# Formosat3 / COSMIC: Constellation Observing System for Meteorology, Ionosphere and Climate

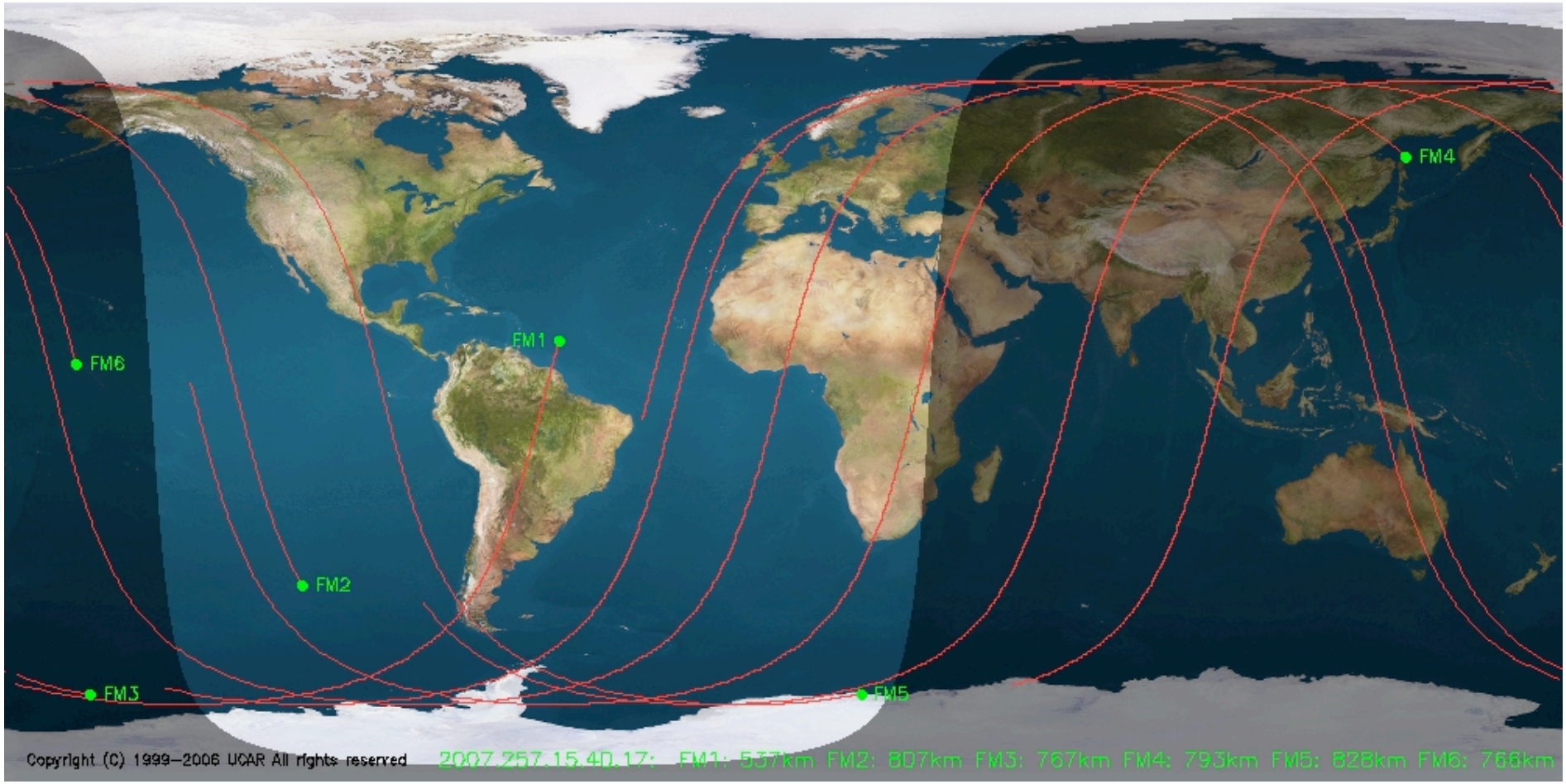
## Mission Status Successes and Challenges

Christian Rocken, Sergey Sokolovskiy, Doug Hunt, Bill Schreiner,
Stig Syndergaard, Janet Zeng, Ben Ho, Bill Kuo

OPAC-3 Workshop 18 Sept. 2007

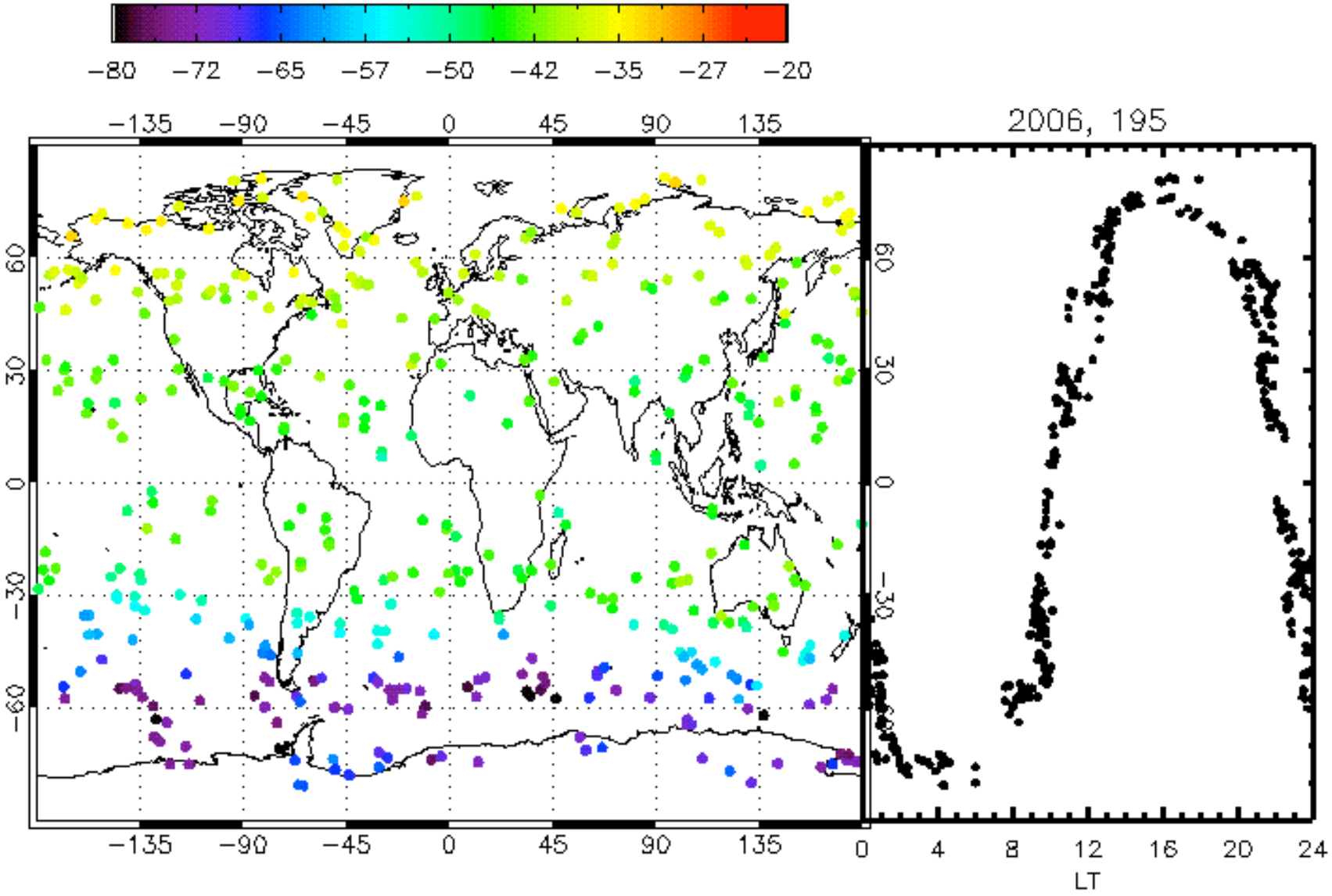
COSMIC

# Current Constellation Sept. 14, 2007



# Evolving COSMIC Constellation

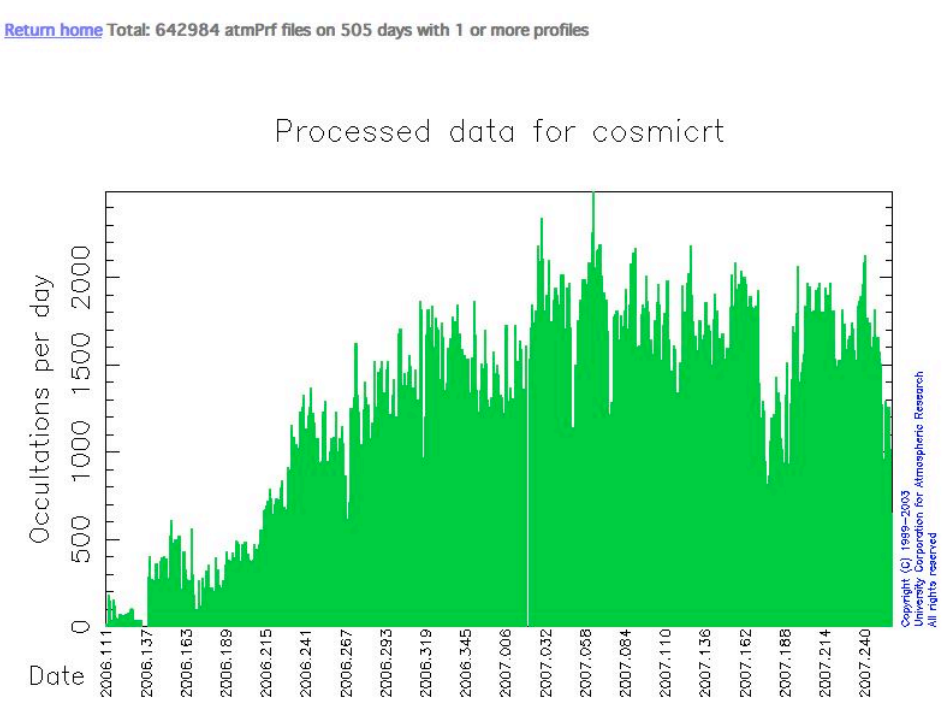
## Temperature [C] at 100 mb (16km)

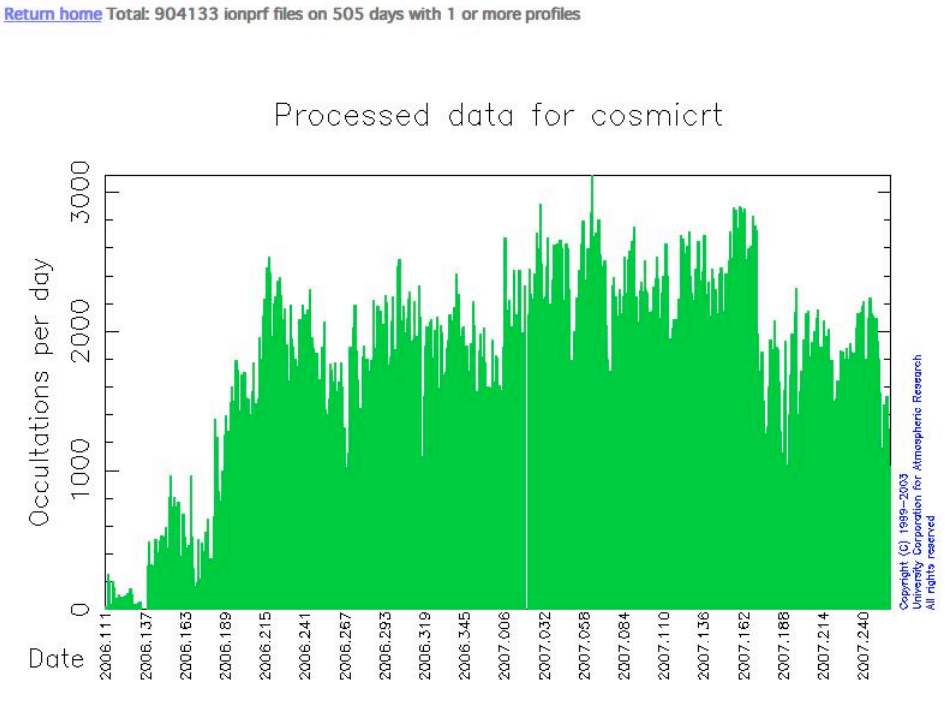


# Number of Daily Profiles

645,000 Neutral Atmosphere

904,000 Ionosphere



# 600 data users have registered

http://www.cosmic.ucar.edu

* Select the 'Sign Up ' link under COSMIC

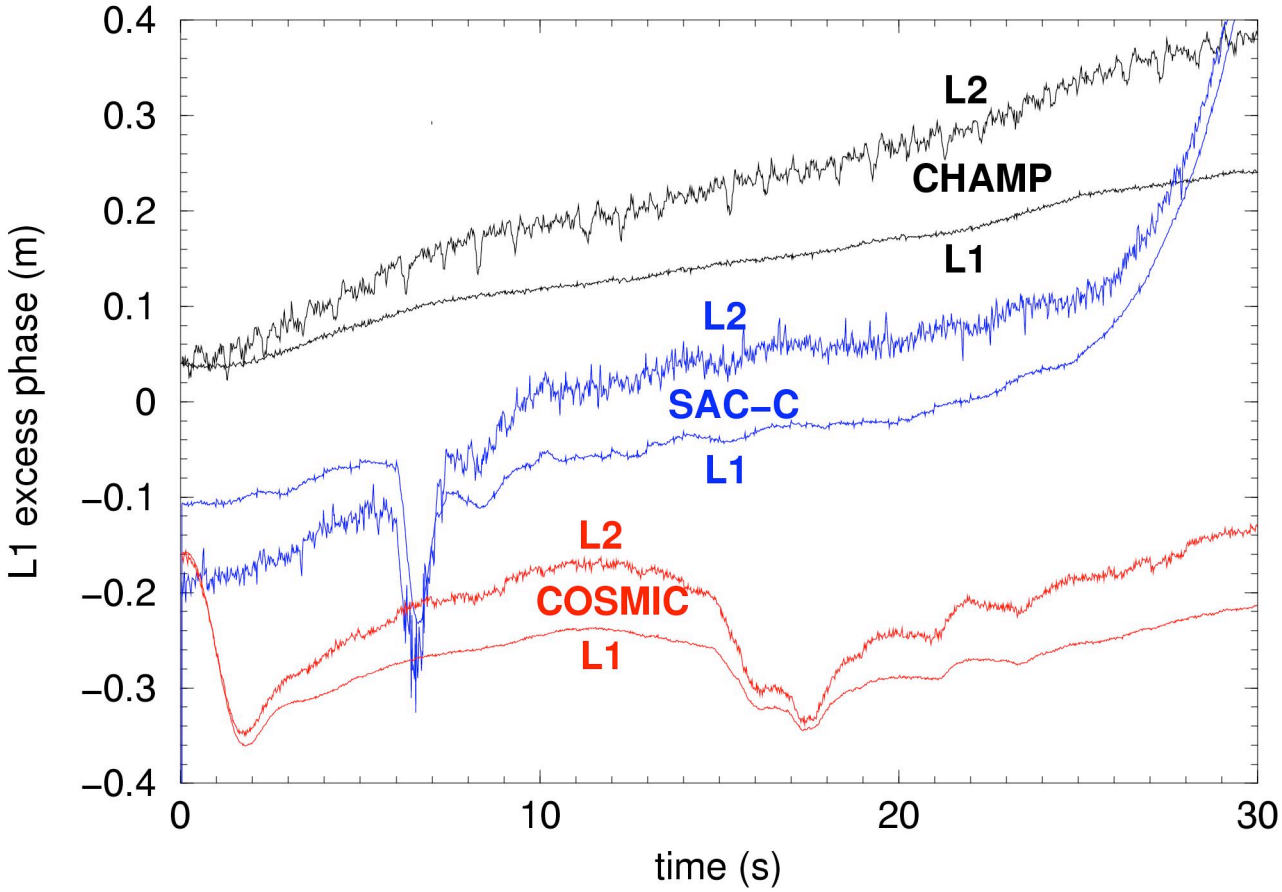
•Accept data use agreement

* Enter information:
Name, Address, email, user_id, Password, planned use of data

• An email will be sent within 2-3 business days to indicate access has been granted.

