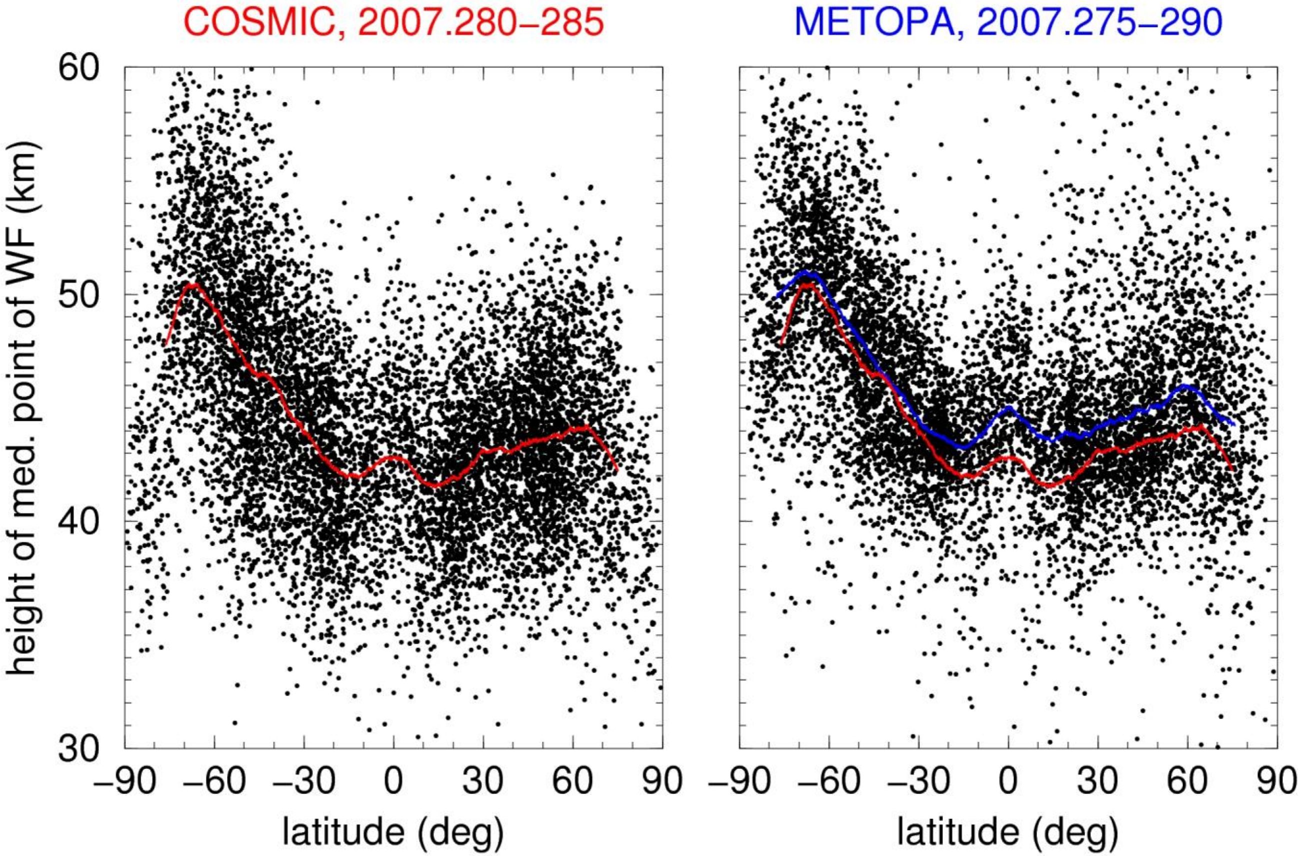
Iono-corrected bending angle

# Comparison of METOP/GRAS and COSMIC Refractivity




Metop has ~0.5% smaller standard deviation at 50 km
cause for different bias > 20 km is not understood

