# Quality Assessment of GPS RO Bending Angle Data at the UCAR CDAAC


Bill Schreiner

Sergey Sokolovskiy, Doug Hunt, Bill Kuo

UCAR COSMIC Program Office


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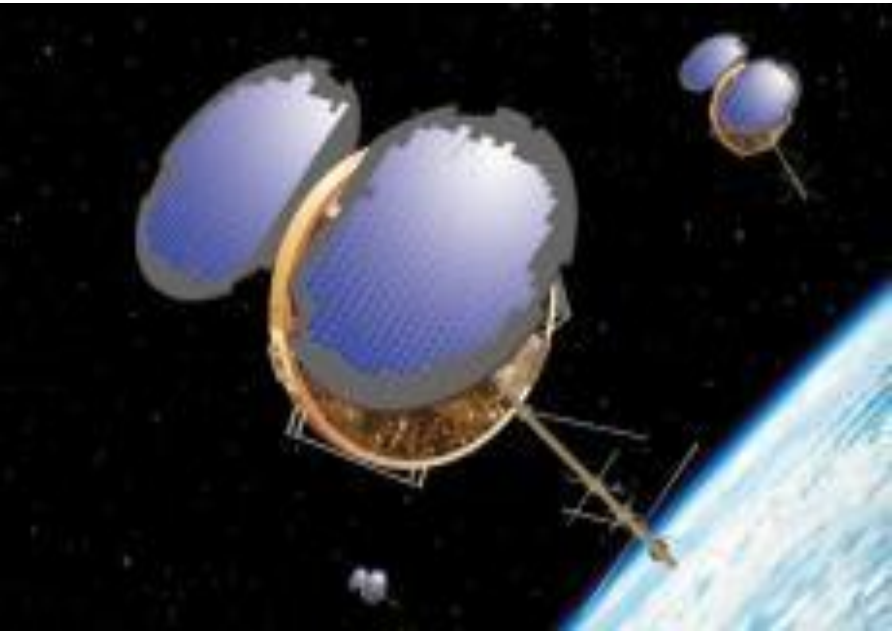
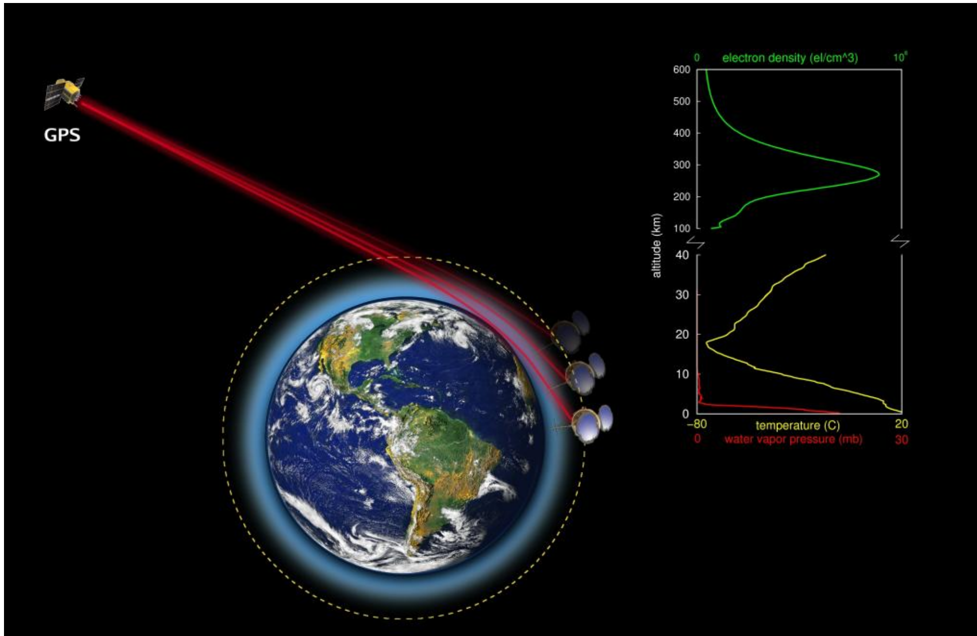
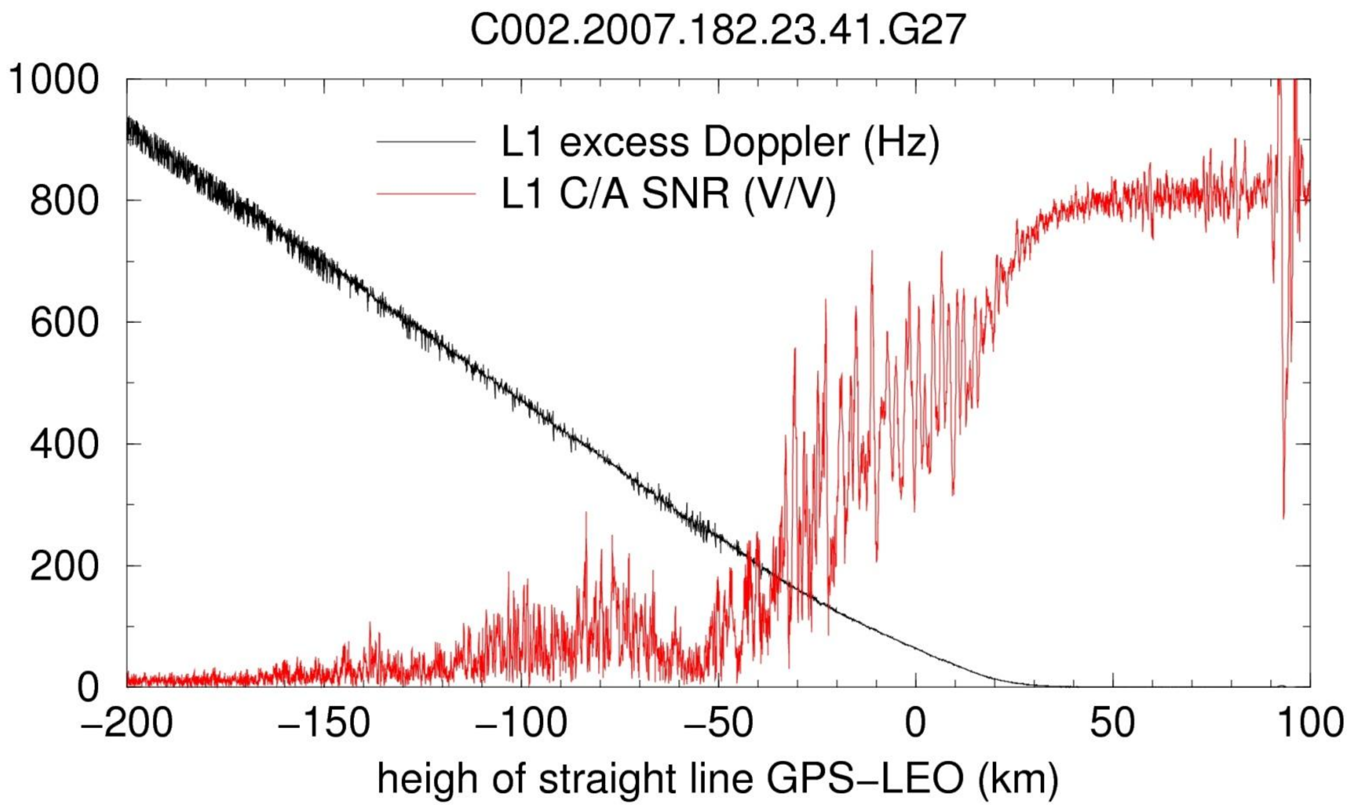




Upper stratosphere and lower troposphere are the regions of maximum errors and uncertainty of the GPS RO inversions




**In the lower troposphere:**
the signal reduces below noise level
in terms of the amplitude
Additive noise - main error source