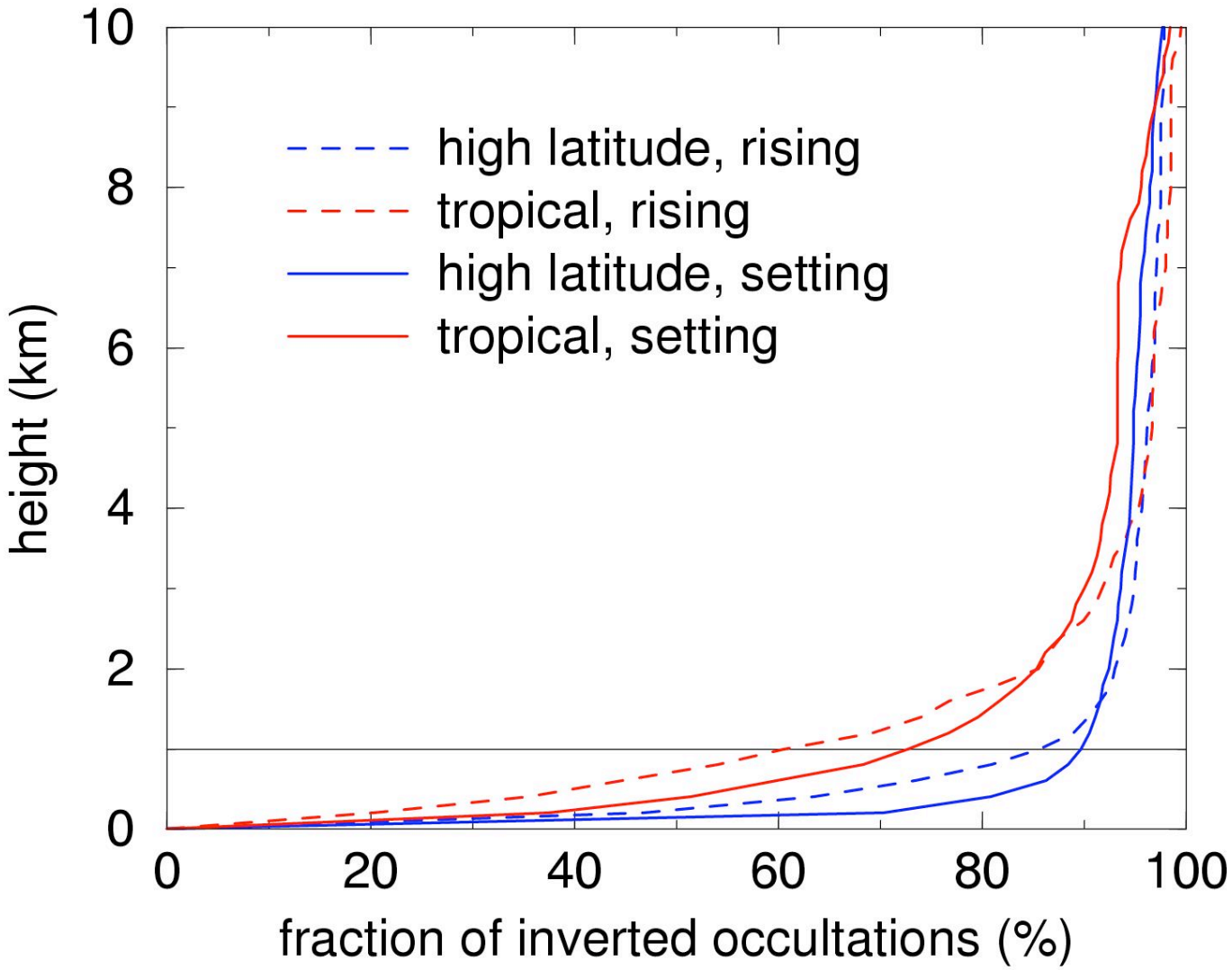
# GPS Data Quality

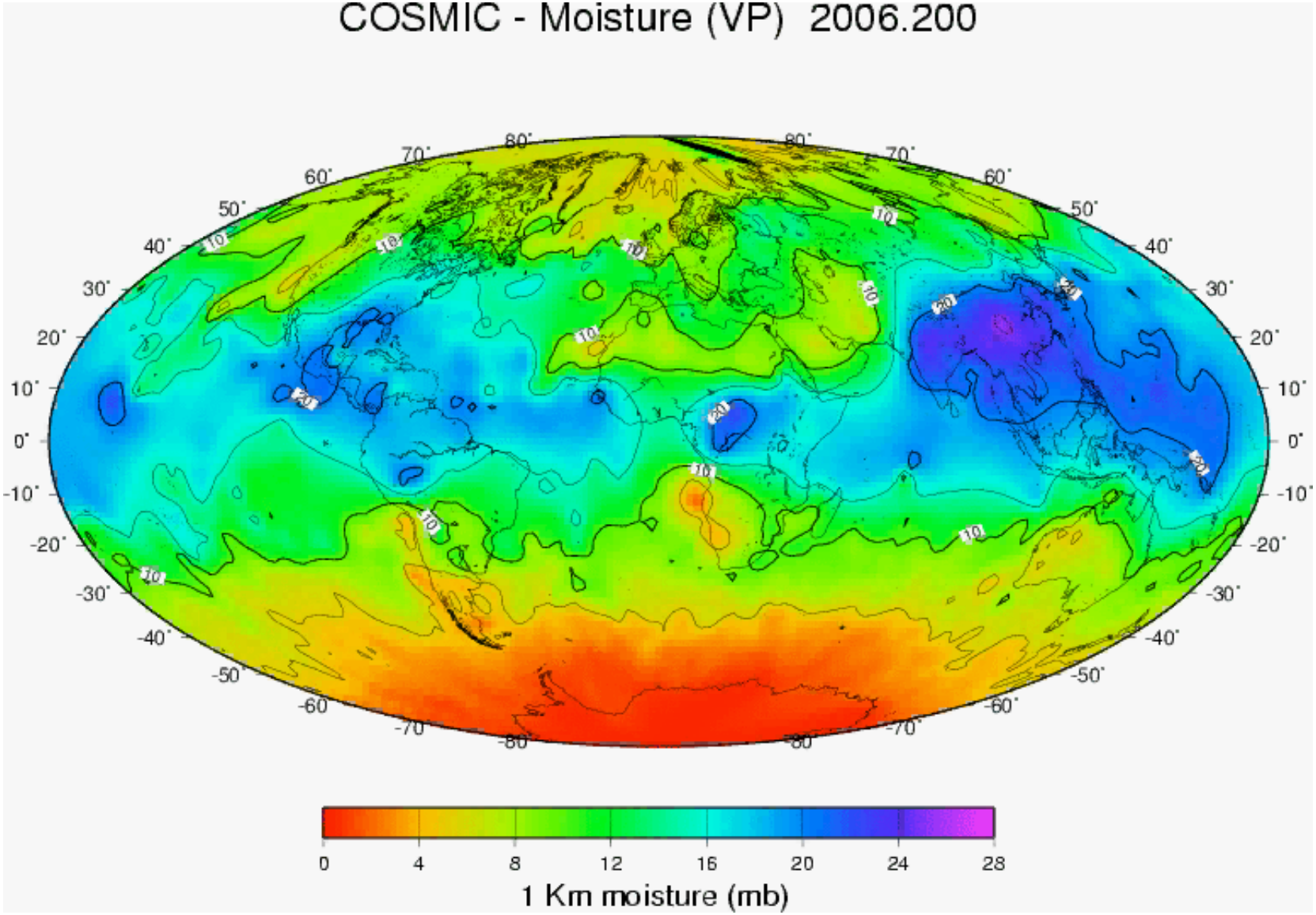
# COSMIC vs. previous missions Phase Noise Comparison



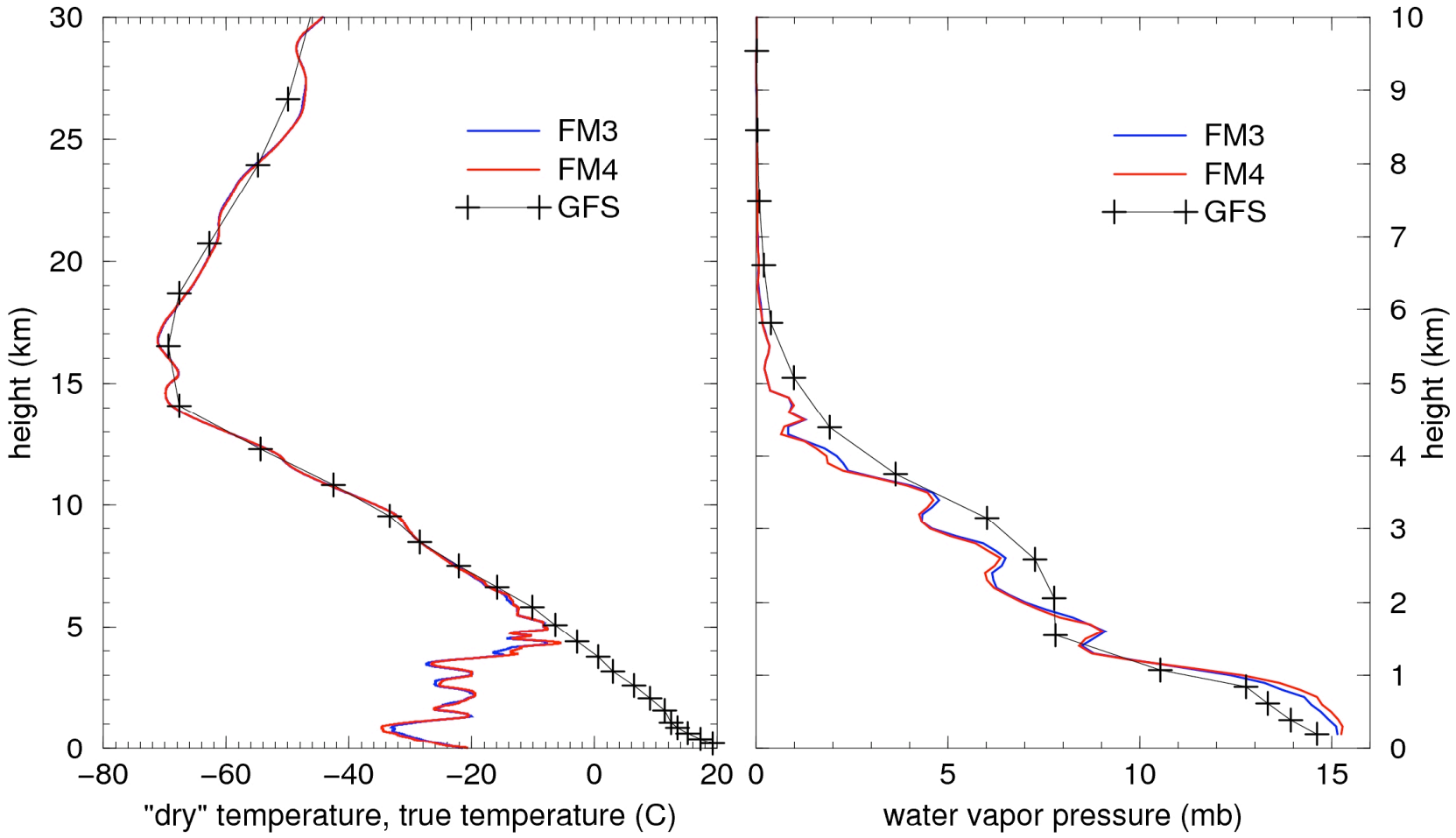

COSMIC L2 phase noise level lower than CHAMP or SAC-C

# Penetration of setting/rising soundings

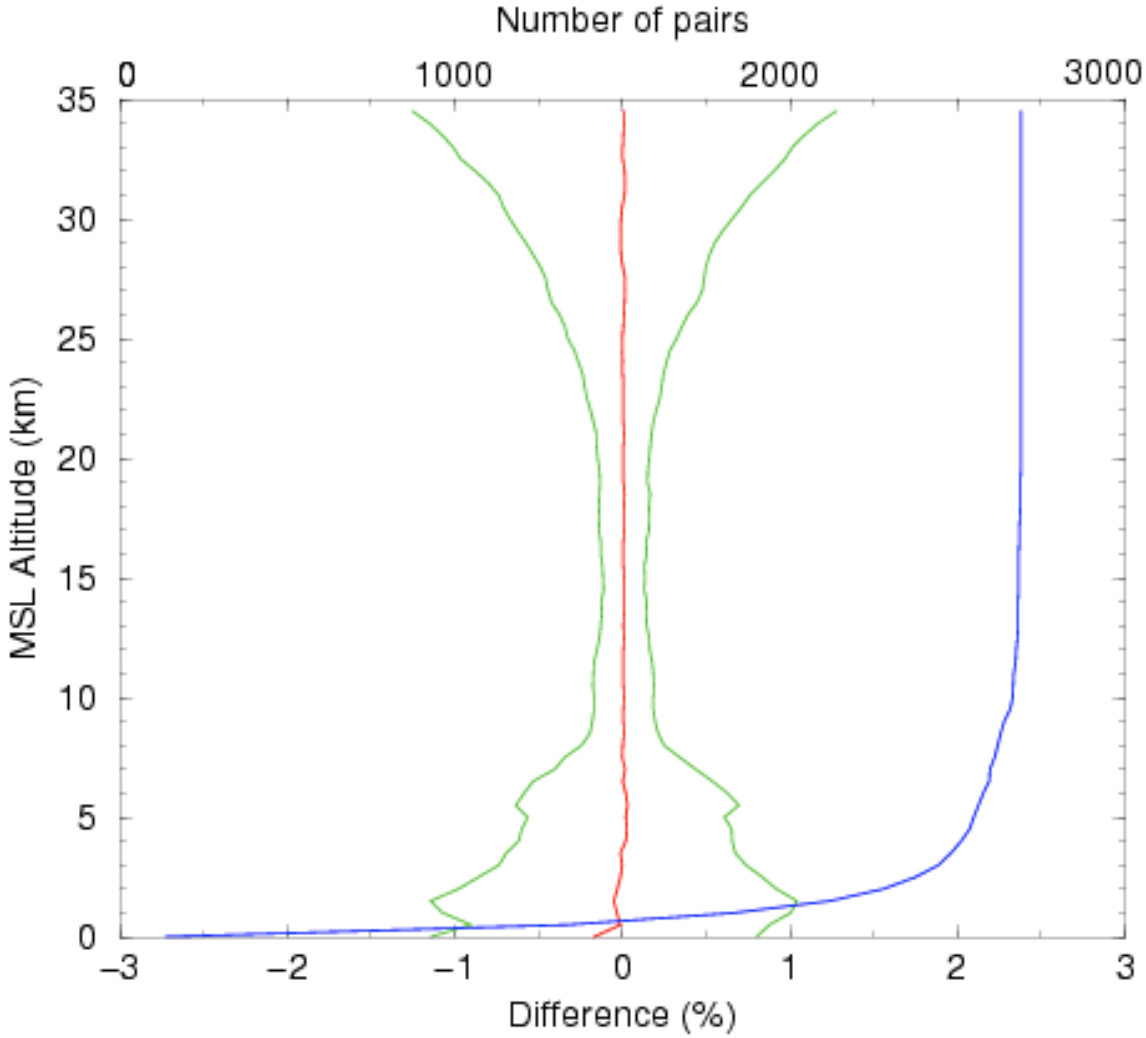



COSMIC - Moisture (VP) 2006.200
0
4
8
12
16
20
24
28
1 Km moisture (mb)