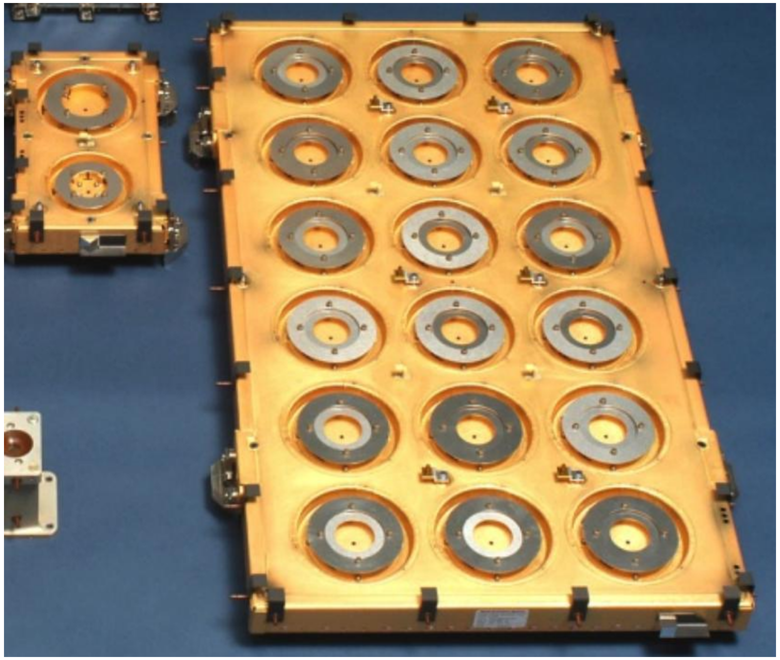
# Comparison of the height where CDAAC processing assigns equal weight to climatology and observations (statistical optimization of bending angles)