**In the upper stratosphere:**
the signal reduces below noise level
in terms of the exc. phase (Doppler)
Multiplicative noise - main error source

# Outline

- Processing overview
- POD Quality
- Bending angle assessment
  - Upper atmosphere
  - Lower troposphere
- Summary

# Data Processing Procedure

**Raw Phase/Amplitude**

↓ Precise Orbit Determination / excess phase process
no error propagation

**Excess Phase (Doppler)**

↓ local transform
no error propagation

**Bending angle**

↓ non-local transform (Abel inversion)
error propagation downward

**Refractivity (density)**

↓ non-local transform (hydrostatic integration)
error propagation downward

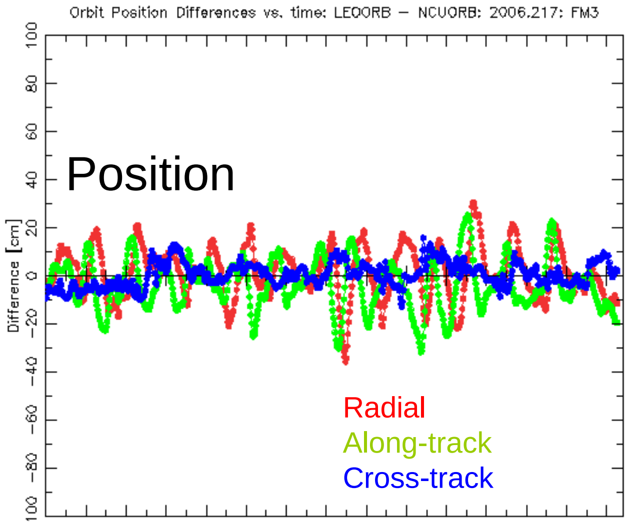
**Pressure, temperature**

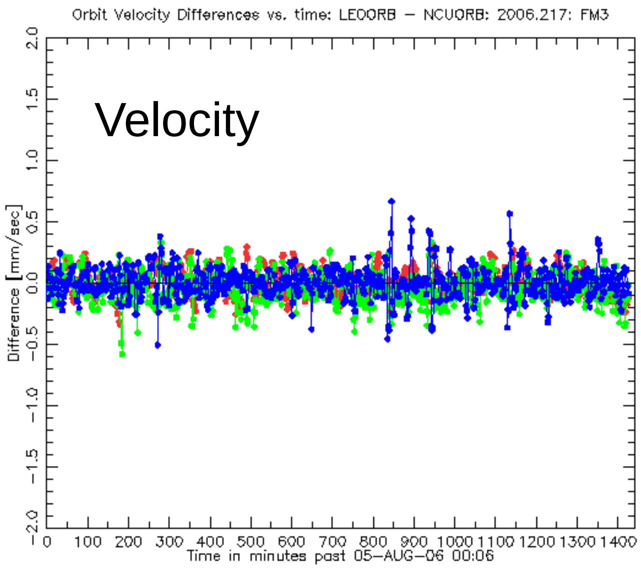
# CDAAC Precise Orbit Determination

- Inter-Agency orbit differences (UCAR,NCTU,GFZ,JPL,EUMETSAT)

| Mission | Agency Source | 3D RMS POS [cm] (VEL: [mm/s]) |
|---|---|---|
| **CHAMP** | JPL/GFZ | 13 (0.2) |
| **GRACE-A** | GFZ | 7 (0.1) |
| **COSMIC** | JPL/NCTU/GFZ | 20 (0.2) |
| **Metop-A/ GRAS** | EUMETSAT | 8 (<0.1) |
| **TerraSAR-X*** | GFZ | 10 (0.1) |

- Mean differences < 0.05 mm/sec (COSMIC)
- Velocity error of 0.1 mm/s results in bending angle error of ~3e-8 rad



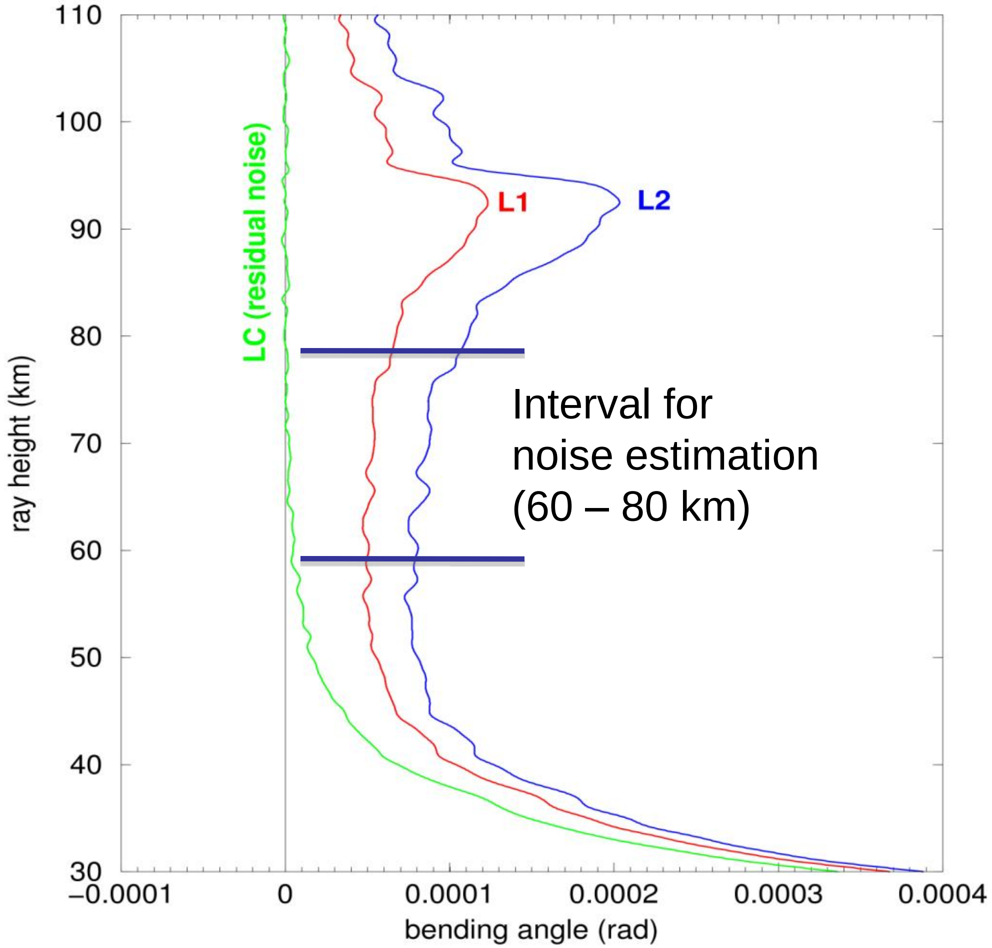
# RO Mission Retrieval Failure Percentages

| Mission | Good Profiles (%) | BAD L2 (%) | Short Occultations < 70 km HSL (%) |
|---|---|---|---|
| COSMIC | 65 | 20 | 10 |
| CHAMP (setting) | 55 | 2 | 14 |
| SAC-C | 63 | 5 | 12 |
| GRACE-A (setting) | 81 | 17 | 1 |
| Metop-A/GRAS | 76 | 13 | 5 |
| TerraSAR-X (setting) | 60 | 10 | 15 |
| C/NOFS (setting) | 50 | 1 | 40 |