# Comparison of collocated Profiles



# Statistical comparison of FM3-FM4 Soundings separation < 10 km



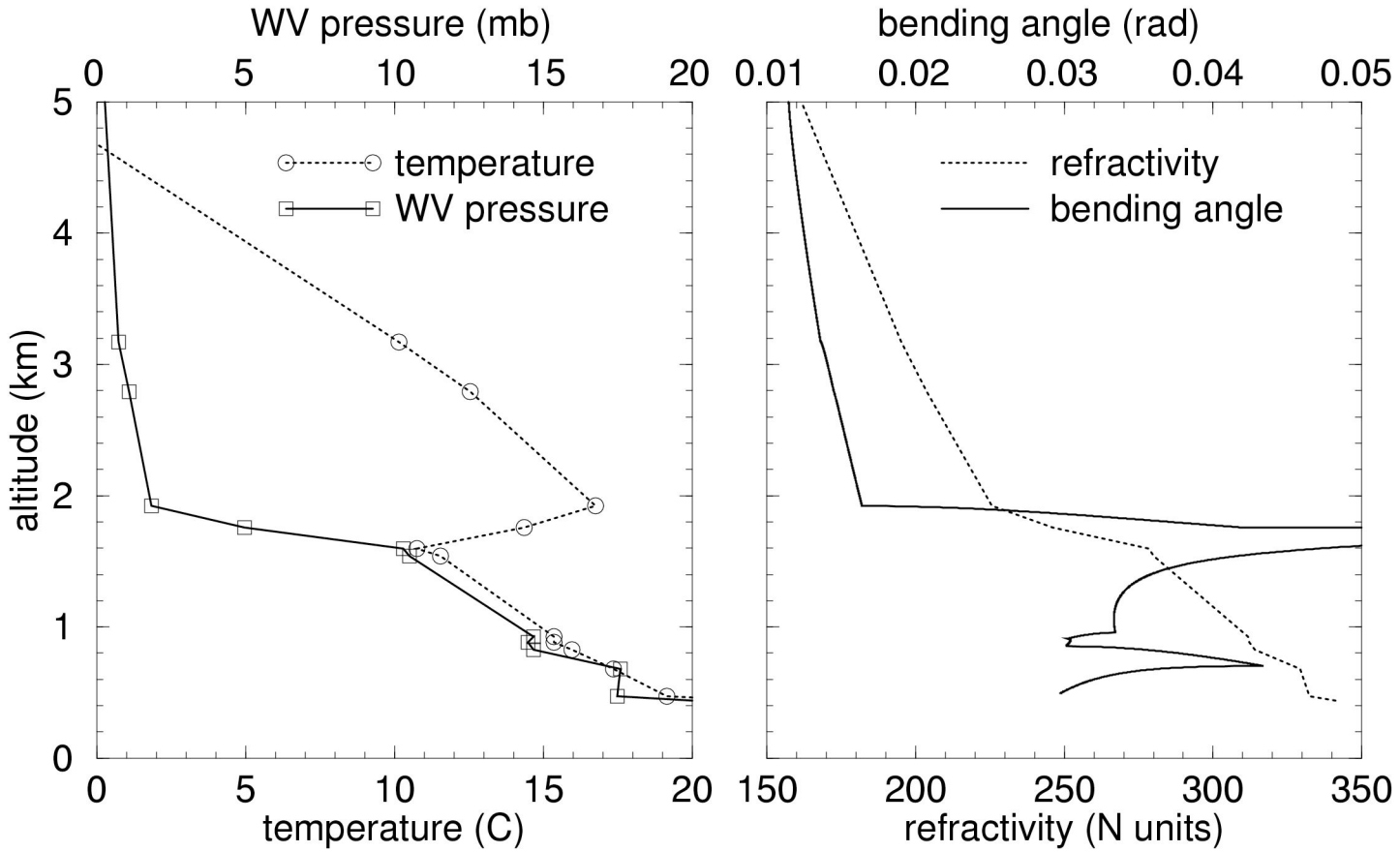

0.2% precision between 10-20 km

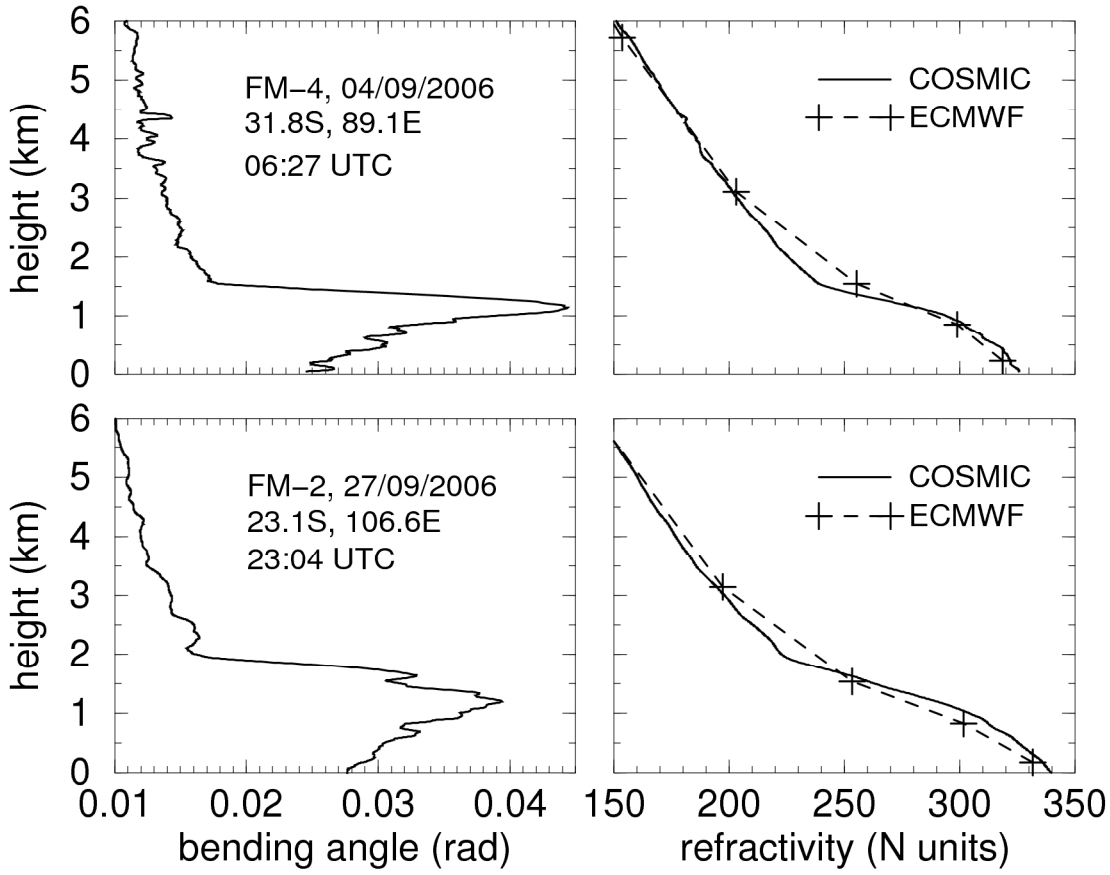
Schreiner et al. 2007

COSMIC

# Neutral Atmosphere Results

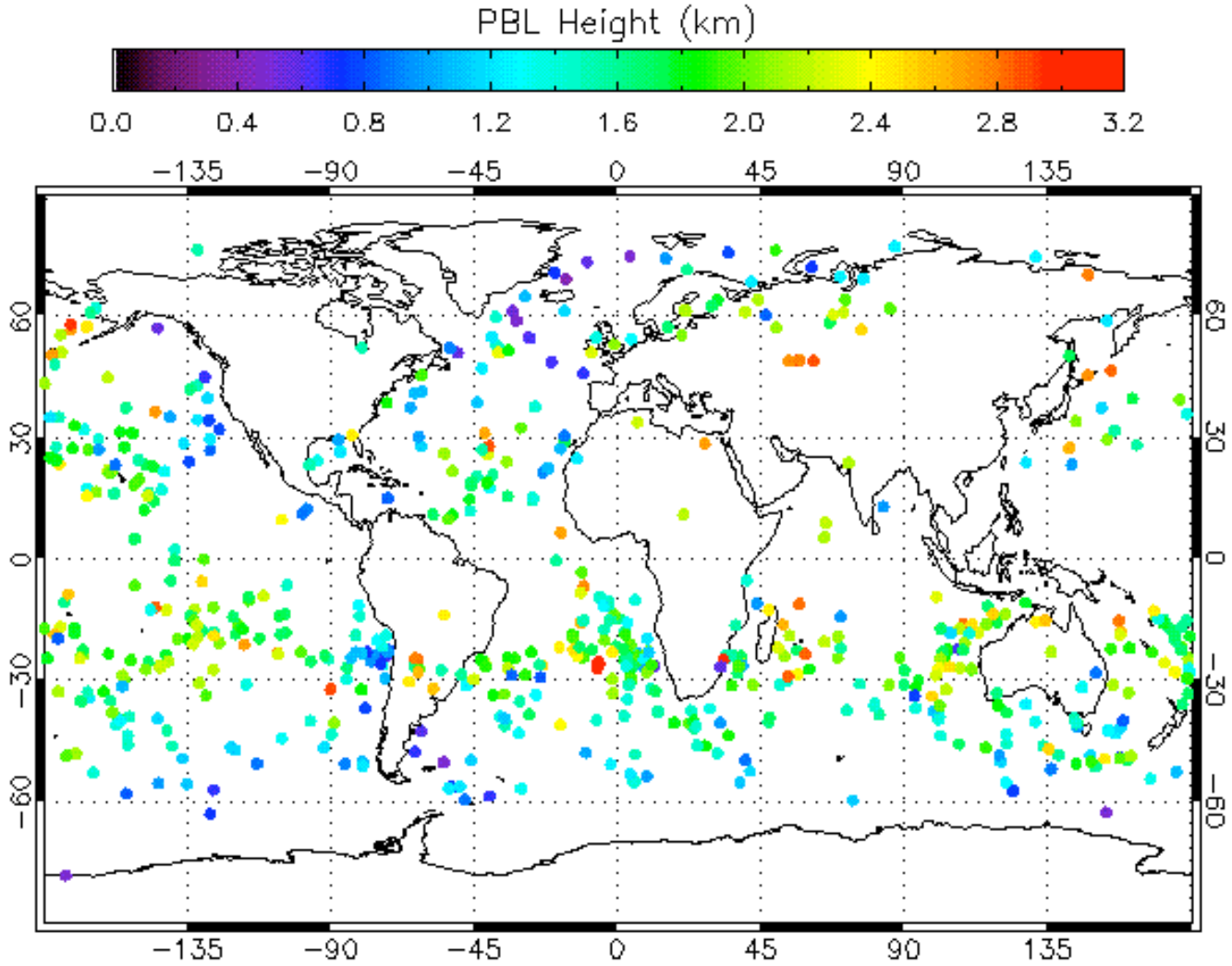
# Detecting the Atmospheric Boundary layer with RO




FM–4, 04/09/2006
31.8S, 89.1E
06:27 UTC
COSMIC
ECMWF
FM–2, 27/09/2006
23.1S, 106.6E
23:04 UTC
COSMIC
ECMWF
height (km)
height (km)
0
1
2
3
4
5
6
0.01
0.02
0.03
0.04
bending angle (rad)
150
200
250
300
350
refractivity (N units)

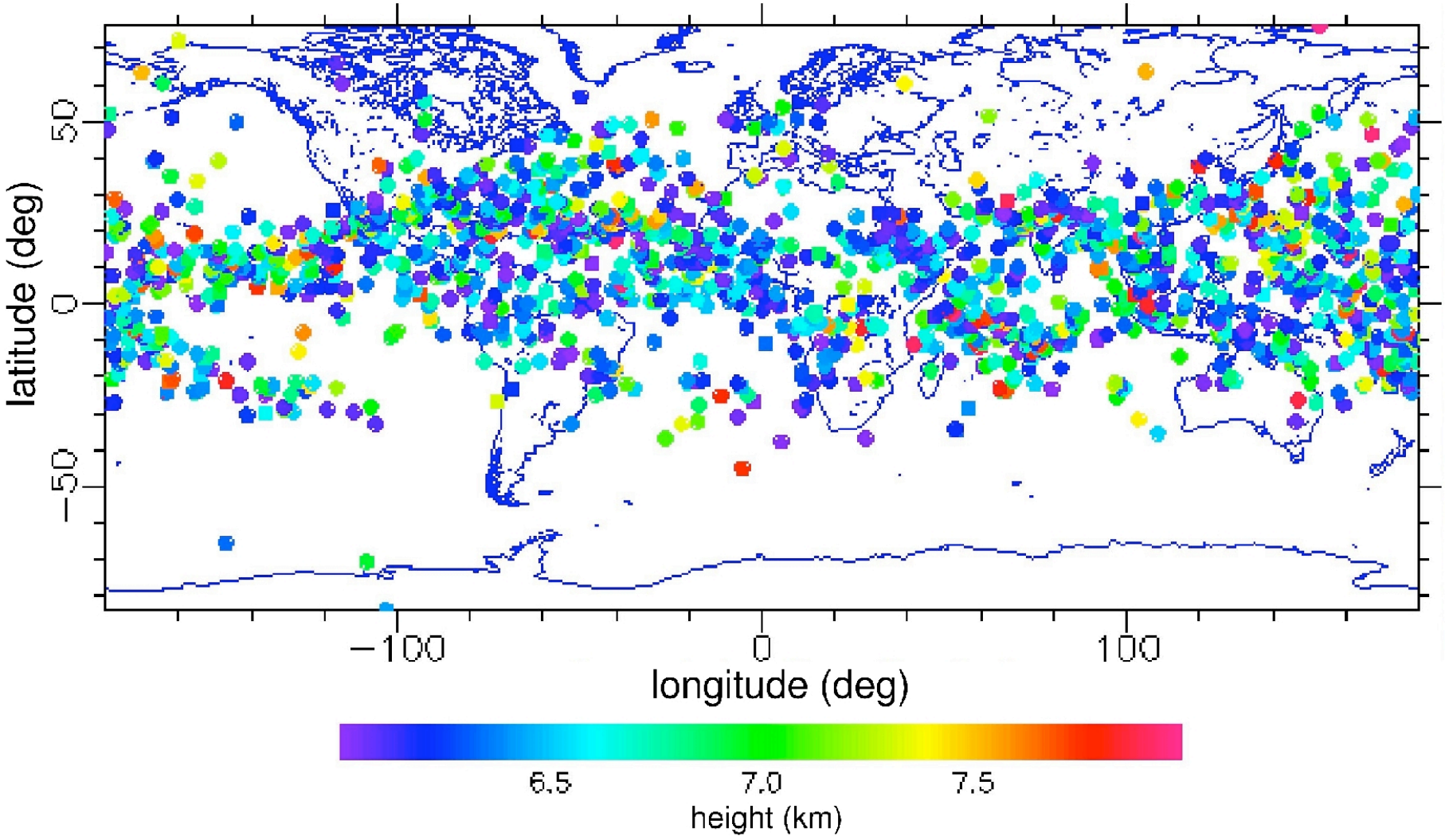
# ABL Height Observations During COSMIC Year 1