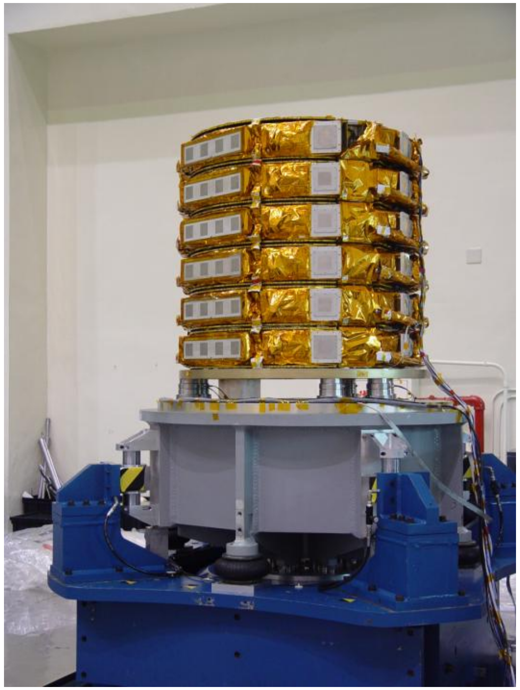

In the SH COSMIC and Metop data are used to same height

In the tropics and NH lower noise in Metop extents height by 2 km

# Antenna Improvements



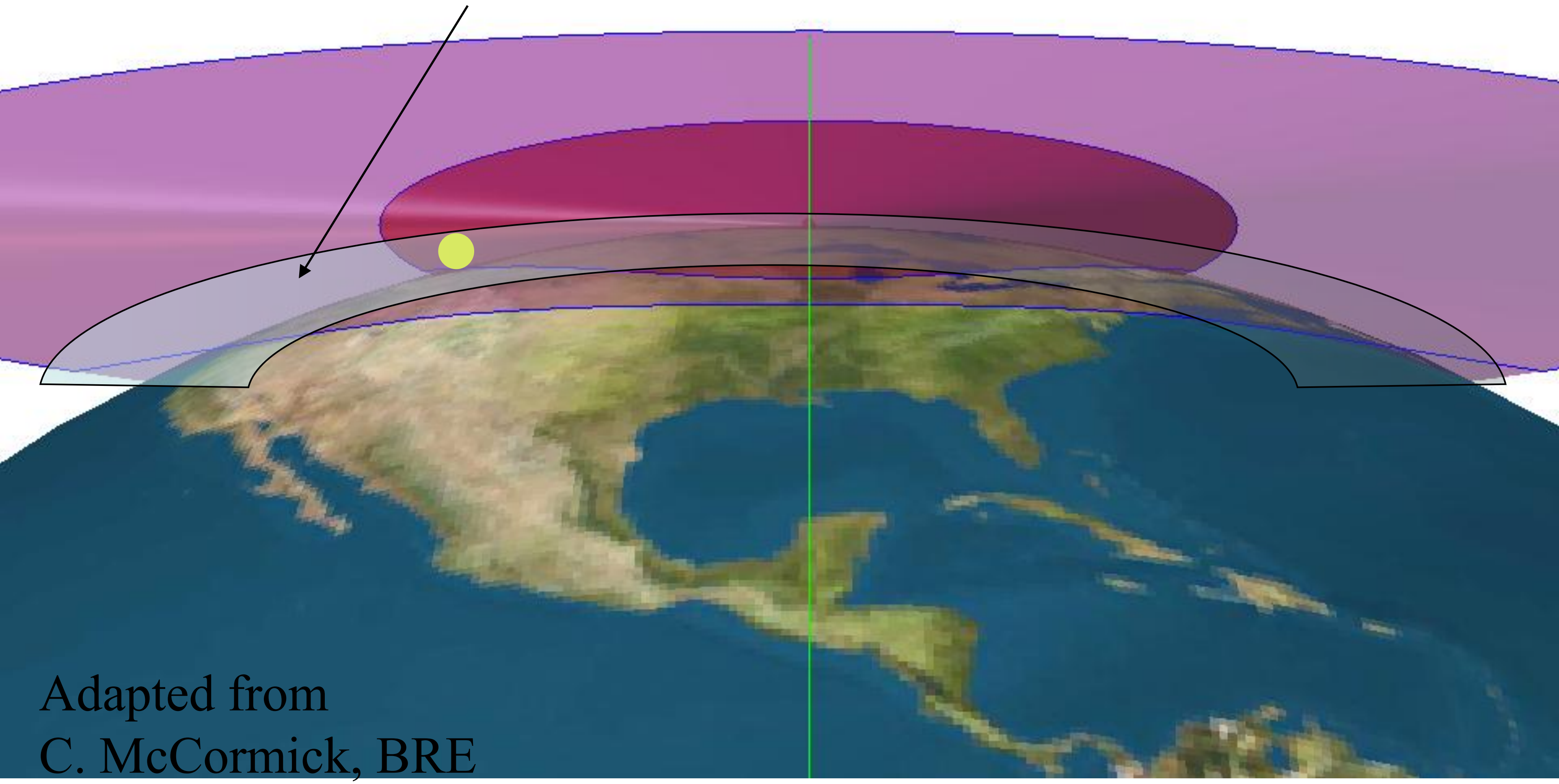
GRAS antenna



COSMIC antenna

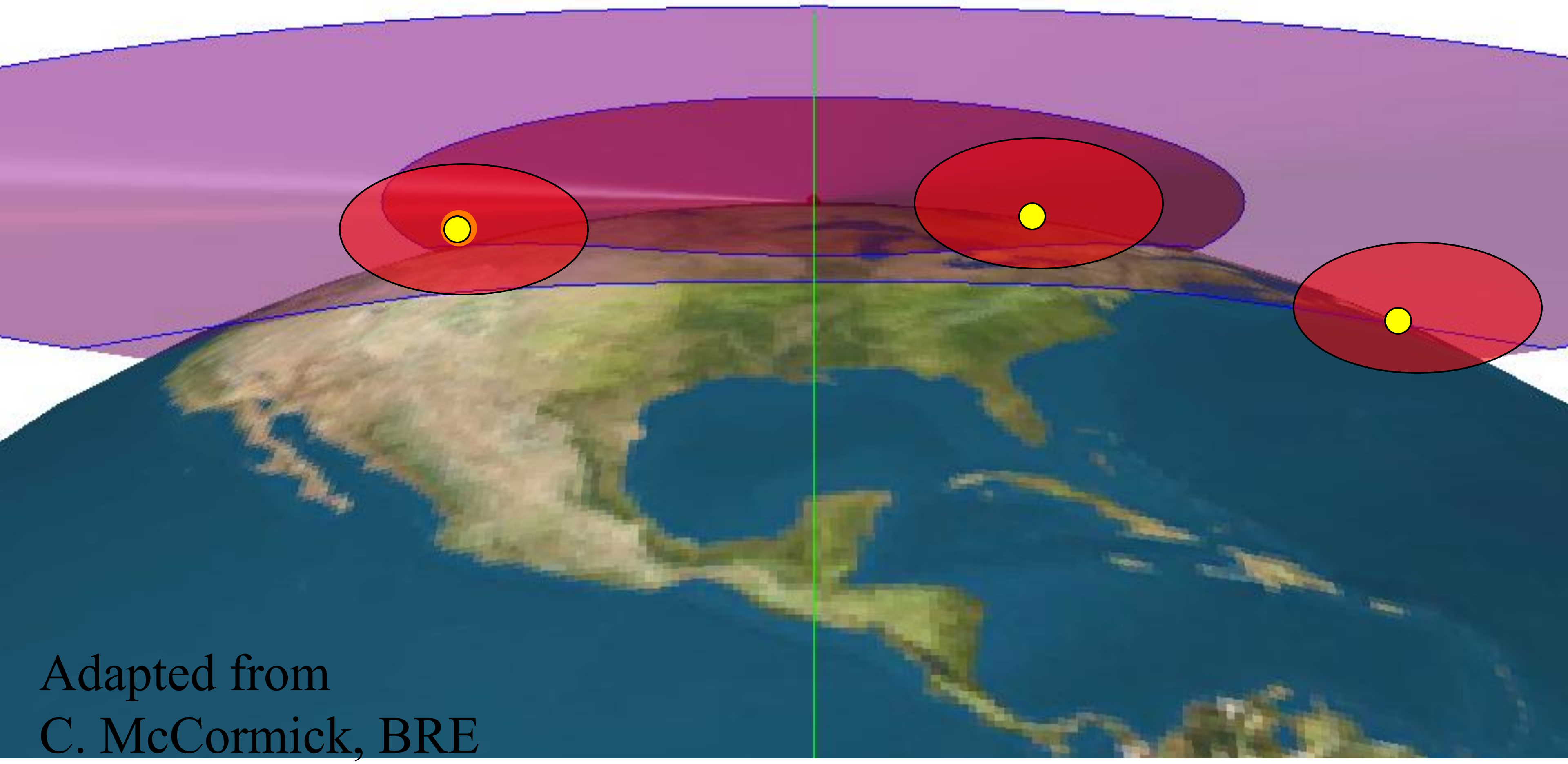
# COSMIC Antenna field of view (10 dB and 7 dB areas)