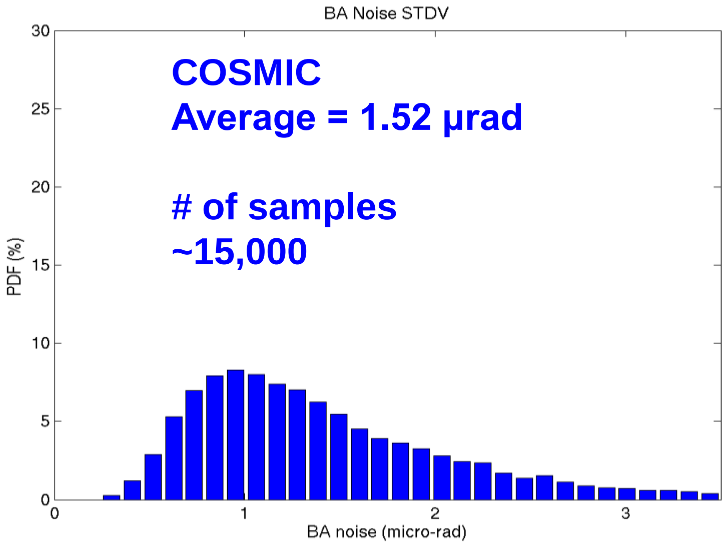
Approximate percentages for one month of data

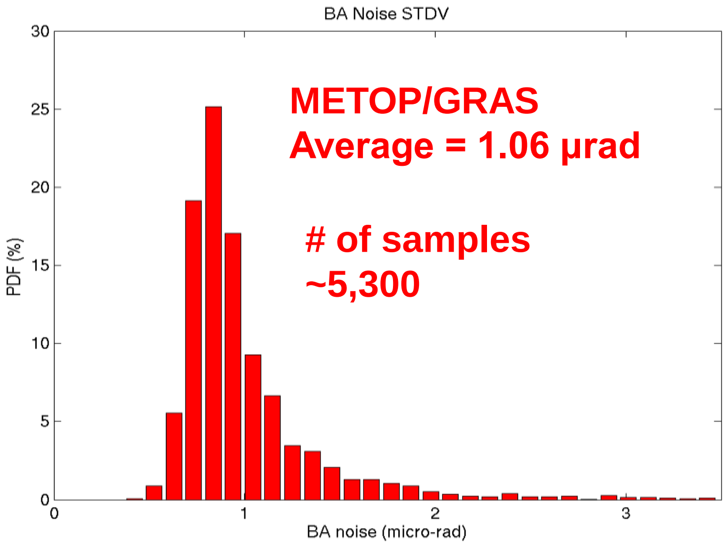
# Bending angle noise between 60 and 80 km

- BA Noise (STDV) =
  standard deviation of difference of the observation bending angle from the 1st guess between 60 and 80 km




Histograms of STDV between 60 - 80 km



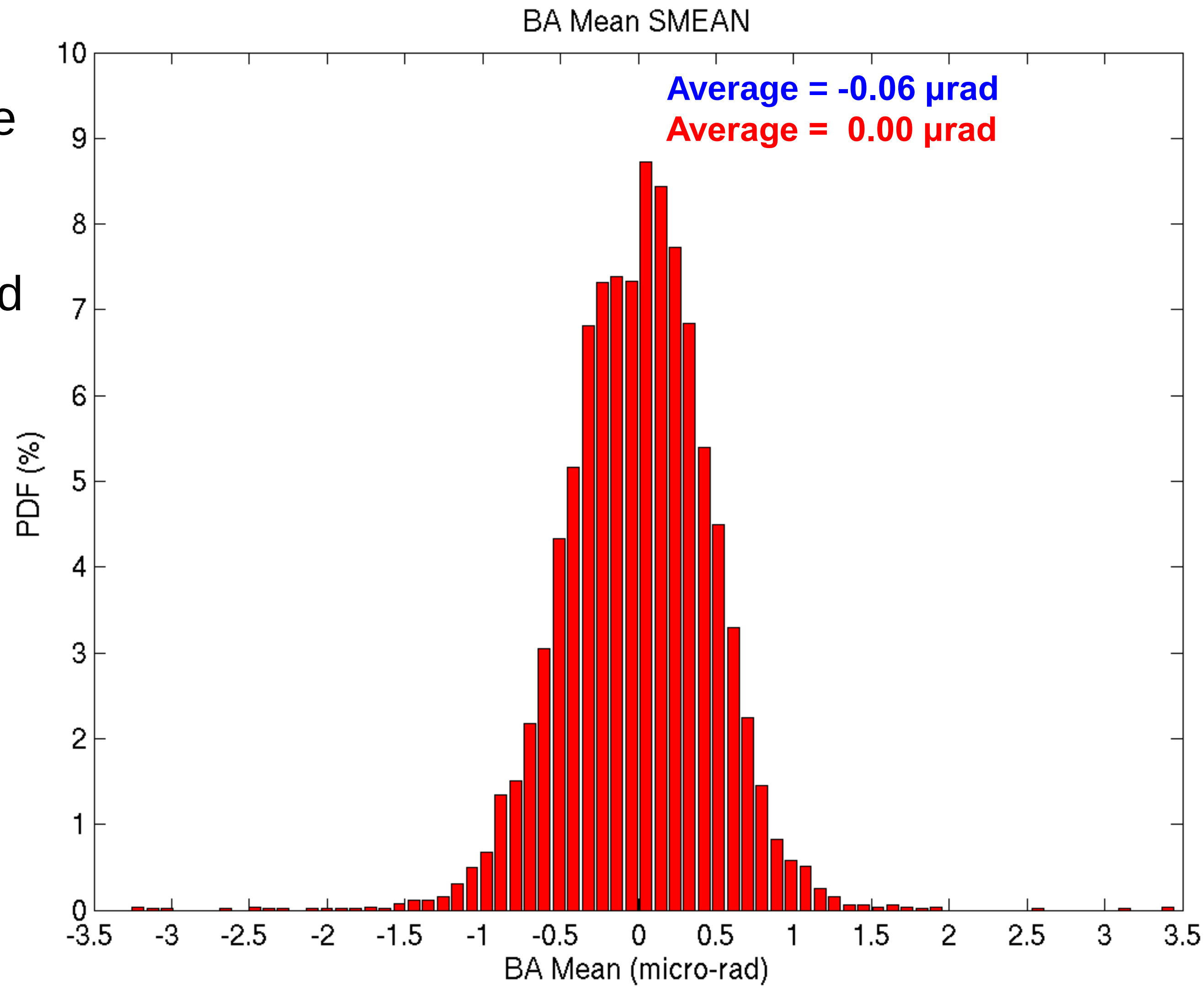



# Bending angle mean between 60 and 80 km

- BA Mean (SMEAN) = mean difference of the observation bending angle from the 1st guess between 60 and 80 km

Different averages are significant -
May be due to large scale ionospheric residuals that are a function of local time.