(bending angle gradient > 1e-2 rad/dH, height < 3 km)




2006.196

# Detection of Convection / Turbulence




September 2006

# Weather Analysis and Prediction

# Leading Weather Center Newsletters

JCSDA Quarterly

No. 18, March 2007

Joint Center for Satellite Data Assimilation • 5200 Auth Road • Camp Springs • MD • 20746 Editor: George Ohring
NOAA.....NASA.....US Navy.....US Air Force Web-site: www.jcsda.noaa.gov

## News in This Quarter

### Science Update

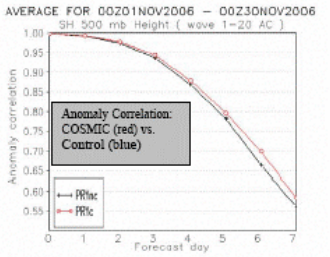
### Cosmic Data to be Assimilated Operationally at NOAA

After successful testing at the JCSDA, Global Positioning System (GPS) radio occultation (RO) soundings from the COSMIC mission will go into operational use with the implementation of the Gridpoint Statistical Interpolation (GSI)/Global Forecast System (GFS) system at NOAA/NCEP on May 1st 2007.

In preparation for the assimilation of COSMIC data, the JCSDA developed, tested and incorporated the necessary components to assimilate GPS RO profiles. These components include forward operators and associated tangent linear and adjoint models, quality control algorithms, error characterization models, data handling, decoding procedures, and verification and impact evaluation techniques.

Impact tests indicate that the assimilation of GPS RO observations improves the fit to rawinsonde observations by reducing the mean and root-mean-square differences in the upper troposphere and stratosphere. The anomaly correlation (AC) scores for both the Northern and Southern Hemispheres also improved with the use of COSMIC data for the test period, November 2006. In general, the improvement in AC scores will be more or less significant depending on the meteorological situation and the model performance for the period under study. The accompanying figure shows the 500 hPa geopotential height AC as a function of the forecast range in the Southern Hemisphere for November 1st to 30th 2006. The assimilation of COSMIC data (PRYc, in red) improves the AC scores when compared to the control run (PRYnc, in black). Both PRYnc and PRYc experiments assimilate all the observations currently being used in operations. Therefore the difference between the runs is due to the impact of assimilating COSMIC data.

COSMIC, the Constellation Observing System for Meteorology, Ionosphere and Climate, a joint Taiwan-U.S. project, was launched in April 2006. The scientific foundation for COSMIC is the radio occultation (limb sounding) technique. The six-satellite constellation provides high vertical resolution information on atmospheric temperature/humidity at about a thousand locations each day.
(Lidia Cucurull, JCSDA/NCEP)



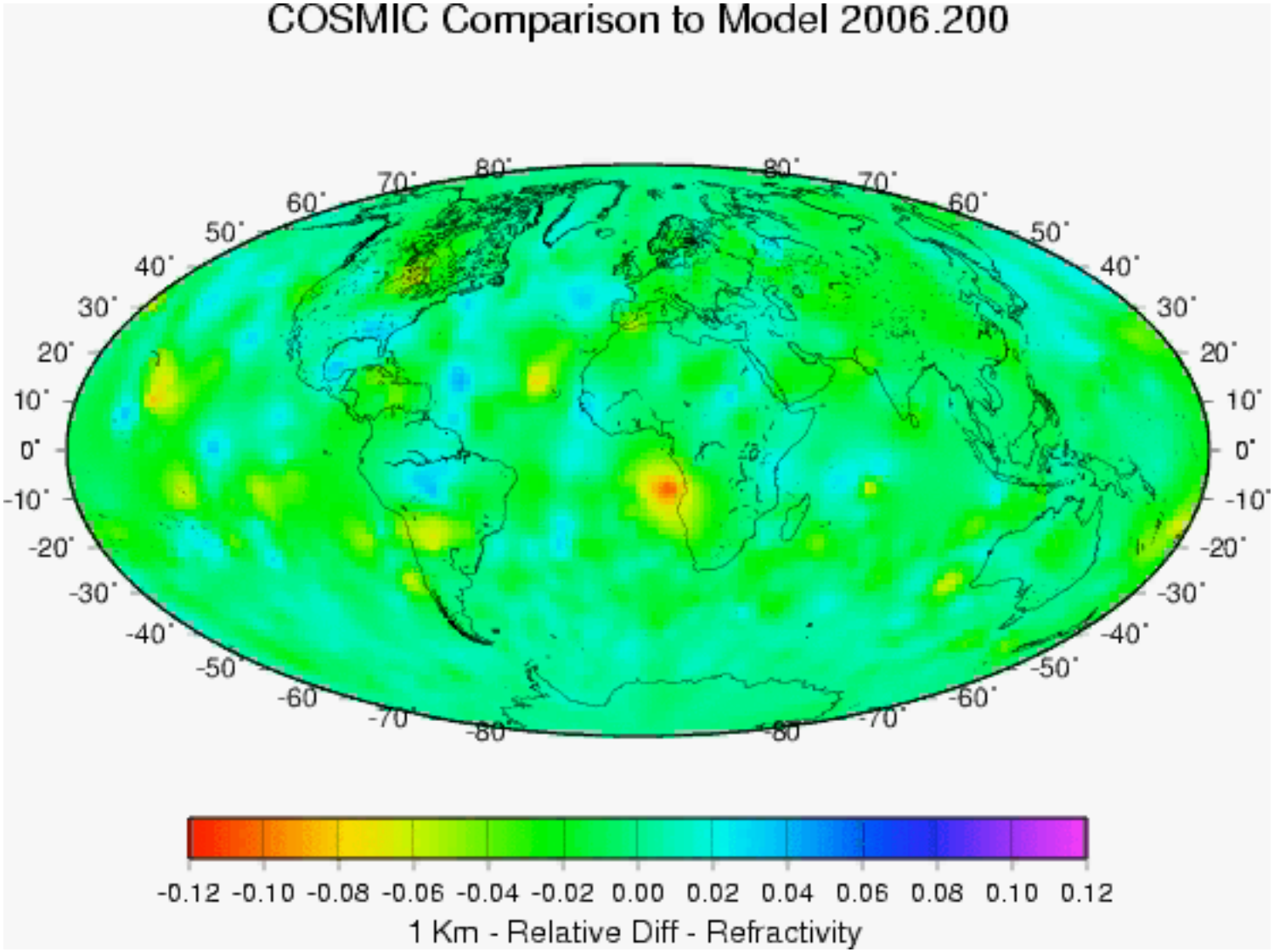

Anomaly correlation scores (Red: With COSMIC; Blue: without COSMIC) for the 500 mb height field in the Southern Hemisphere as a function of the forecast length.

### Assimilation of MLS Ozone Observations Improves Antarctic Ozone Hole Depiction

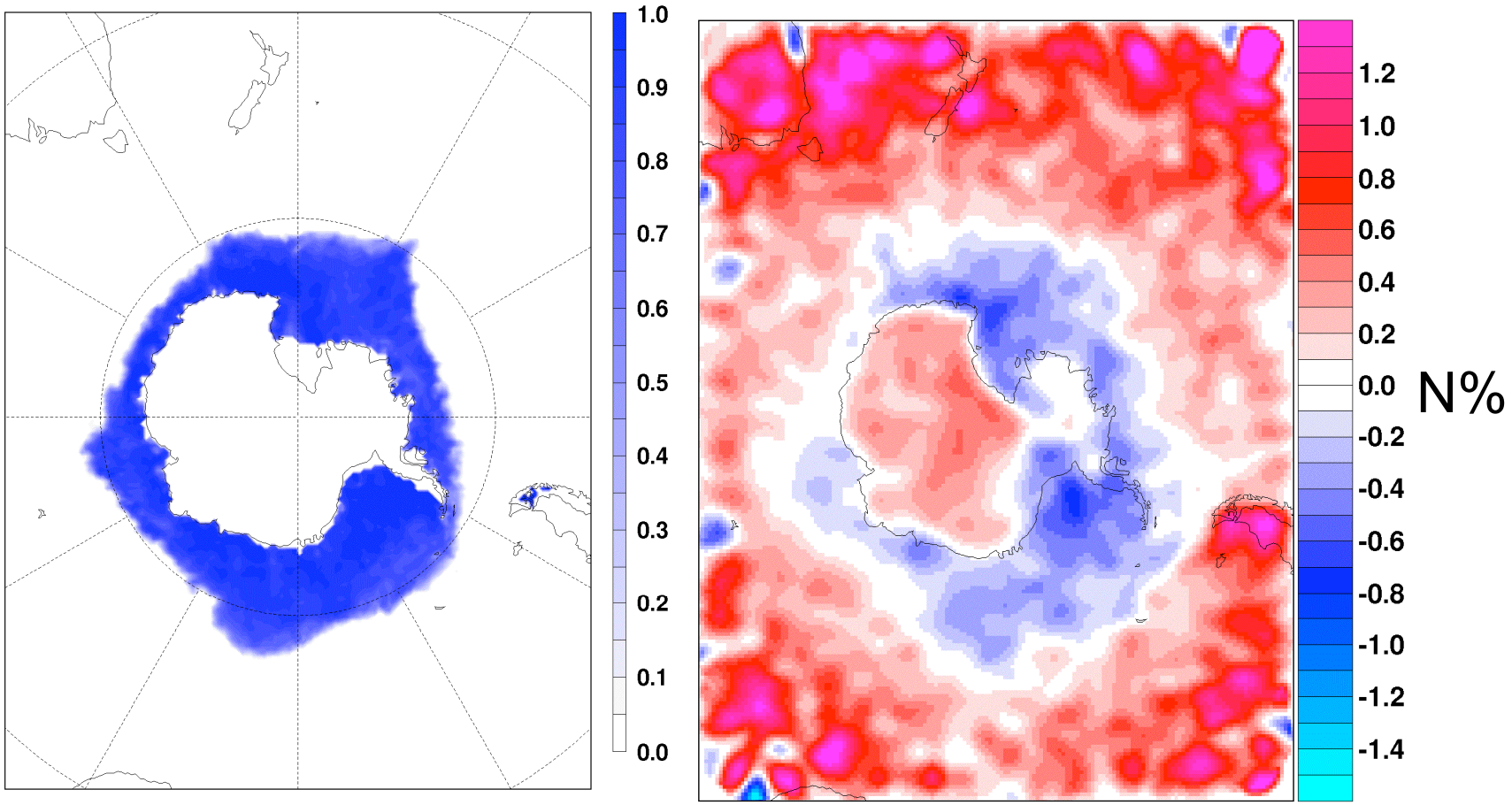
NASA's EOS Aura satellite provides comprehensive atmospheric chemical composition measurements. For example, the Aura Microwave Limb Sounder (MLS) instrument captures ozone profiles with the vertical resolution of about 3 km in the stratosphere. These data can be used to constrain stratospheric ozone in atmospheric models, potentially improve assimilation of infrared radiances, and provide a better field for radiative computations. In combination with Aura's Ozone Monitoring Instrument (OMI) total column ozone measurements, the MLS ozone data can also be used to estimate tropospheric ozone, which is an important component of the air quality.

The Goddard Earth Observing System-5 (GEOS-5) Data Assimilation System at NASA Goddard's Global Modeling and Assimilation Office (GMAO) uses the Gridpoint Statistical Interpolation (GSI) as its analysis component. Recently, scientists at the GMAO modified the GSI code to add assimilation of ozone profiles, such as those produced by ozone retrievals from the Aura MLS.