GRAS Antenna Field of View (12-14 dB)

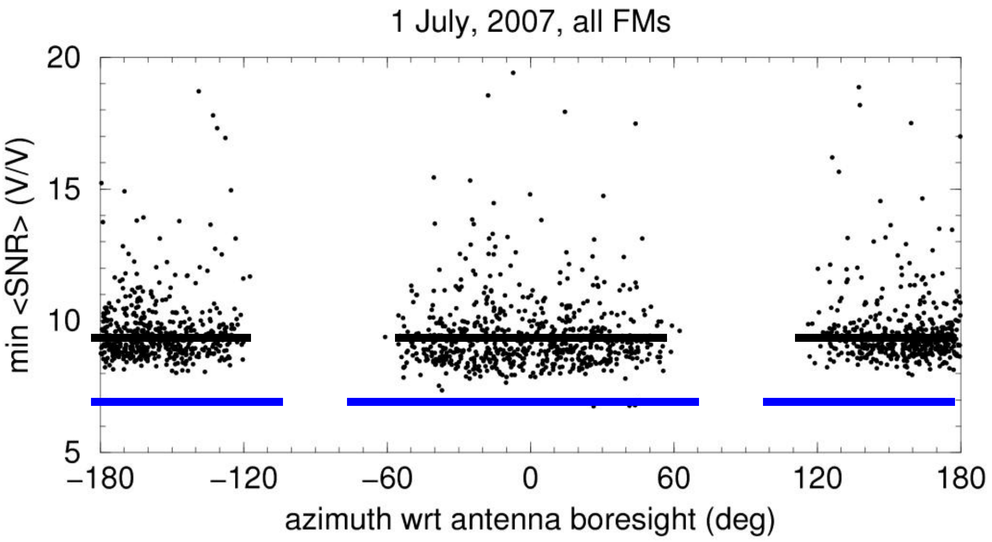


Adapted from
C. McCormick, BRE

# Steerable High Gain Antenna Field of View
# (Considered for COSMIC Follow on)



# Observed Background Noise for COSMIC




BG noise level as function of azimuth wrt antenna boresight

The design goal for COSMIC II is to lower the noise floor and to broaden the azimuth (i.e for side viewing occultations)

QuickTime™ and a
decompressor
are needed to see this picture.