**COSMIC and METOP/GRAS: 2007.274-283**

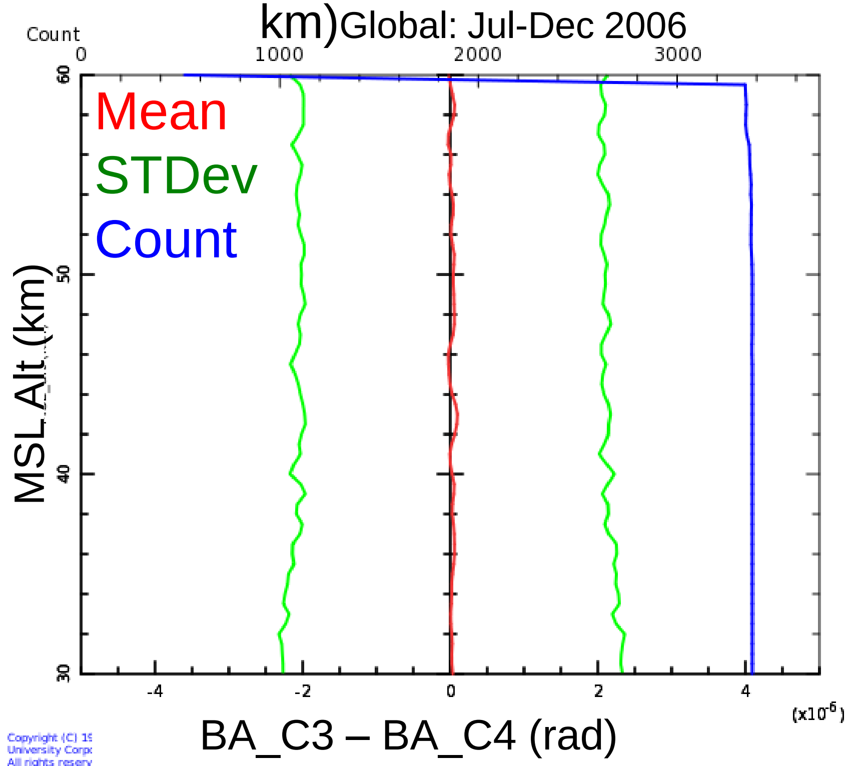


# Bending Angle Differences between COSMIC3 and COSMIC4

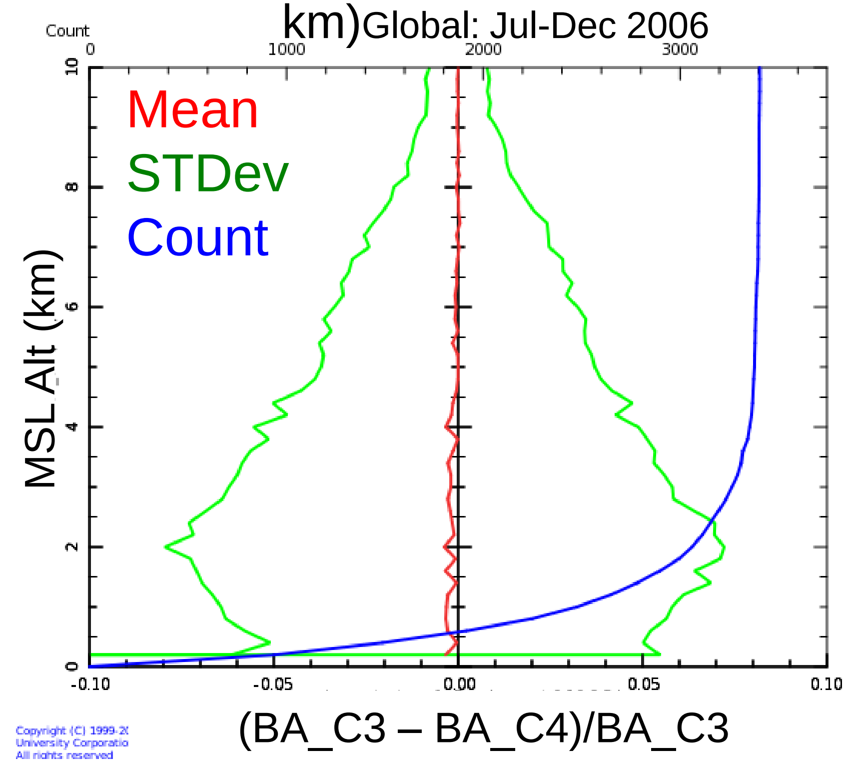
**Left Panel**: Bending angle differences vs altitude between COSMIC3 and COSMIC4 collocated profiles (TPs < 10 km, same PRN). The average of the mean differences over the height range is ~3.0e-8 +/- 4e-8 radians.

**Right Panel**: Bending angle differences vs altitude between COSMIC3 and COSMIC4 collocated profiles. The mean differences of up to ~0.5% below 4 km can be explained by systematically smaller L1 Signal-to-Noise Ratios observed for COSMIC3 as compared to COSMIC4.

High Altitude (30 – 60 km)

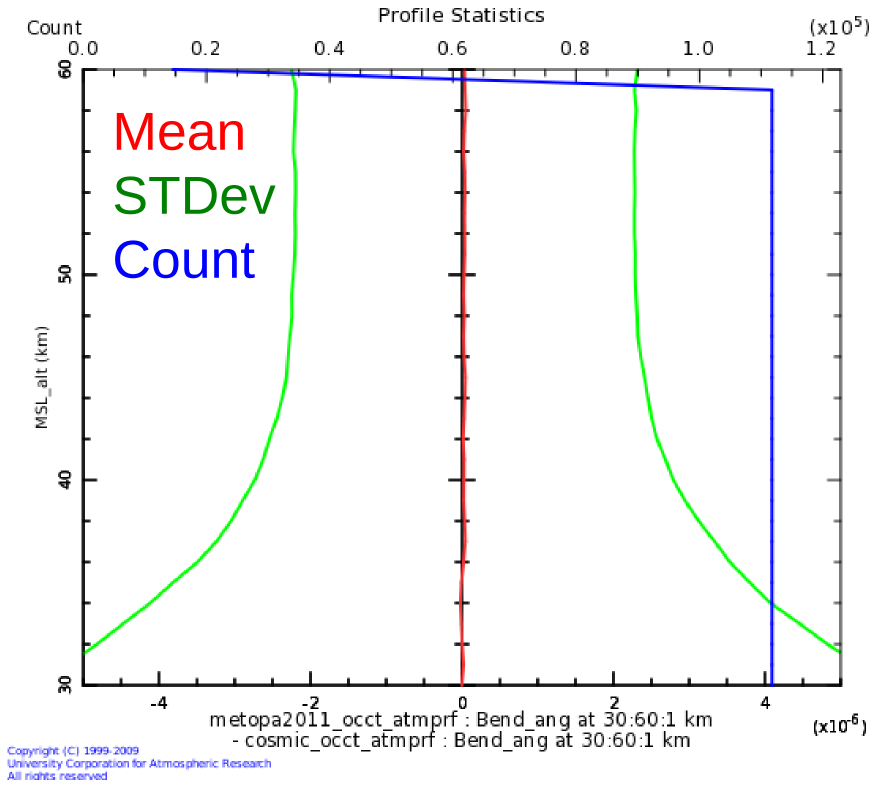


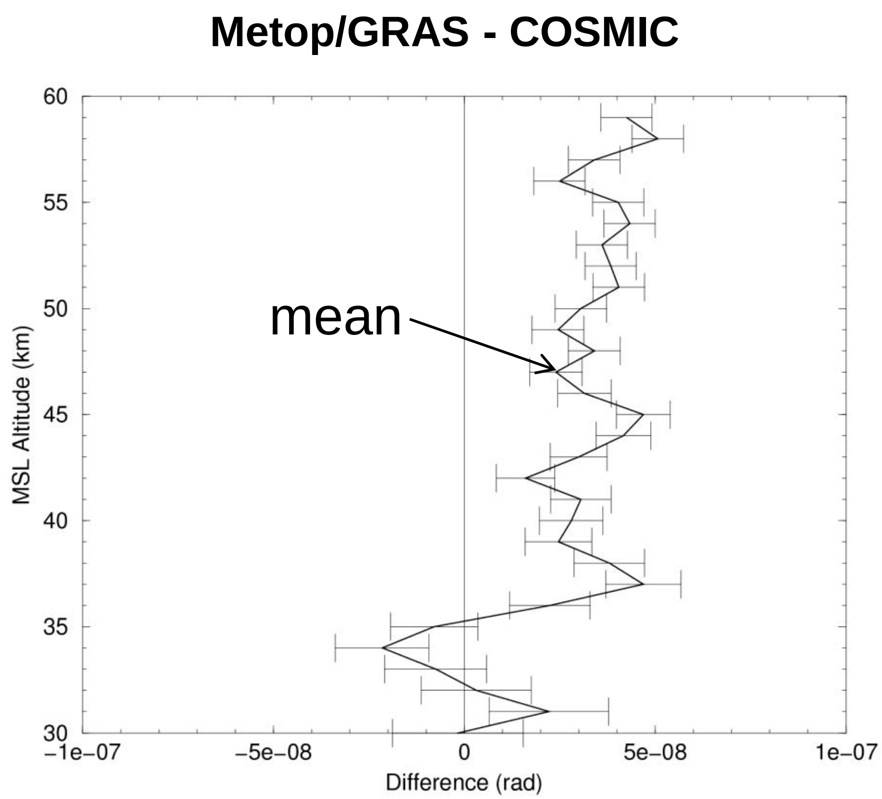

Lower Troposphere (0-10 km)