The results from a recent one-month assimilation of MLS ozone data are very encouraging. The figure below compares zonal mean ozone partial pressure (mPa) at the end of the one-


COSMIC Comparison to Model 2006.200
80˚
70˚
60˚
50˚
40˚
30˚
20˚
10˚
0˚
-10˚
-20˚
-30˚
-40˚
-50˚
-60˚
-70˚
-80˚
-0.12 -0.10 -0.08 -0.06 -0.04 -0.02 0.00 0.02 0.04 0.06 0.08 0.10 0.12
1 Km - Relative Diff - Refractivity

# COSMIC Data Reveal Antarctic Model Error

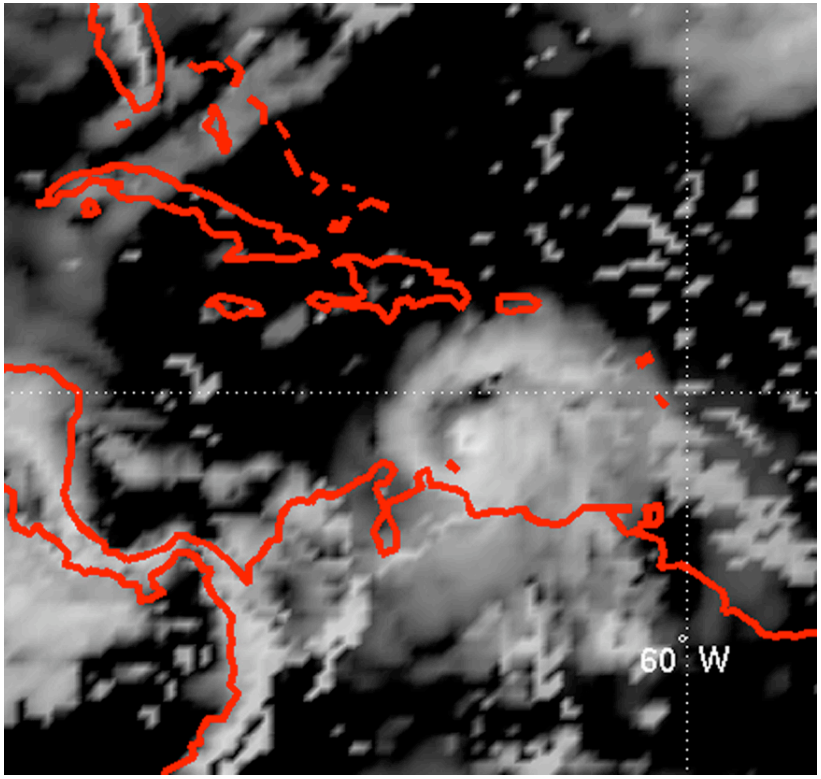



Sea Ice

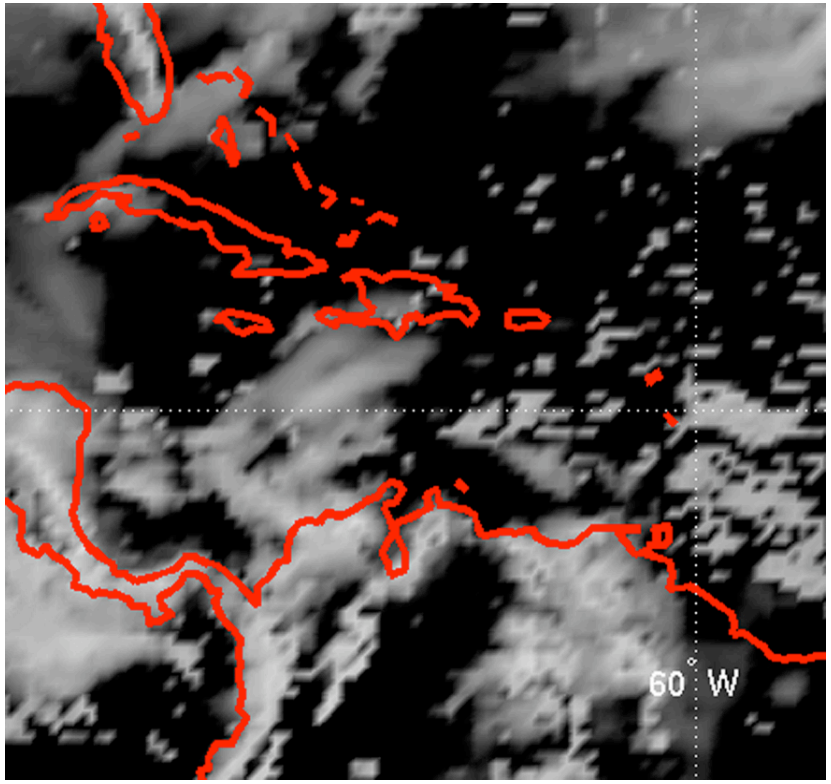
WRF model error

# Using COSMIC for Hurricane Ernesto Prediction

With COSMIC



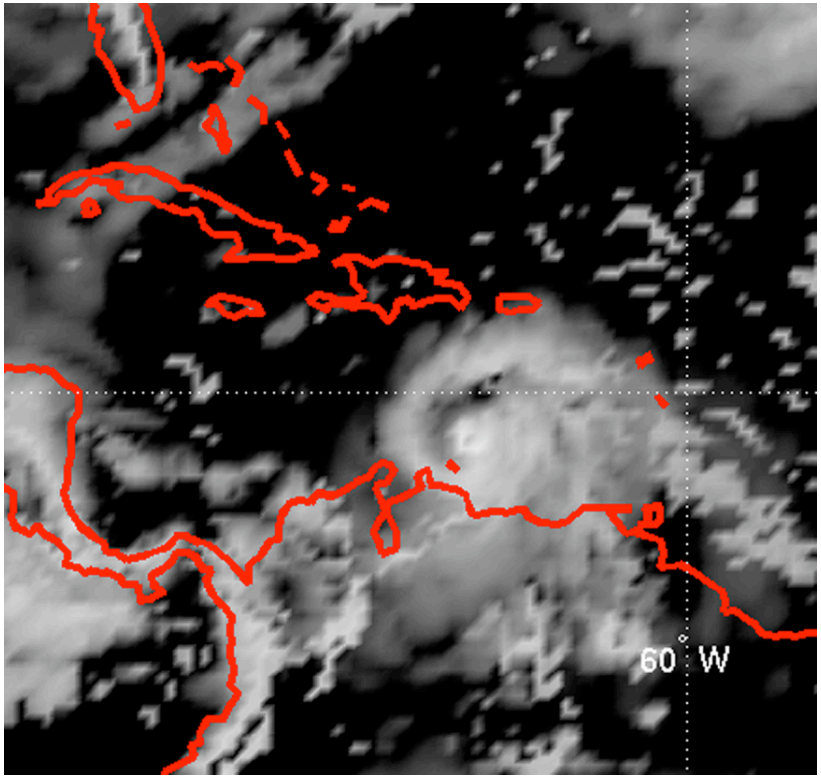

Without COSMIC



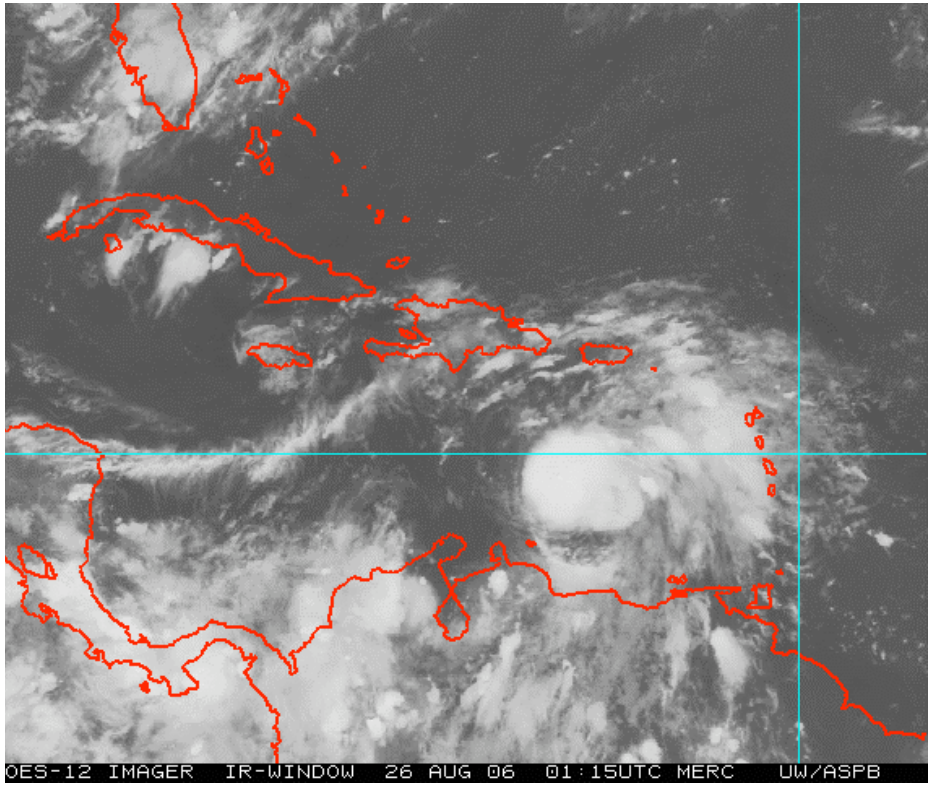

Results from Hui Liu, NCAR

# Using COSMIC for Hurricane Ernesto Prediction

With COSMIC




GOES Image



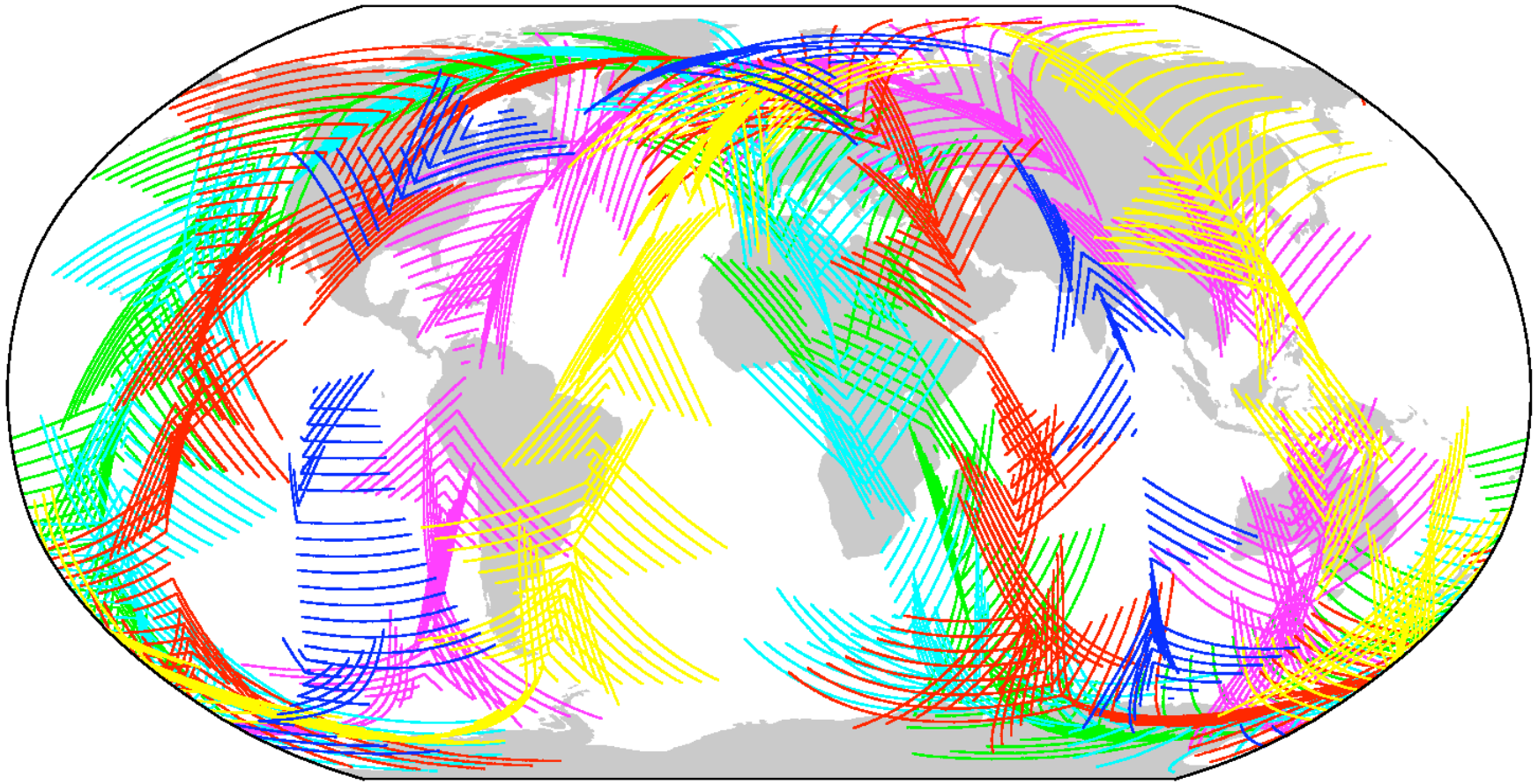

GOES Image from Tim Schmitt, SSEC

COSMIC

# Ionosphere and Space Weather

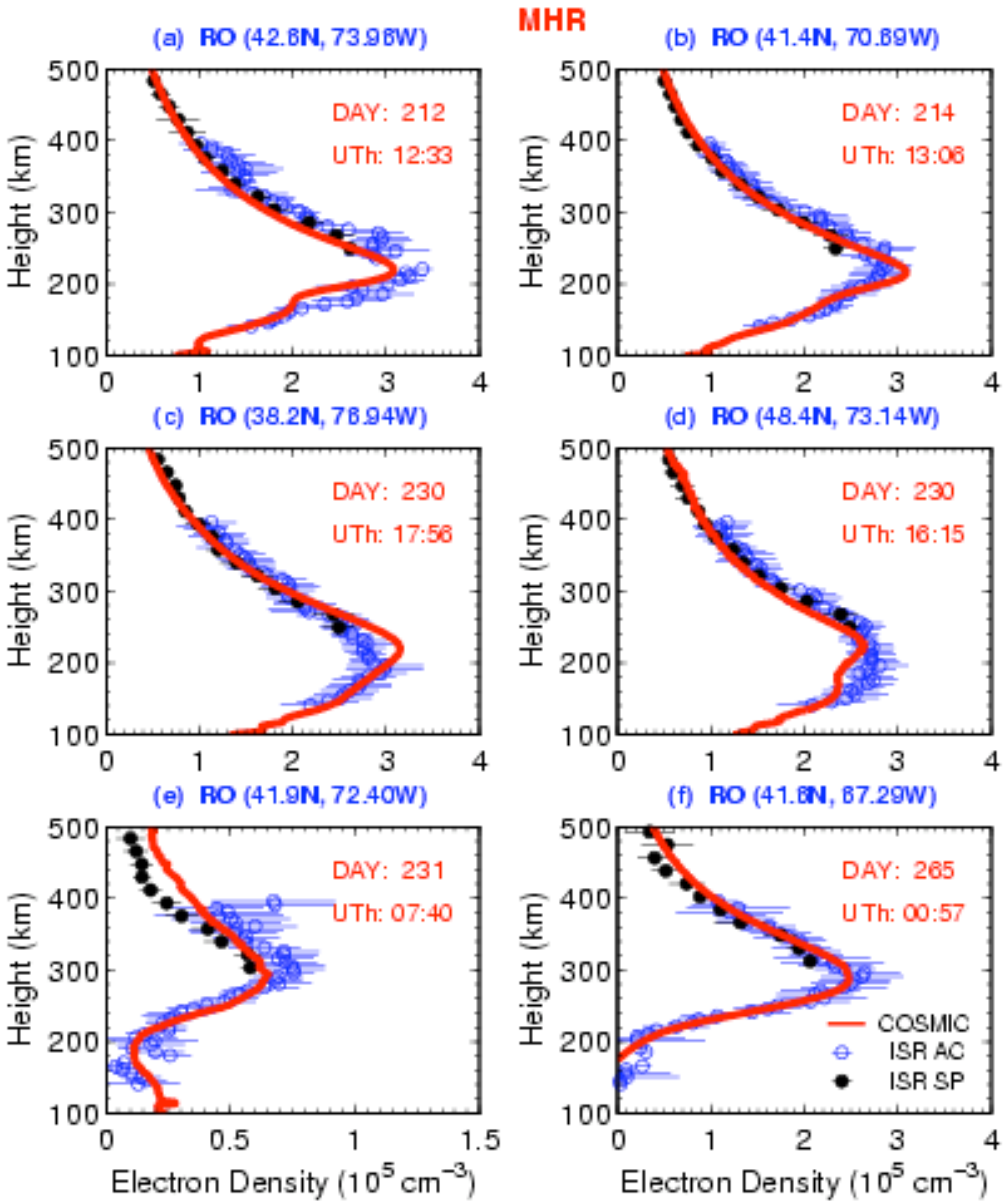
# GPS - COSMIC Links in the Ionosphere 100-minutes