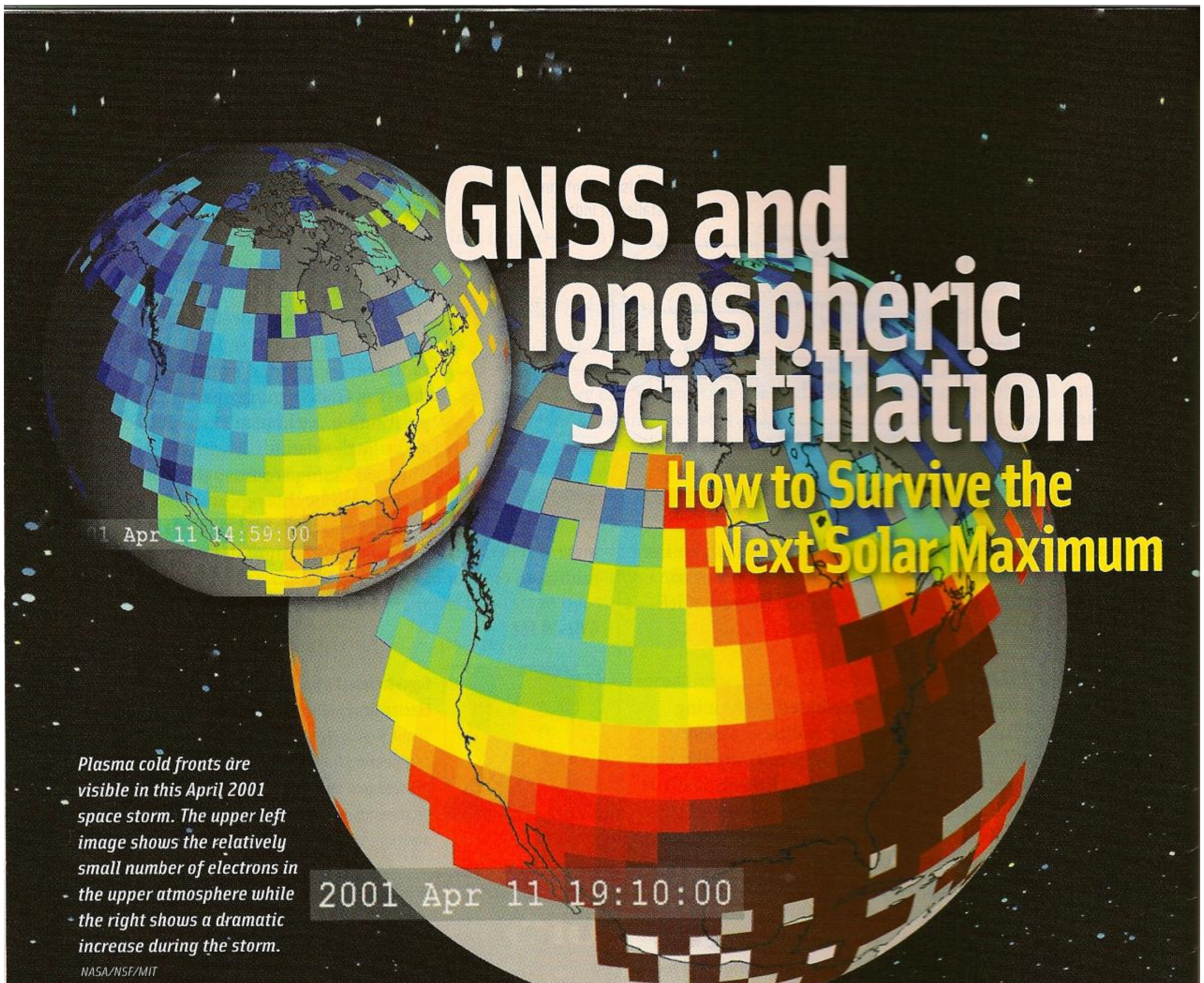
C. McCormick, BRE

# An Orange ?


SOHO Image

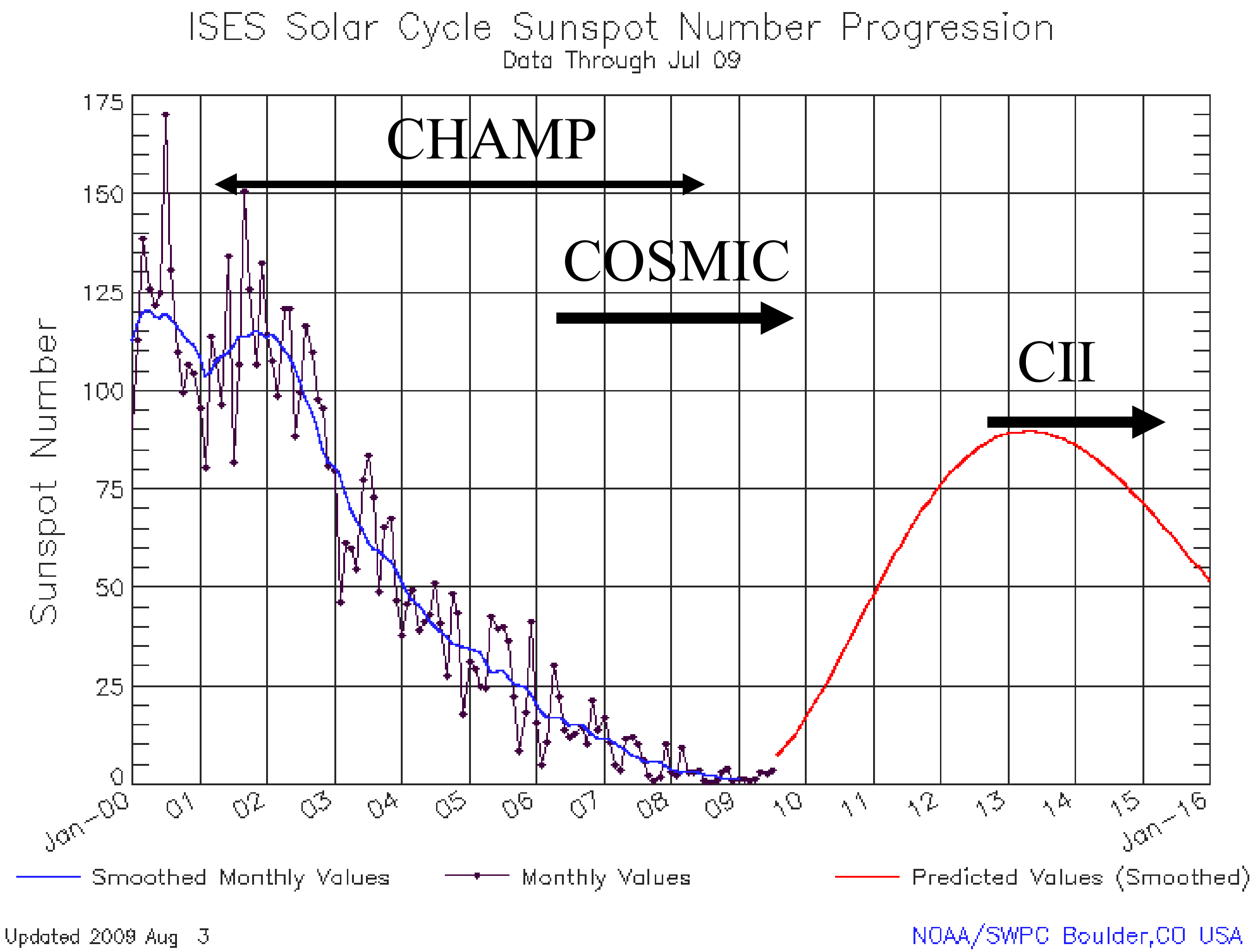
….. no it is the Sun on August 20, 2009

