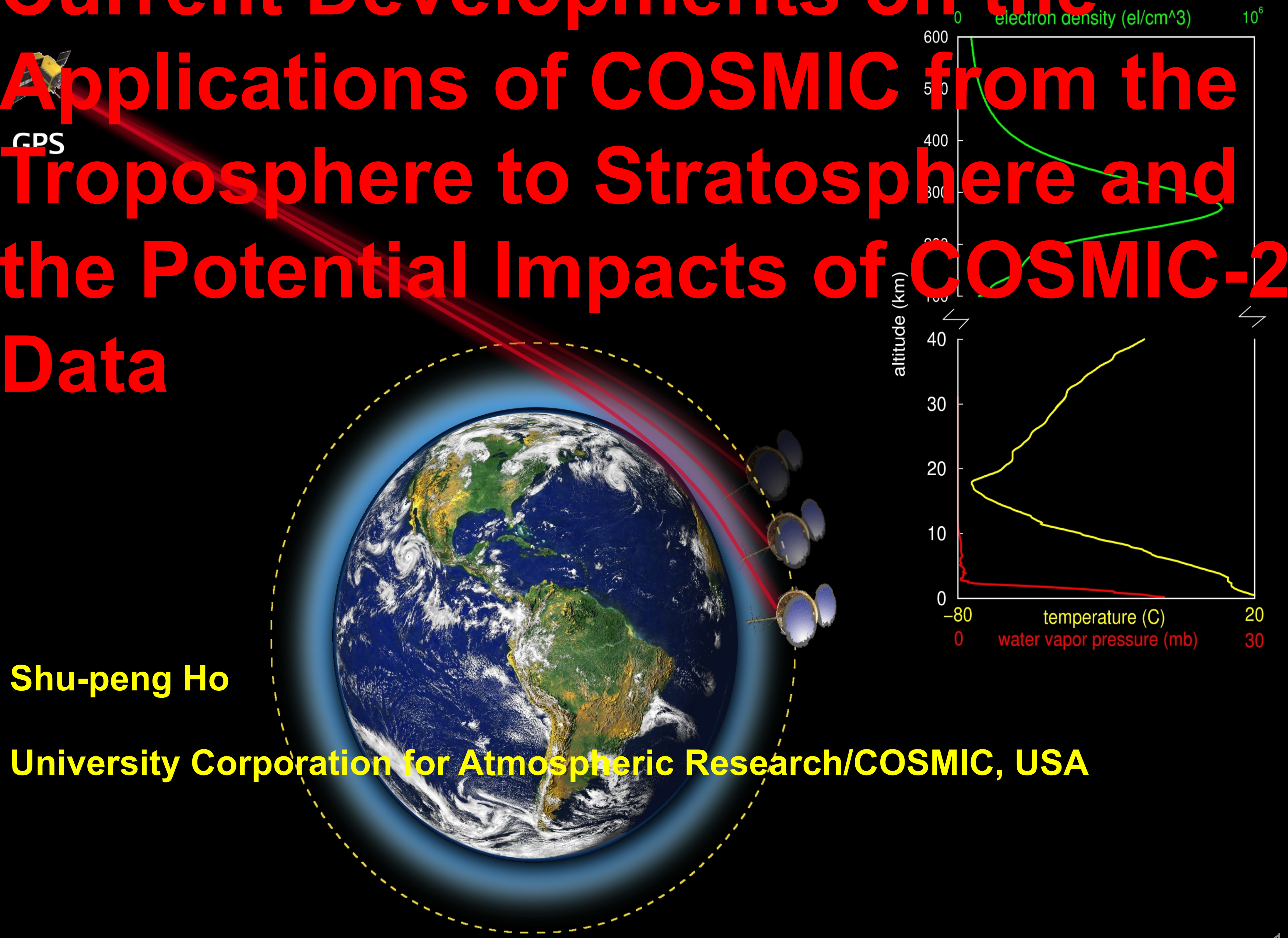
Current Developments on the Applications of COSMIC from the Troposphere to Stratosphere and the Potential Impacts of COSMIC-2 Data