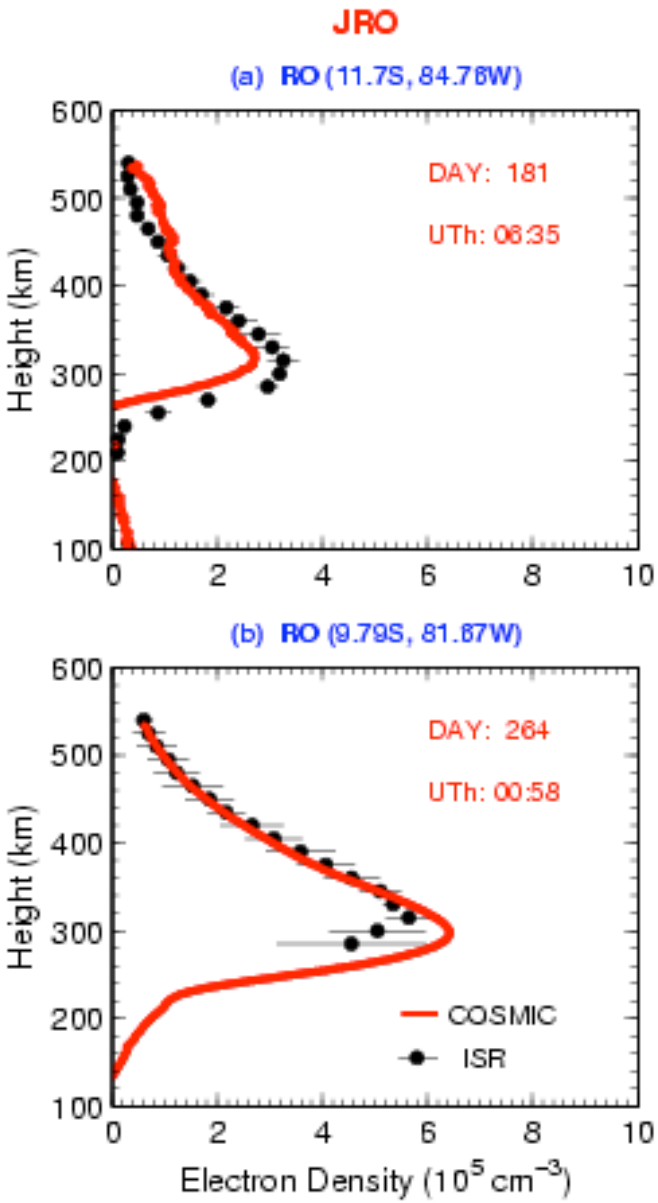
(June 2007 Constellation)



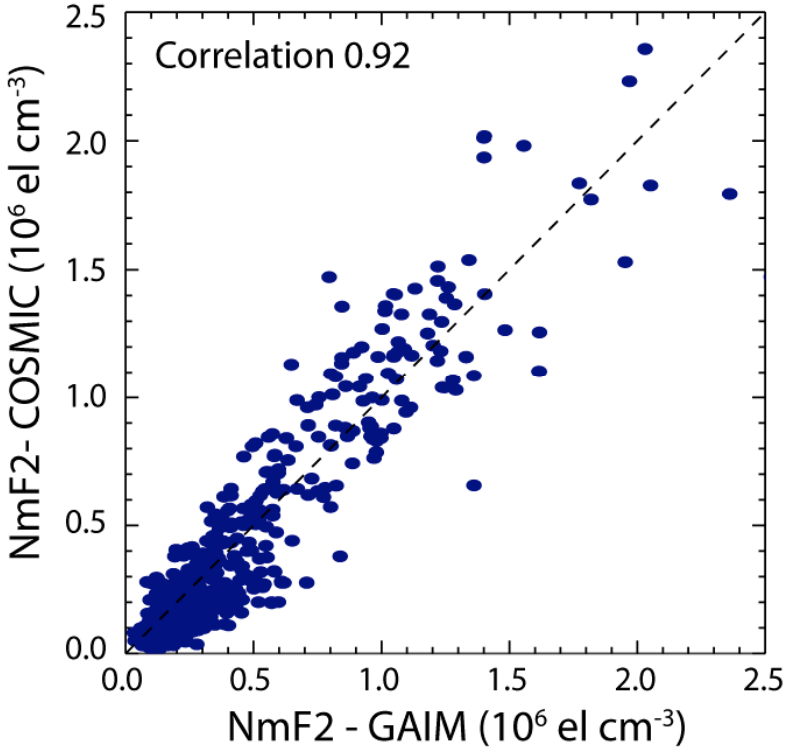
# Comparisons with ISR data

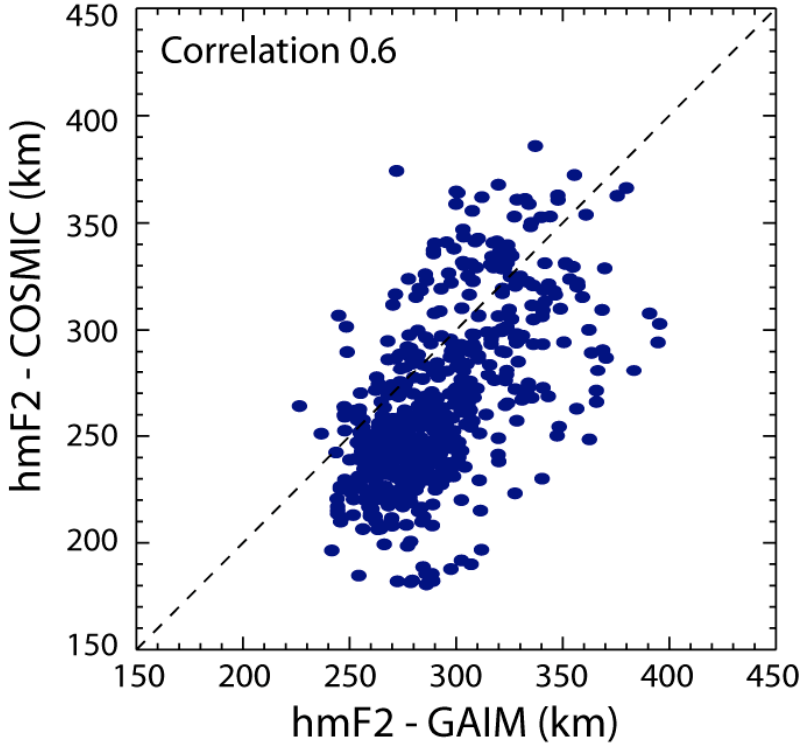
[Lei et al., submitted to JGR 2007]