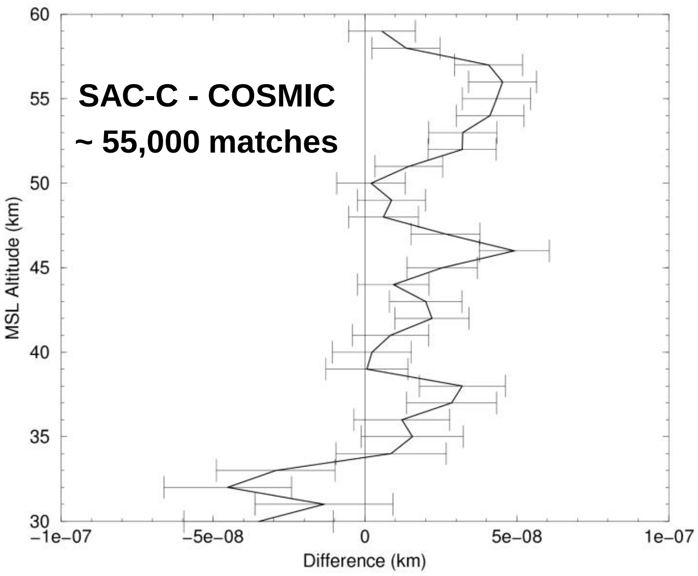
# Systematic Bending Angle Differences
# COSMIC vs Metop/GRAS

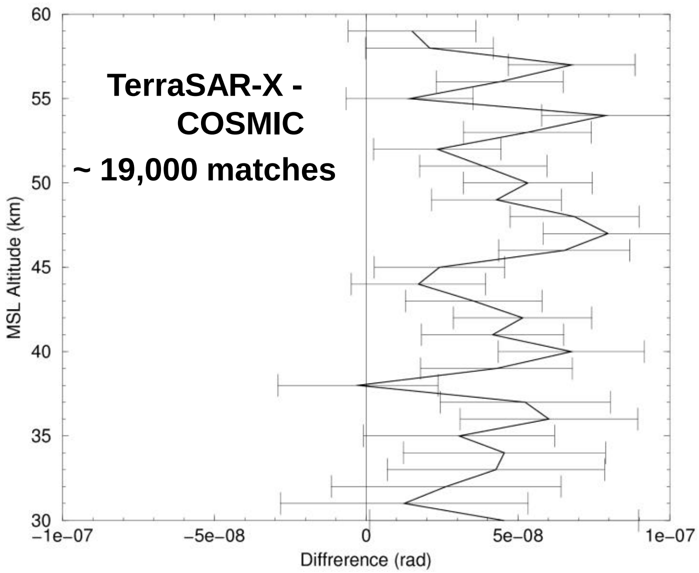
**(~112,000 Collocations within 2 hours/300 km, Oct 2007-Dec 2011)**