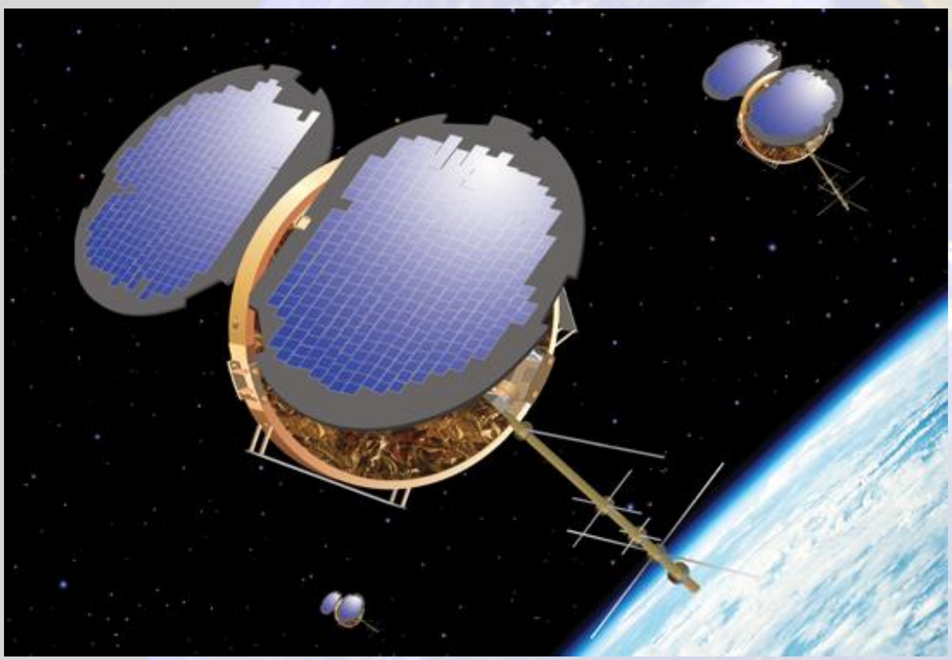


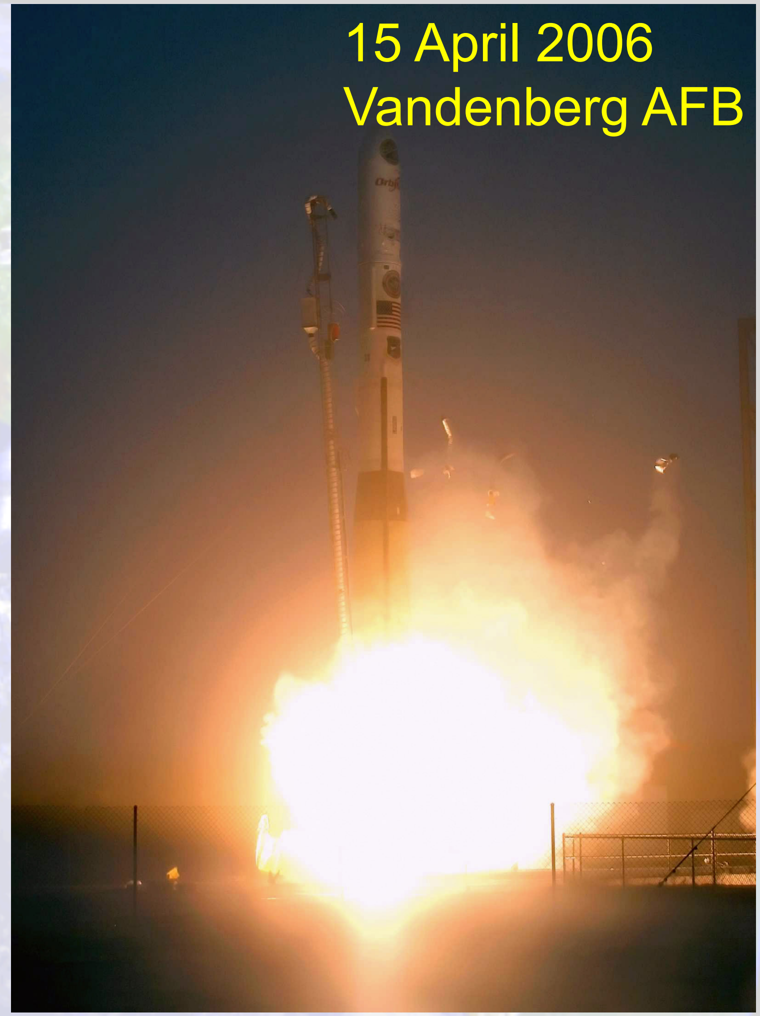
Shu-peng Ho

University Corporation for Atmospheric Research/COSMIC, USA

Formosat-3/COSMIC

Transformative atmospheric profiling





COSMIC launch picture provided by Orbital Sciences Corporation

Sixth FORMOSAT-3/COSMIC Data Users' Workshop

30 October - 1 November 2012

Boulder, Colorado, U.S.A

Theme : Bridge to the future; and Bridge to other communities

The purpose of this workshop is to provide a forum for scientific discussions between the RO community and the weather, climate, and space weather communities, which is crucial to capitalizing the scientific opportunities provided by past, current, and future RO missions. A dialogue between RO data providers and data users is also important to ensure optimal use of RO data for research and operational applications.