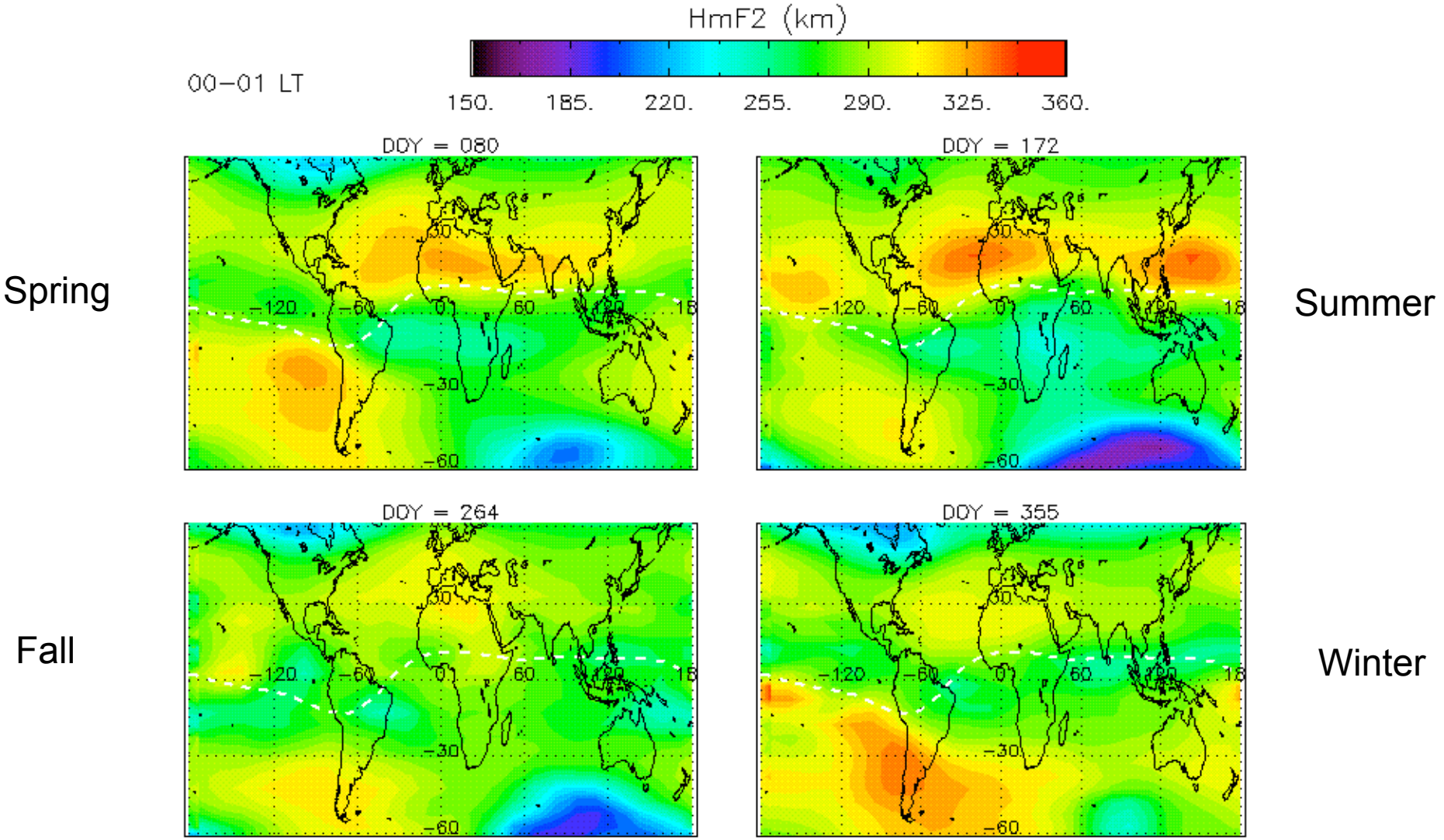



# Statistical Comparison COSMIC - GAIM

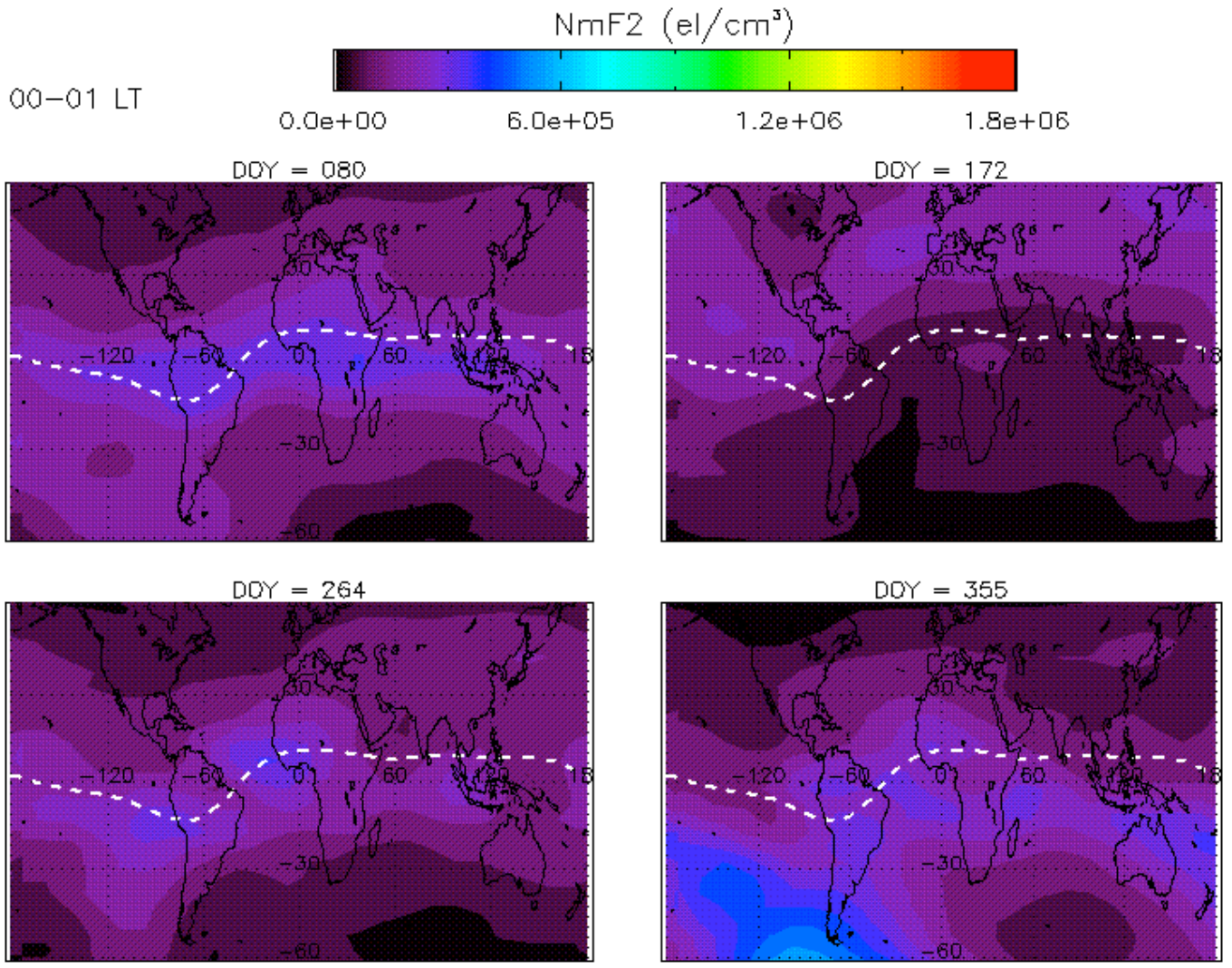


# Global HmF2 As Function of LT



# Global NmF2 As Function of LT



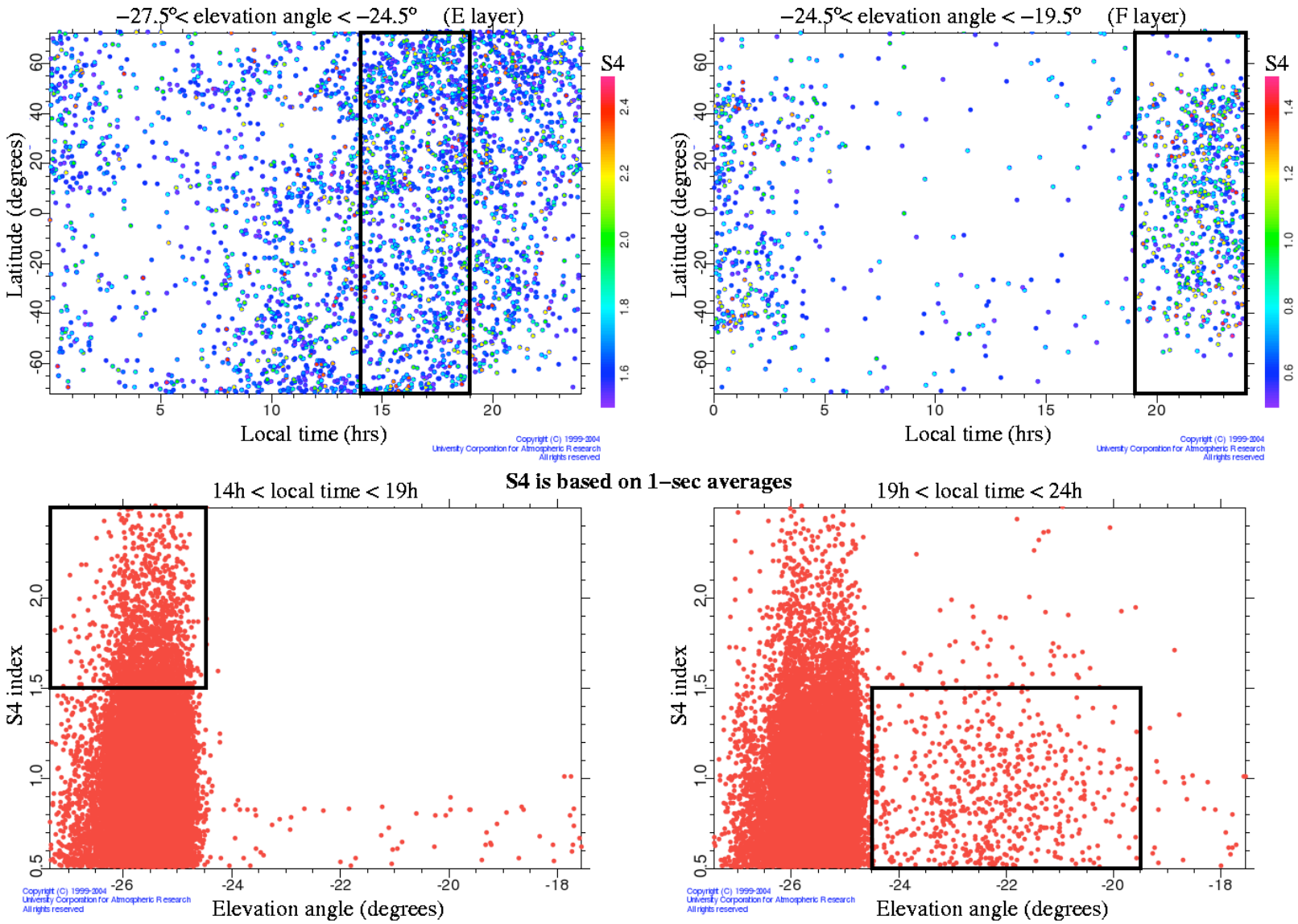

Spring

Summer

Fall

Winter

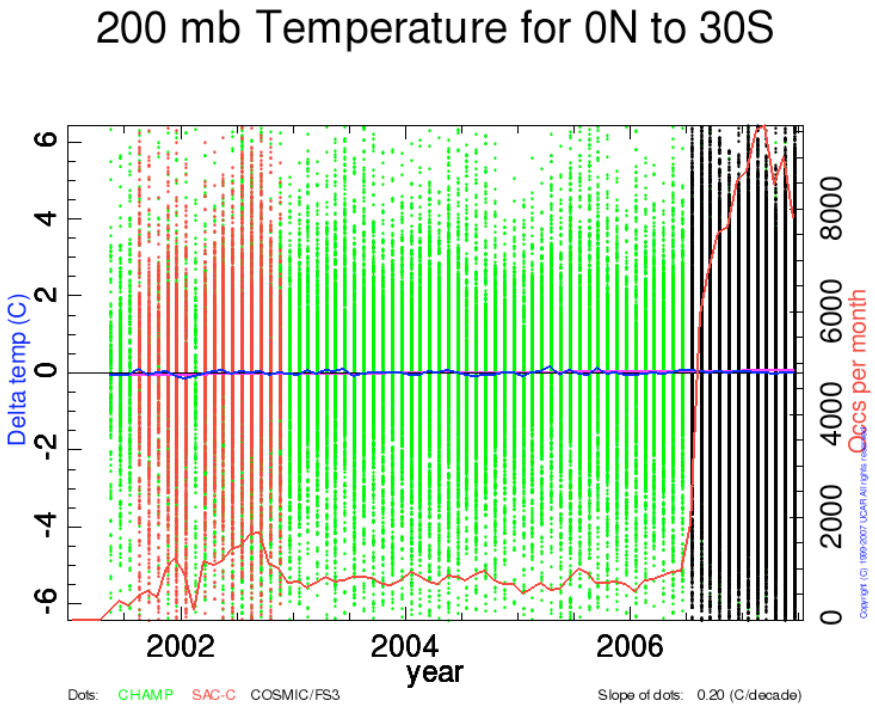
# Amplitude scintillations (S4 index)

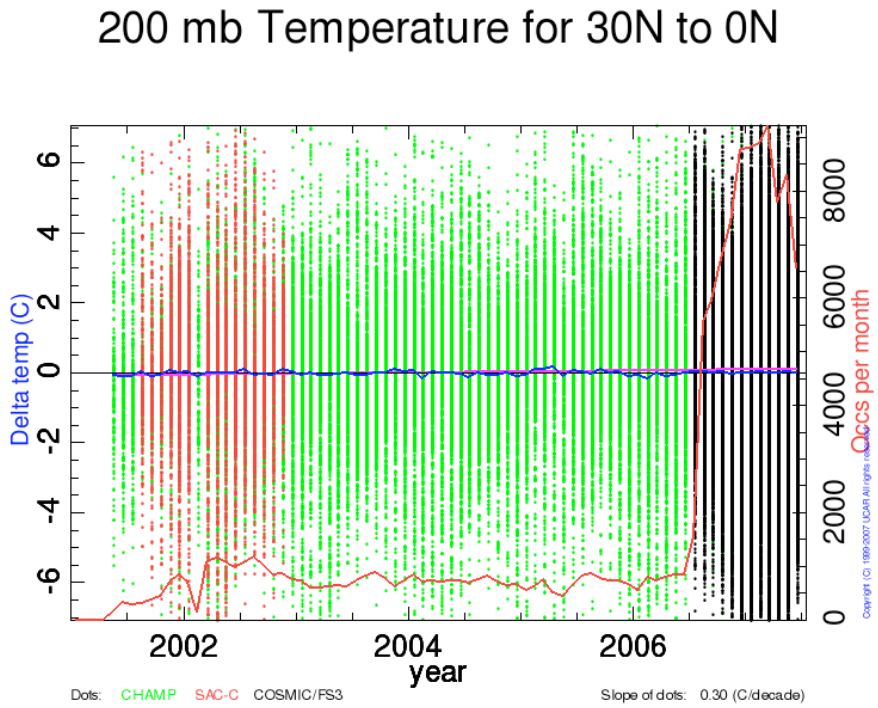



- S4 based on 1-sec averages; allows calculation of S4 based on *n*-sec averages

# Climate

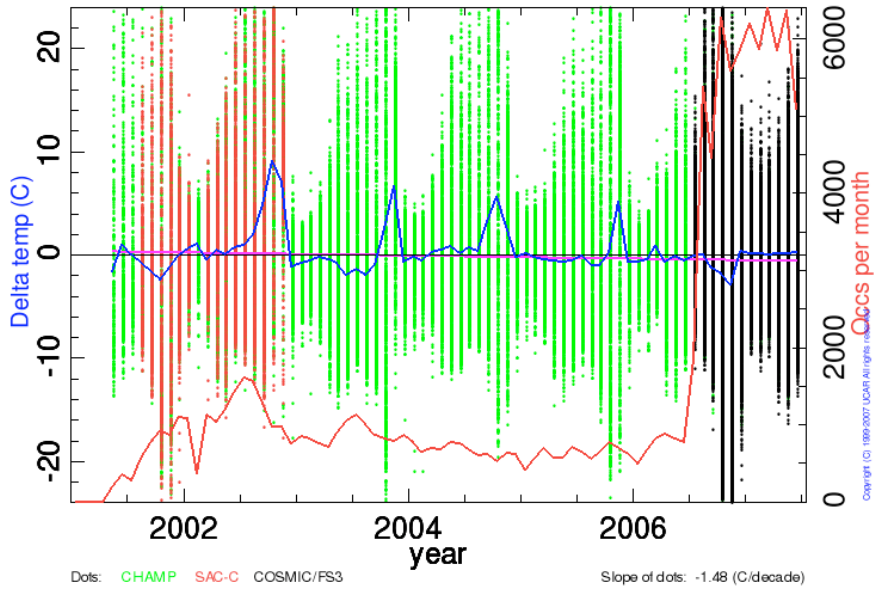
# 6-Year RO Temperature Anomaly Trend
# Tropics, 200 mb (~12 km)