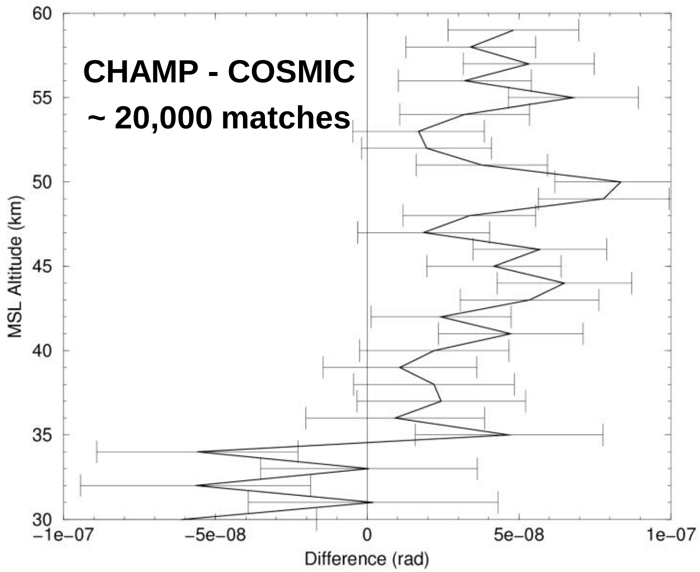


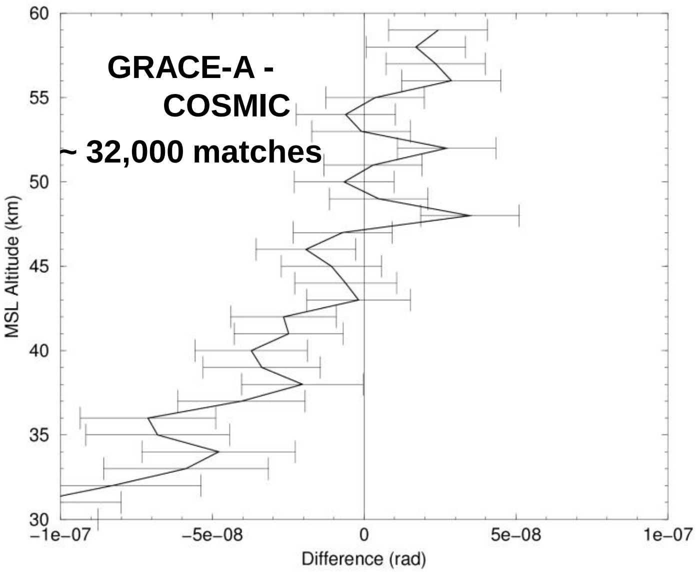



# Systematic Bending Angle Differences COSMIC vs Other missions



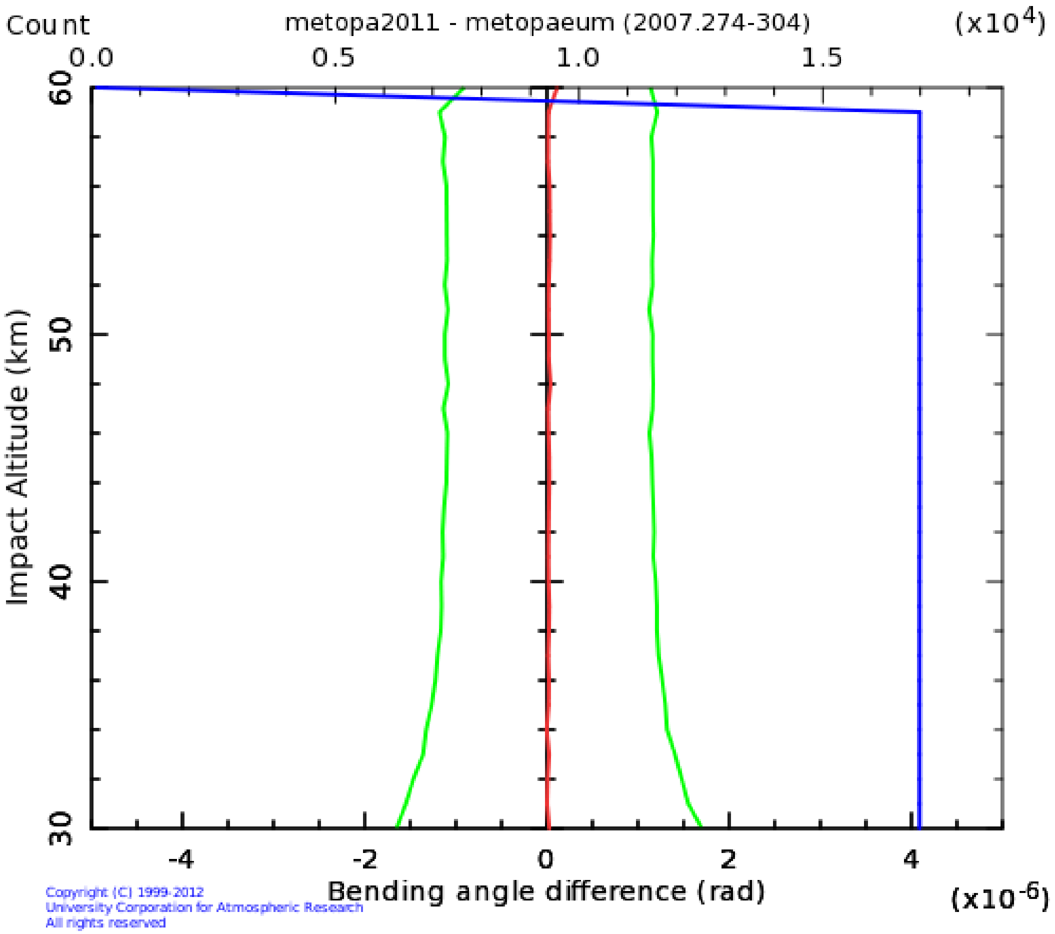



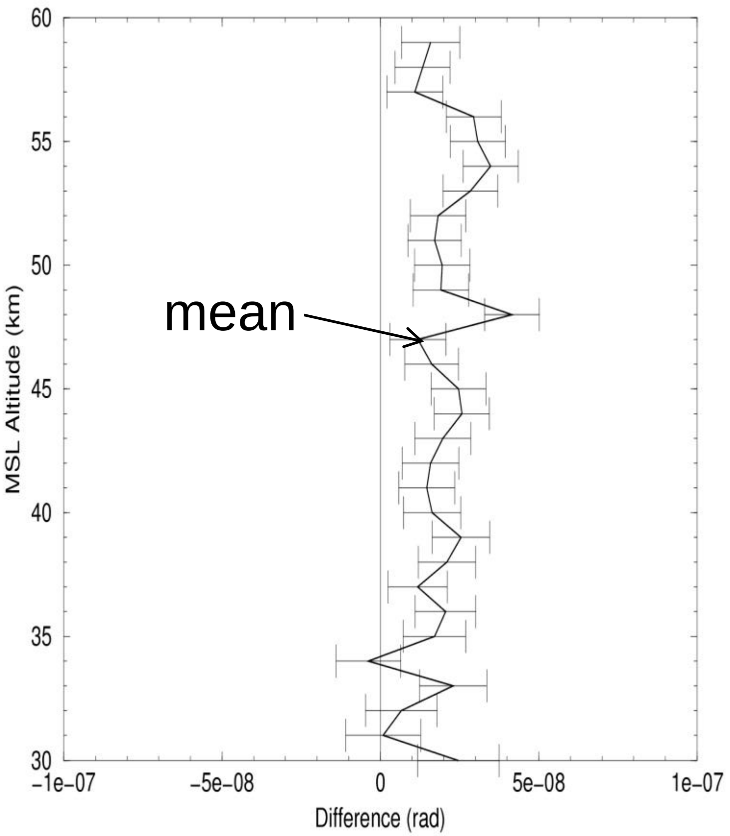



# Metop/GRAS Systematic Bending Angle Differences UCAR vs EUMETSAT

## (~17,000 Collocations Oct 2007)



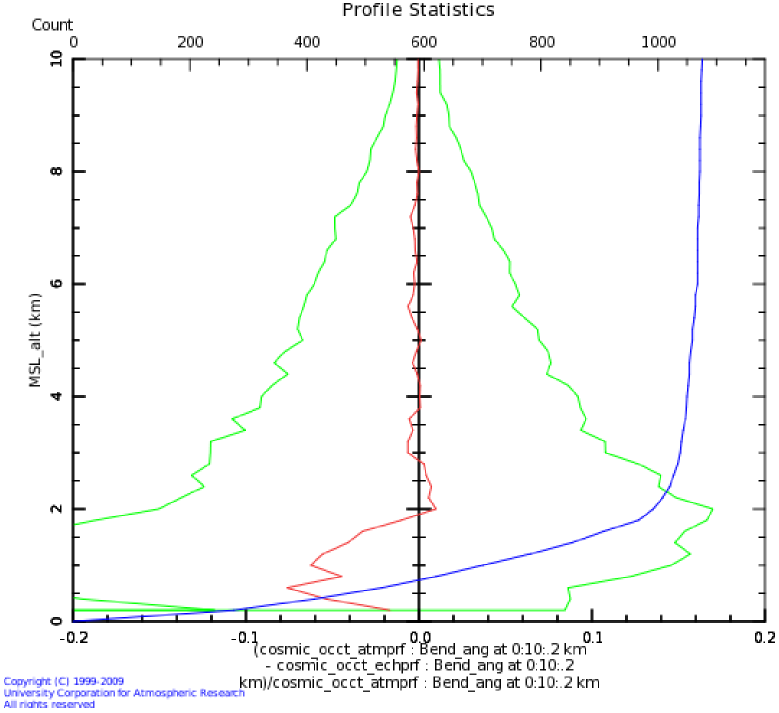




) km altitude

# Statistical comparison of COSMIC retrieved Bending Angles to ECMWF In Tropics

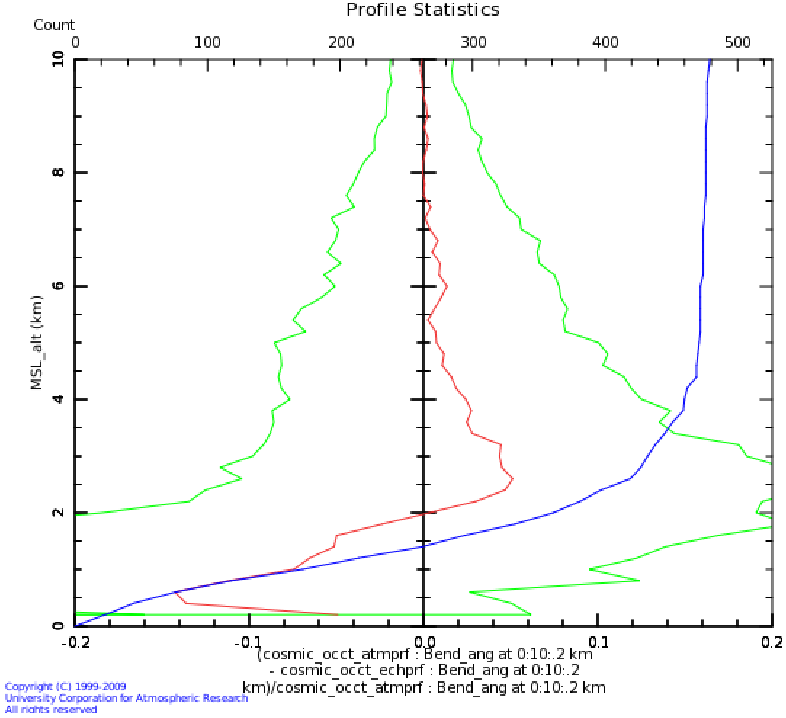
Red lines: mean deviation
Green lines: +/- standard deviation
Blue lines: penetration (bottom heights of retrieved profiles)