Background

1. **Since the launch of COSMIC in 2006, we have organized five COSMIC Data Users Workshop, to discuss accomplishments in:**

- **RO operation and algorithm development**
- **Meteorology application**
- **Climate**
- **Ionosphere**

through accessing COSMIC data from CDAAC.

What have we accomplished ? What are outstanding issues remaining?
Who are using these data/who are not ? Help users to better use the RO data.

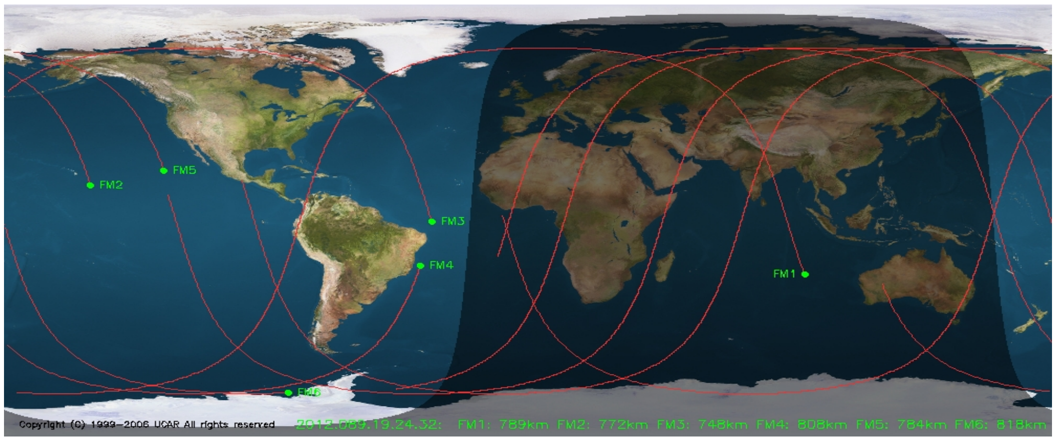
2. Beyond 2016

COSMIC-II is coming: First launch in 2016, second launch in 2018.

What RO data we can expect from CDAAC ? What more scientific applications we can explore using these data ? How can we bridge ourselves to the future and other science community.

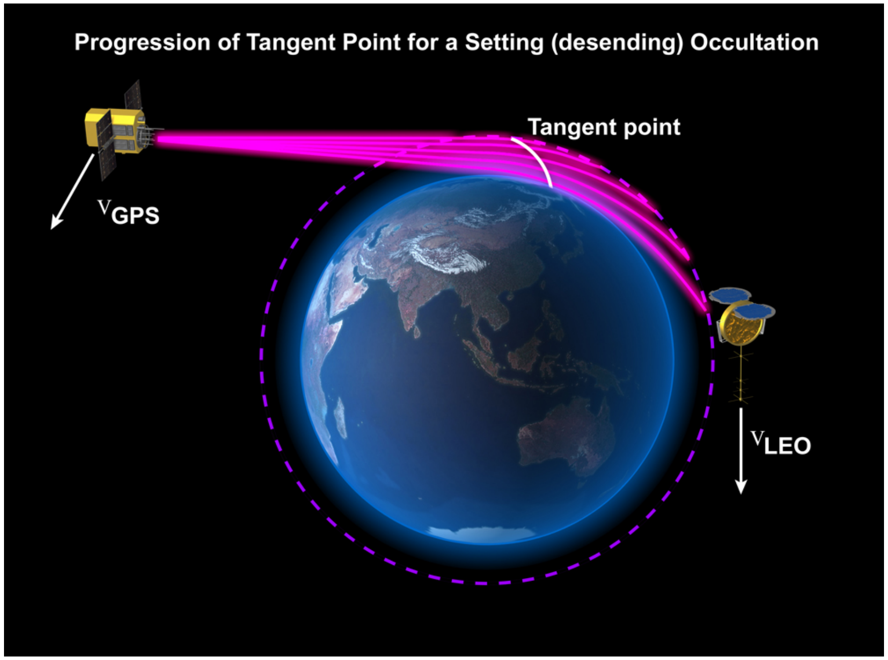
- **Invited talks**
- **Student program**
- **Sub-group meeting**
- **Good foods**
- **Many more ….**