# Cover Story "Inside GNSS" July / August 2009 (Kintner et al)

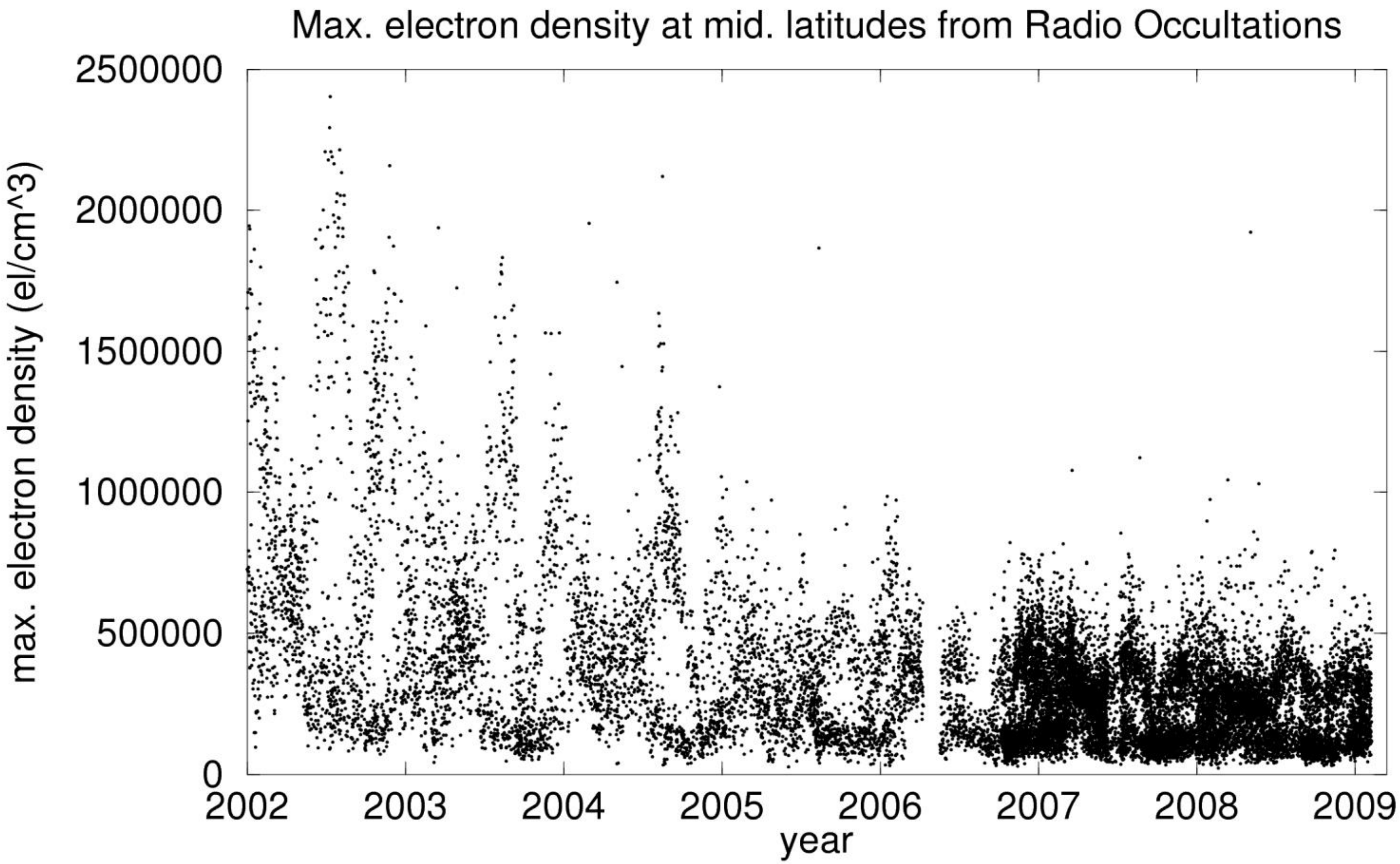



What will the RO community have to do to "survive" the next "Solar Maximum"