## GPS azimuth: 0-10 deg
## SNR ~ 700-900 V/V



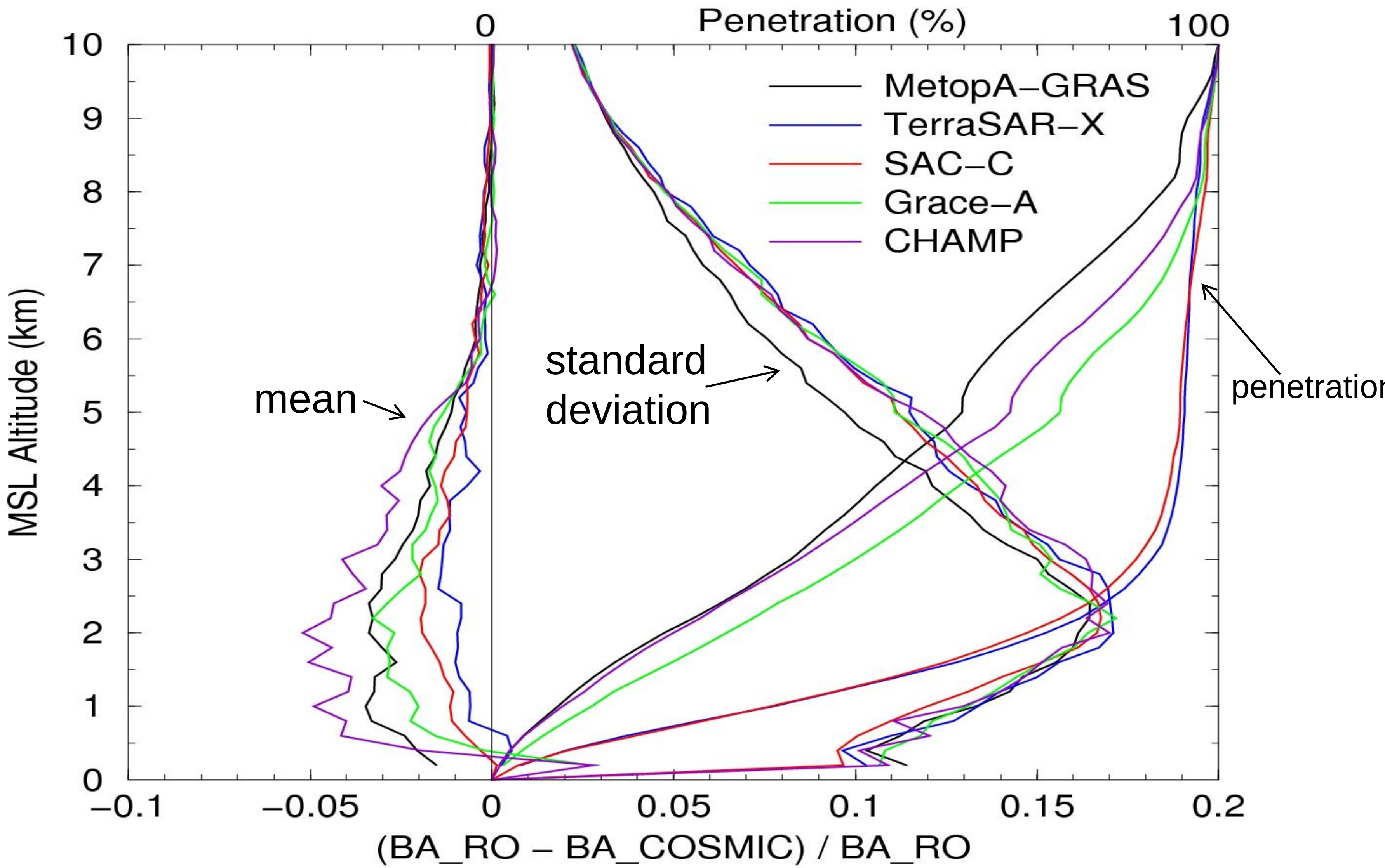

**~ 70% profiles penetrate to 1 km**

## GPS azimuth: 50-60 deg
## SNR ~ 400-600 V/V



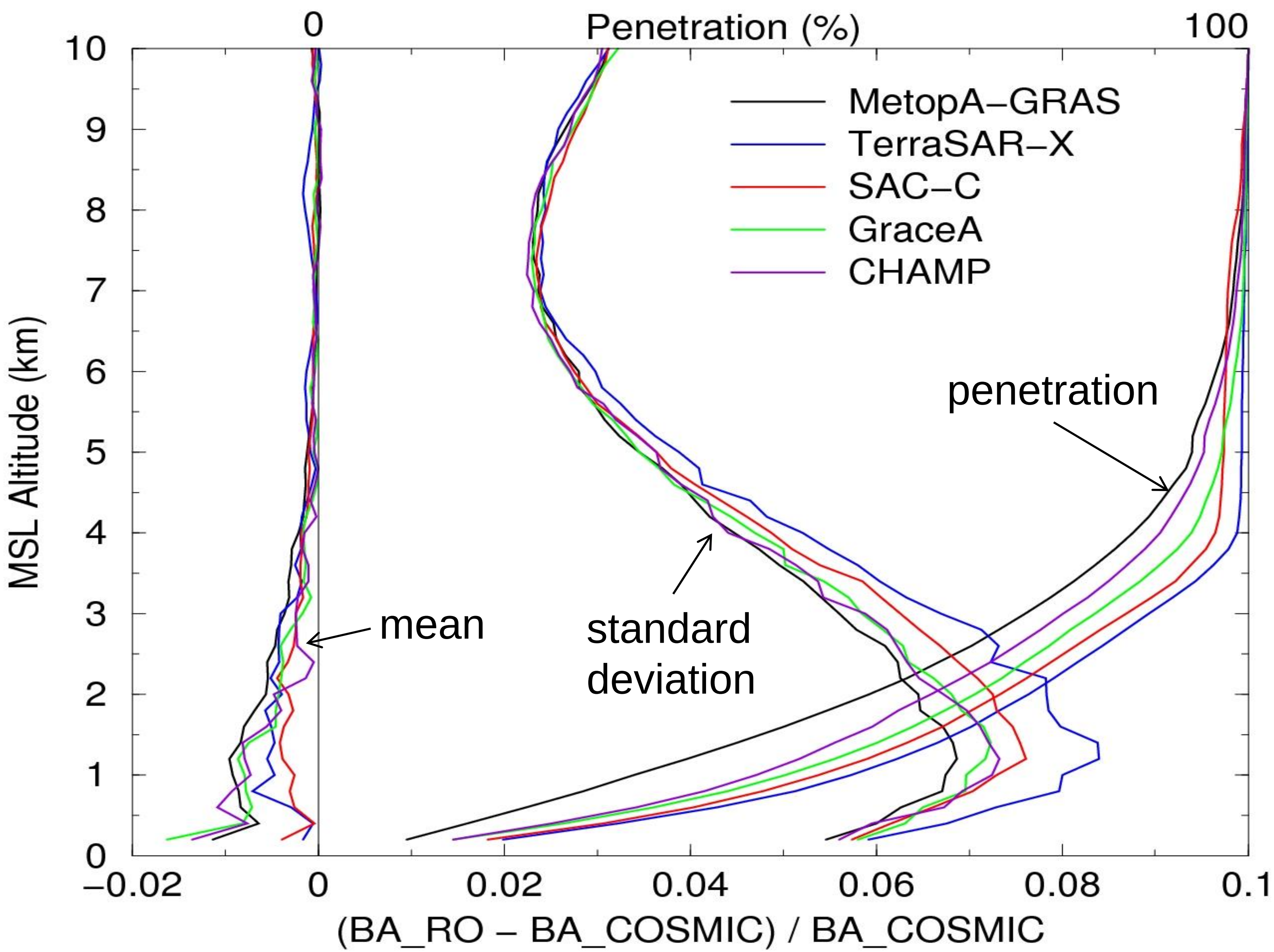

**~ 30% profiles penetrate to 1 km;** mean and standard deviation **(inversion errors)** are substantially larger

# Bending Angle Differences with COSMIC
## Tropical Lower Troposphere

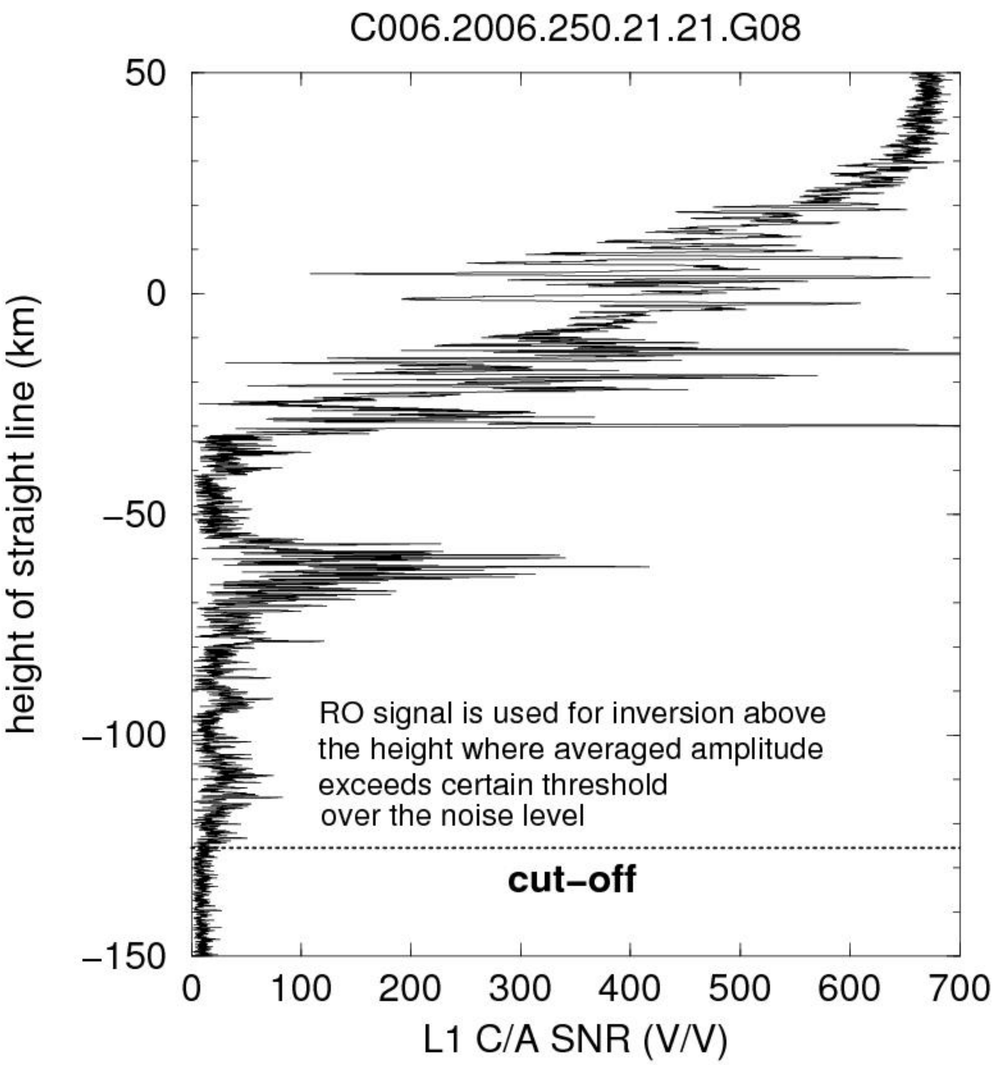


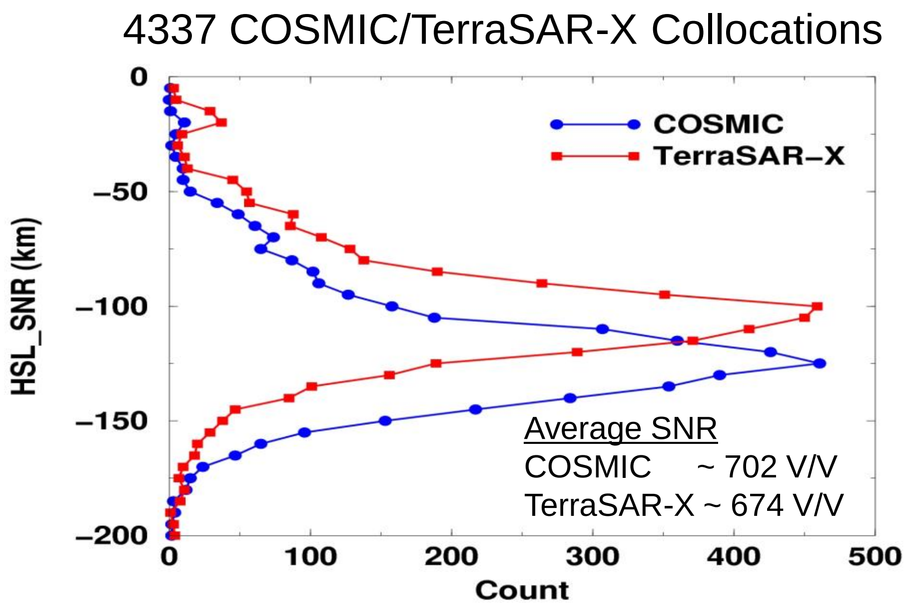
# Bending Angle Differences with COSMIC

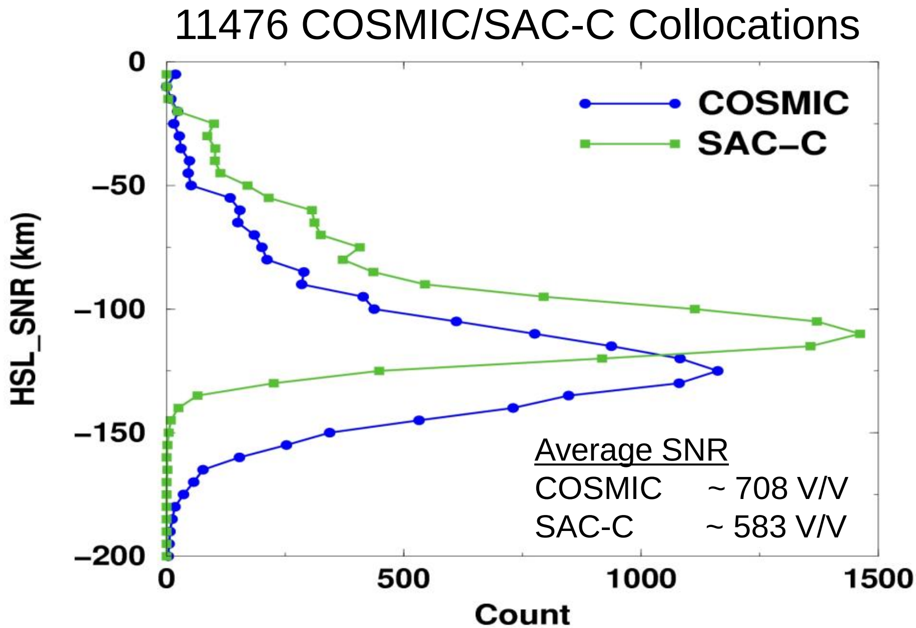
## Polar Lower Troposphere



# RO Signal Truncation in Tropical Lower Troposphere



# Summary

- POD quality suggests potential BA biases of ~1e-8 rad for COSMIC

- Poor L2 signal quality and ‘short occultations’ contribute significantly to retrieval failures at CDAAC

- Upper Atmosphere BA’s
  - No significant BA biases between COSMIC satellites
  - COSMIC BA’s appear biased low relative to other missions by ~ 2-3e-8 rad (GRACE-A compares worse with COSMIC)
  - UCAR BA’s larger (~2e-8 rad) than EUMETSAT BA’s for Metop-A/GRAS

- Lower Troposphere BA’s
  - HSL tracking depth and SNR significantly impact penetration and BA’s by several percent in tropics (~1% polar regions)
  - COSMIC BA’s consistently larger than other missions

# Acknowledgments


- NSF
- Taiwan's NSPO
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UCAR NSF NASA USAF NOAA NSPO ONR

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