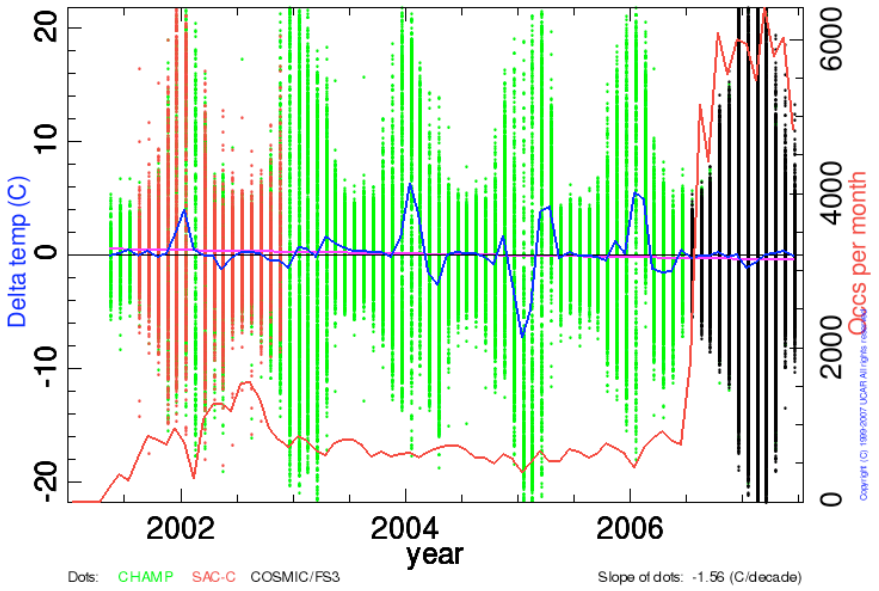



# 6-Year RO Temperature Anomaly Trend
# Polar Stratosphere, 50 mb (~21 km)

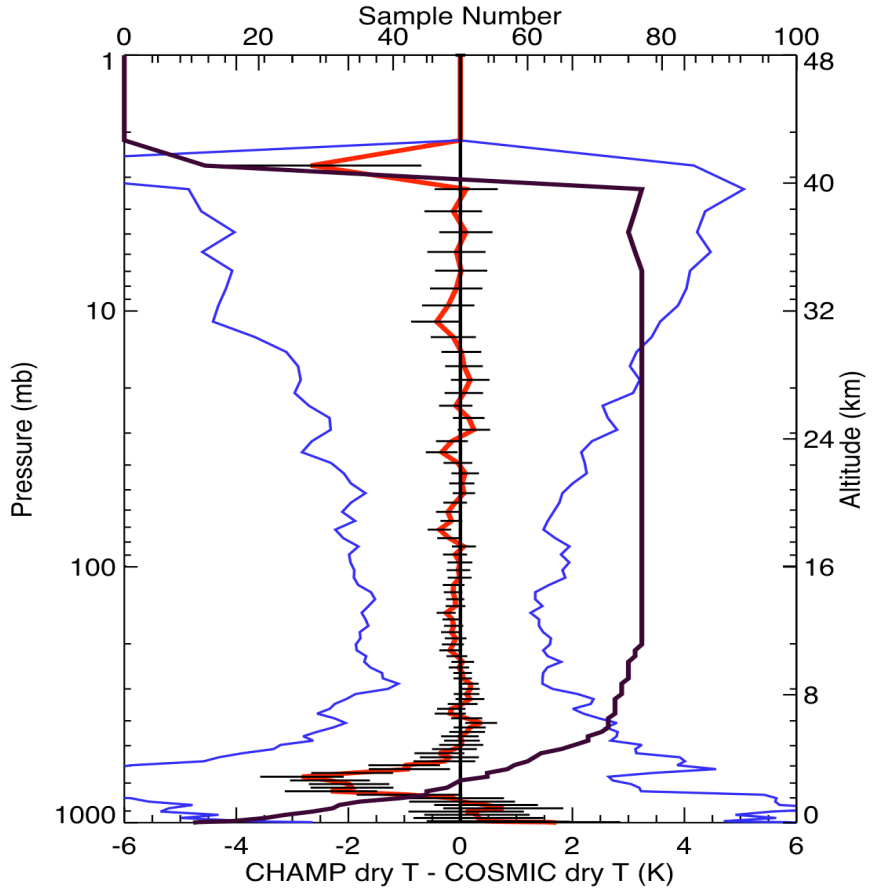
50 mb Temperature for 60S to 90S



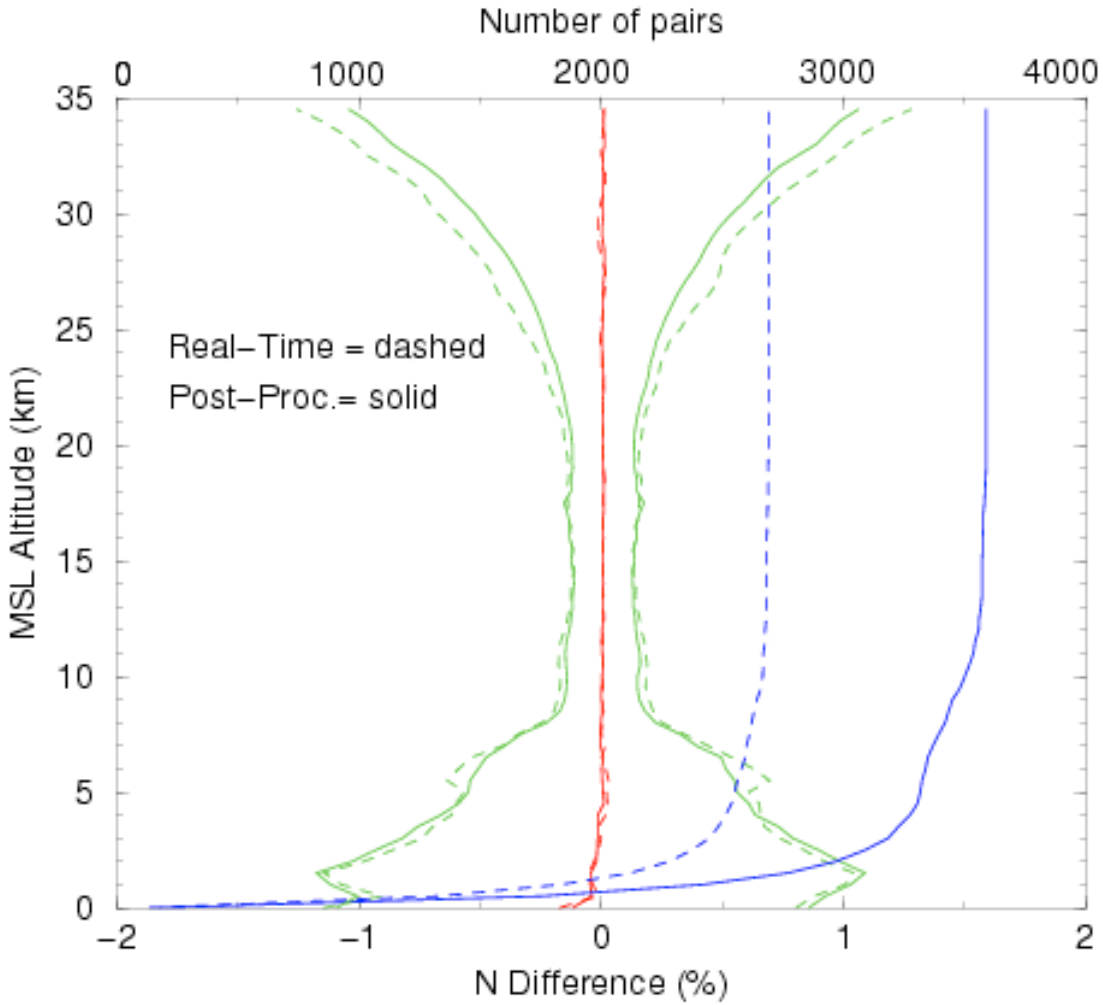

50 mb Temperature for 90N to 60N



# COSMIC - CHAMP Mission Comparison



# Post processing vs. Real-time solution

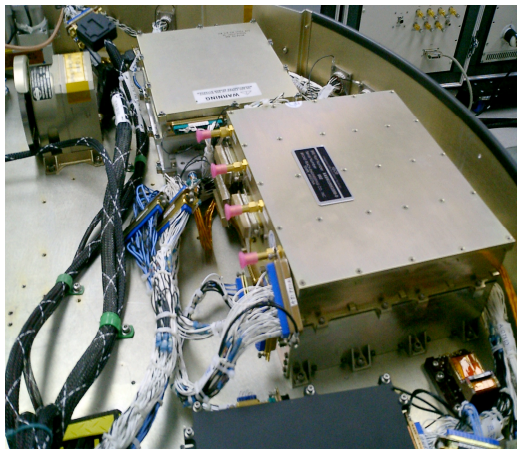


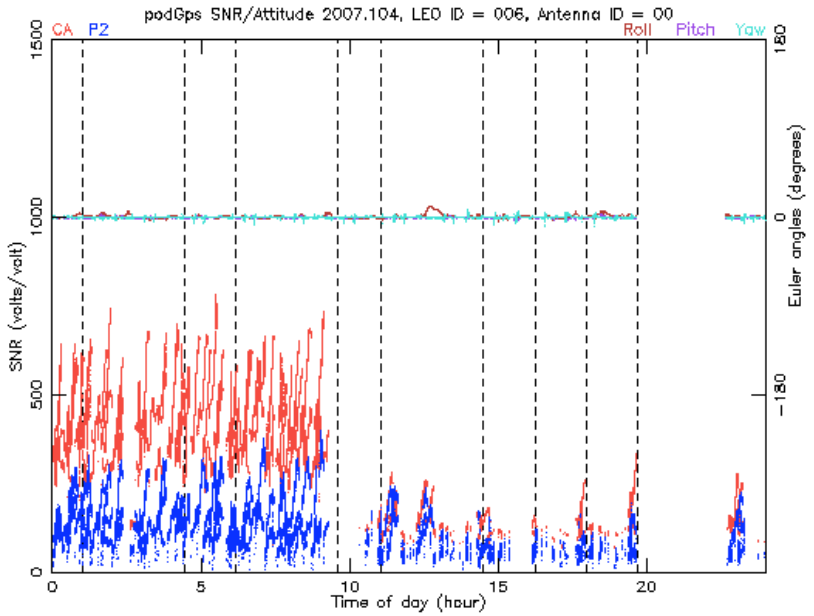
# Mission Challenges:

## Challenges and Solutions

# GPS Occultation Payload Status

- Checkout showed good hardware performance
- Average daily soundings - 1500 - 2000 (depending on constellation activities)
  - Daily record 2400 soundings
- Downlink delays of payload data
  - Clustering of satellites and spacecraft thrusting events limiting numbers of payload dumps - data latency improving as the constellation gets deployed
  - Approximately 80% of of data now meets 3 hour latency goals
- Perplexing RF problems





# GPS Occultation Payload Firmware Issues

**Summary of JPL-provided GPS firmware improvements from build 4.3 to build 4.5**

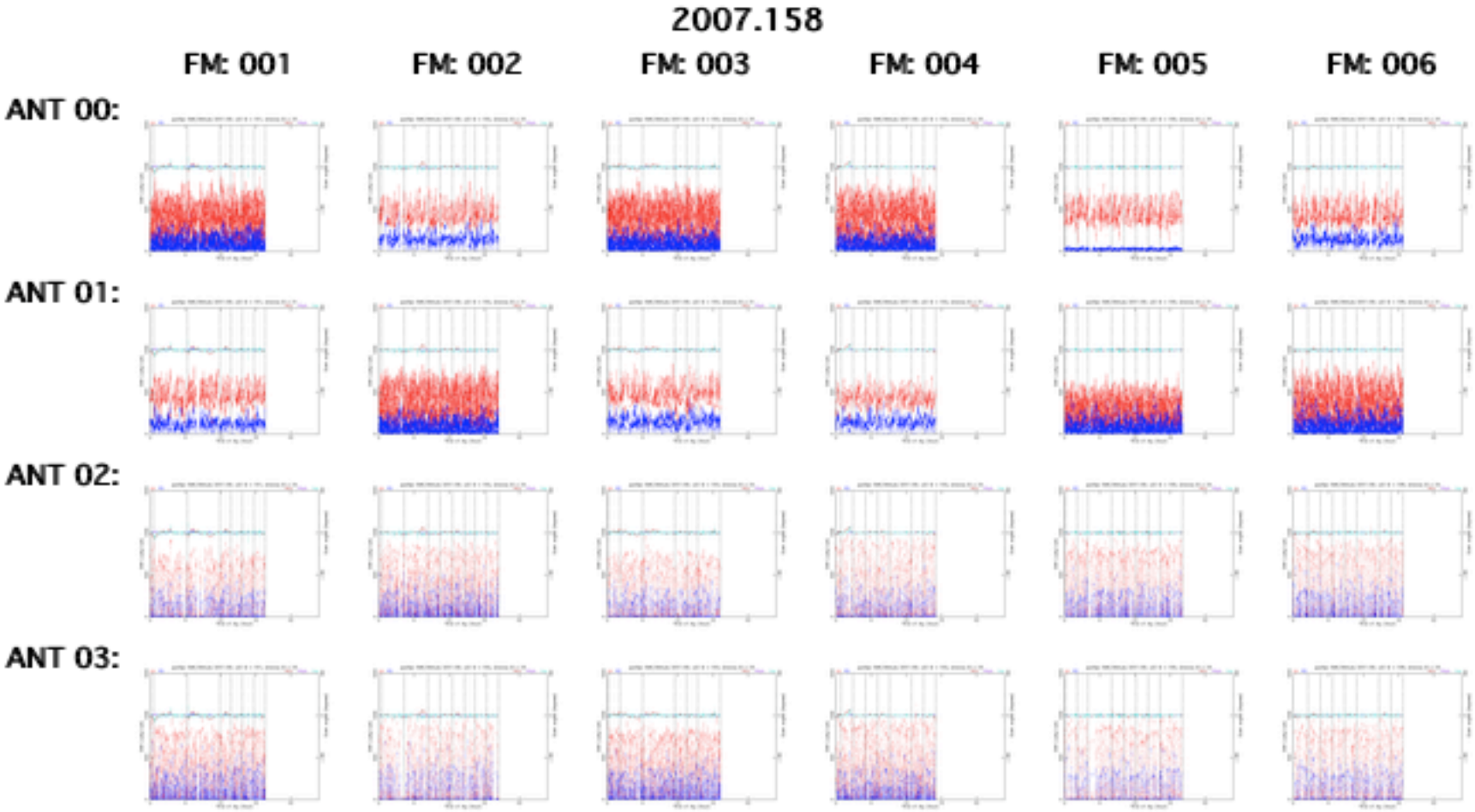
**B4.3 to B4.4 (Uploaded to FM5/FM6 July 2007)**

1) Double L2 tracking loop bandwidth to reduce soundings that fail for “bad L2”. Avoid wrapping of L2. (15% -> 10%)
2) Add ability to use rising side POD antennas as reference antenna and as navigation antenna (in case the setting side POD antenna fails).
3) L2C tracking - including first ever open loop tracking of L2

**B4.4 to B4.5 (to be uploaded mid-Sept 2007)**

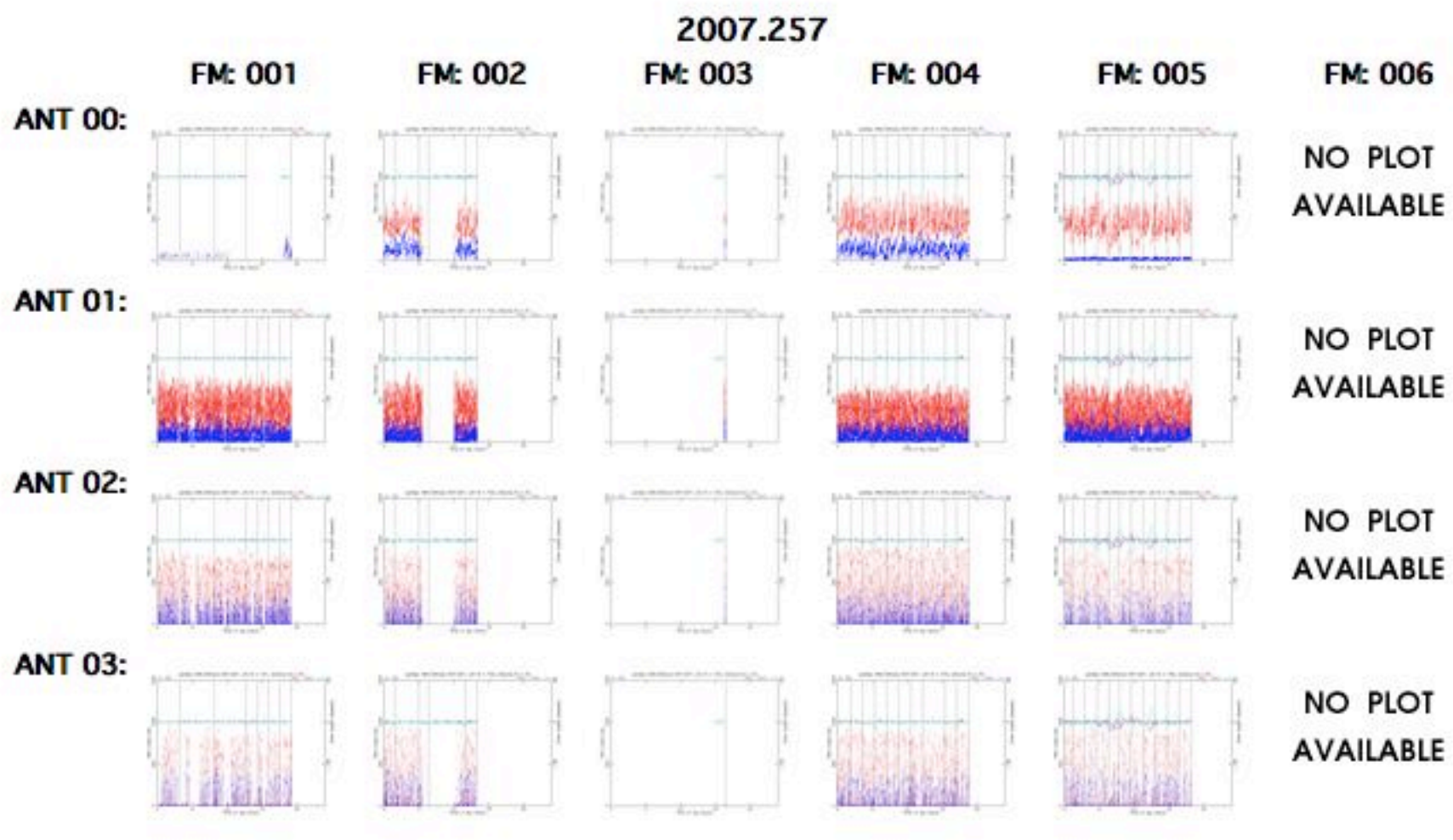
1) Fix L2 (and L2C) tracking problems
2) Output 1-Hz scintillation data
3) Track rising ionospheric occs (in case the setting side POD antenna fails).
4) Fix 1-2 sec gaps in reference link data?

# 6 FMs 4 Antennas SNRs




June 8, 2007, ~19:00 UTC L1_SNR L2_SNR

# Recent Status of COSMIC RO



# GOX and Spacecraft Issues: Atm. Occultation losses

| | S/C Power | S/C Attitude | S/C and GPS Data Gaps | GPS RF trouble | Comm. Error | GPS Firmware |
|---|---|---|---|---|---|---|
| **FM1** | | | ~15% | Intermittent | | 15-25% |
| **FM2** | - PCM issue<br>- lost 1 solar array (10-50%) | | ~15% | Intermittent | | 15-25% |
| **FM3** | SAD stuck (10-50%) | | ~15% | Intermittent | | 15-25% |
| **FM4** | | | ~15% | | | 15-25% |
| **FM5** | | | ~15% | Intermittent<br>Lost POD-RF1 (50%) | | 15-25% |
| **FM6** | | **Often poor** | ~15% | Intermittent | 100% | 15-25% |

# Summary

- Following launch all 6 satellites, and all payloads checked out
- Deployment to final constellation almost complete (raising FM1)
- All 24 GPS antennas (4 per satellite worked)
- Large amount of high quality data resulted in:
  - ~80% of soundings penetrate to lowest km of atmosphere
  - Operational use by world's leading weather centers
  - Demonstration of 0.2% precision of RO observation in 10-20 km height range
  - Extened climate record
  - Remote sensing of global ABL / Convection
  - Improvements to ionospheric models
  - Global scintillation observations
- COSMIC presently faces several difficulties
  - Frequent unexplained drops in SNRs from GPS antennas
  - Lost 1 solar panel on FM2
  - Stuck solar array drive on FM3
  - No communications presently with FM6
- Follow - on mission must be planned now