# The Solar Environment for a COSMIC Follow-on



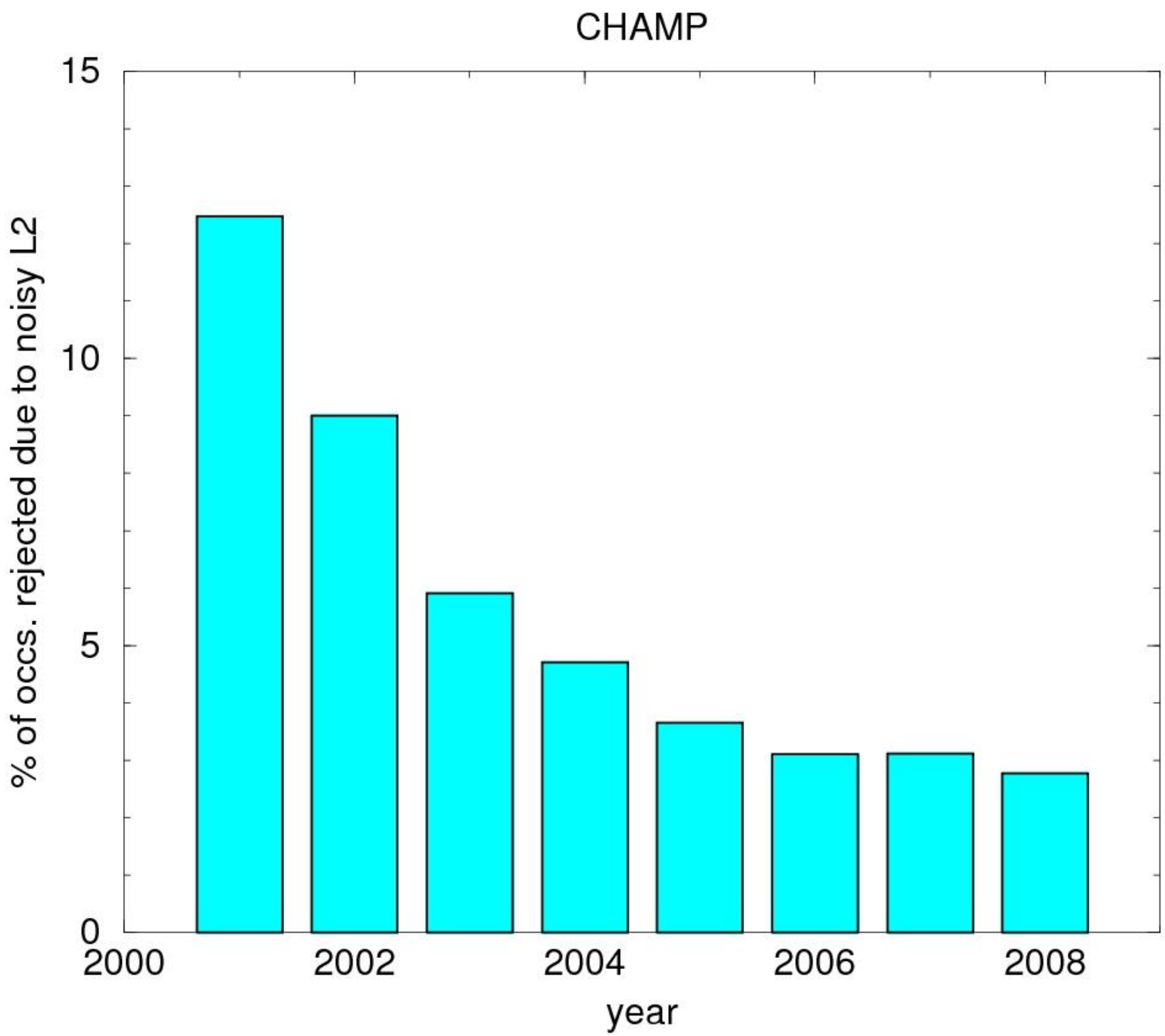
# Maximum Electron Density from CHAMP and COSMIC




maximum electron densities have decreased by factor of 4 since 2002

# Percentage of Failed Soundings

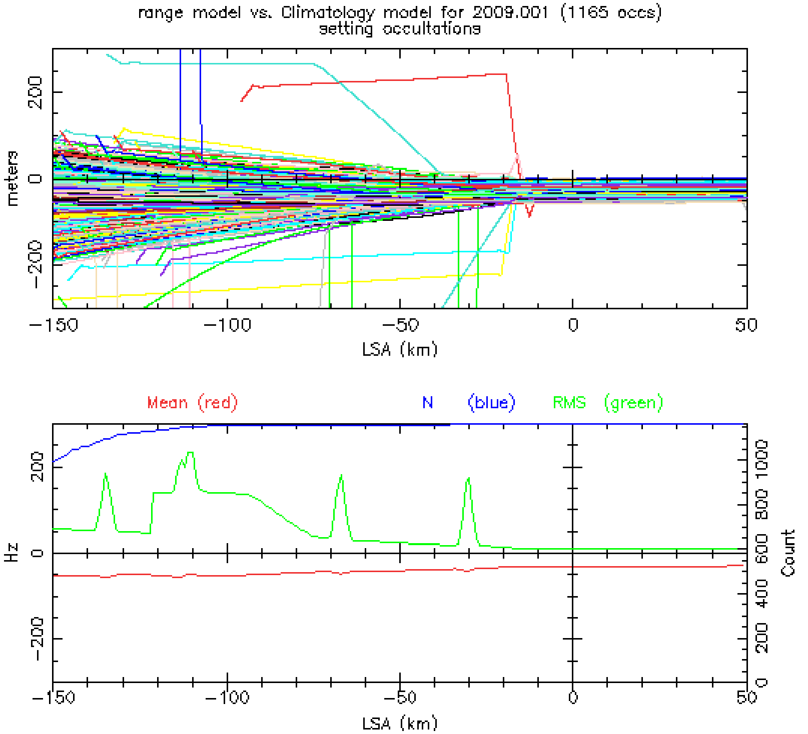
## Soundings rejected due to bad L2 data



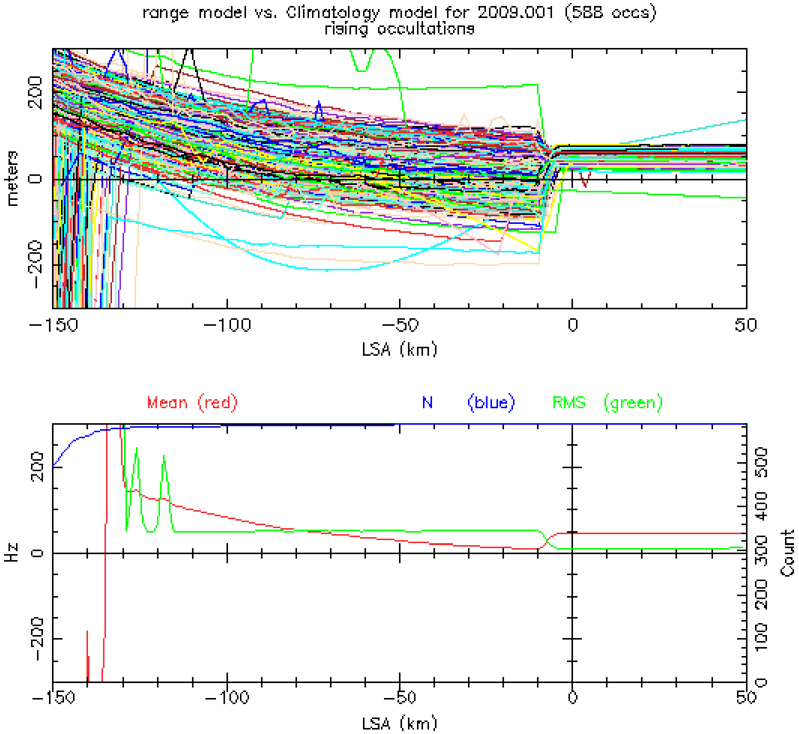
# Verification of COSMIC receiver range model against the model based on GPS and LEO orbits and CIRA+Q

1 January 2009

setting




rising



# Summary and Conclusions

Reduction of background noise for CII is desirable to: (a) avoid deleting ~20% of soundings; (b) allow observations to surface without introducing biases; (c) surface duct detection, (d) extend the observed height in the stratosphere

Metop GRAS has lower background noise than COSMIC

Background noise can be improved by (a) use of ultra stable oscillator in receiver (easy) (b) better antenna gain (not so easy)

Solar Max will affect CII: (a) to improve open loop tracking model, (b) buffer rising occultations and process “backwards after range acquisition”, (c) track at 100 Hz

COSMIC is not getting any younger - while it is important to evaluate what we should and could do better this should not keep us from acting now on developing the follow-on mission !!!