http://www.cosmic.ucar.edu/oct2012workshop/index.html



Outline of Presentation

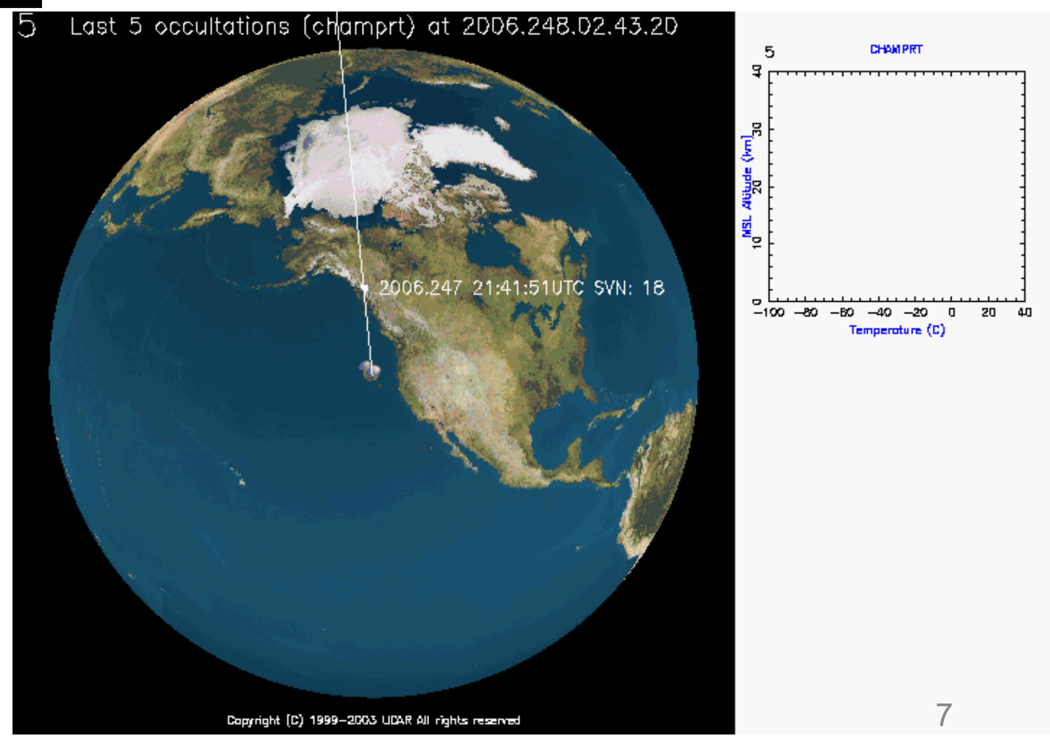
- **Summary of radio occultation (RO) technique and characteristics of RO observations and data quality**
- **Summary and status of COSMIC**
- **Highlights of COSMIC results from Troposphere to Stratosphere**
- **Potential applications of COSMIC II data**



Limb sounding of atmosphere as LEO rises or sets with respect to GPS satellites

Global observations of:

- Pressure, Temperature, Humidity
- Refractivity
- Ionospheric Electron Density

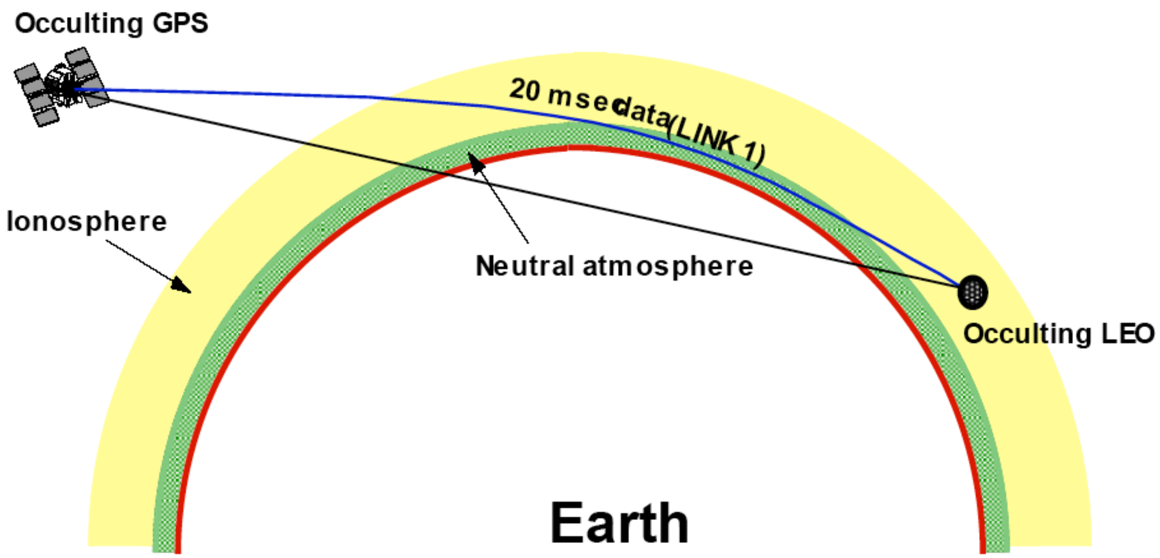


GPS Radio Occultation (GPS RO)

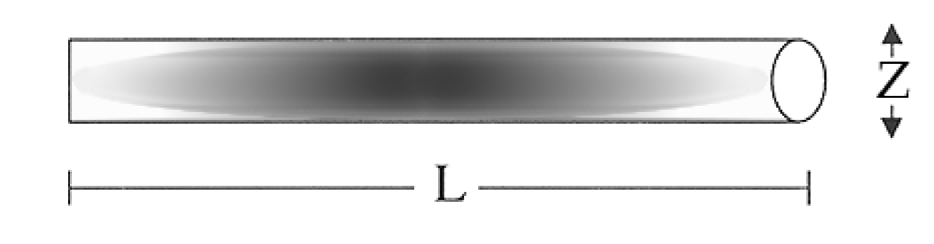
Basic measurement principle:

Deduce atmospheric properties based on precise measurement of phase delay and amplitude.

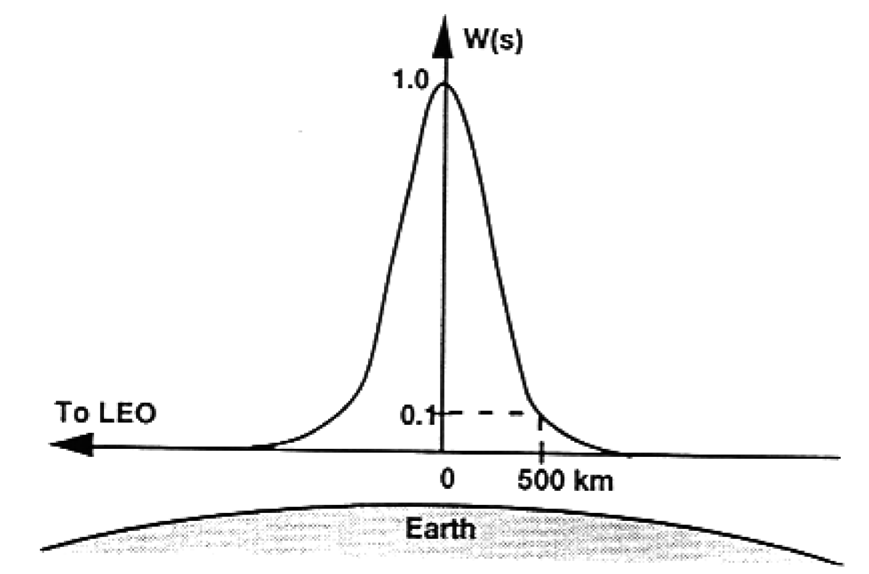
$$N = 77.6\frac{P}{T} + 3.73\times10^{5}\frac{P_W}{T^2}$$



Observed Atmospheric Volume



L~300 km
Z~1 km



Characteristics of GPS RO Data

- **Limb sounding geometry complementary to ground and space nadir viewing instruments**
- **Global 3-D coverage 40 km to surface**
- **High accuracy (equivalent to <1 K; average accuracy <0.1 K)**
- **High vertical resolution (0.1 km surface - 1km tropopause)**
- **Only system from space to resolve atmospheric boundary layer**
- **All weather-minimally affected by aerosols, clouds or precipitation**
- **Independent height and pressure**
- **Requires no first guess sounding**
- **Independent of radiosonde calibration**
- **No instrument drift**
- **No satellite-to-satellite bias**
- **Compact sensor, low power, low cost**

Outline of Presentation

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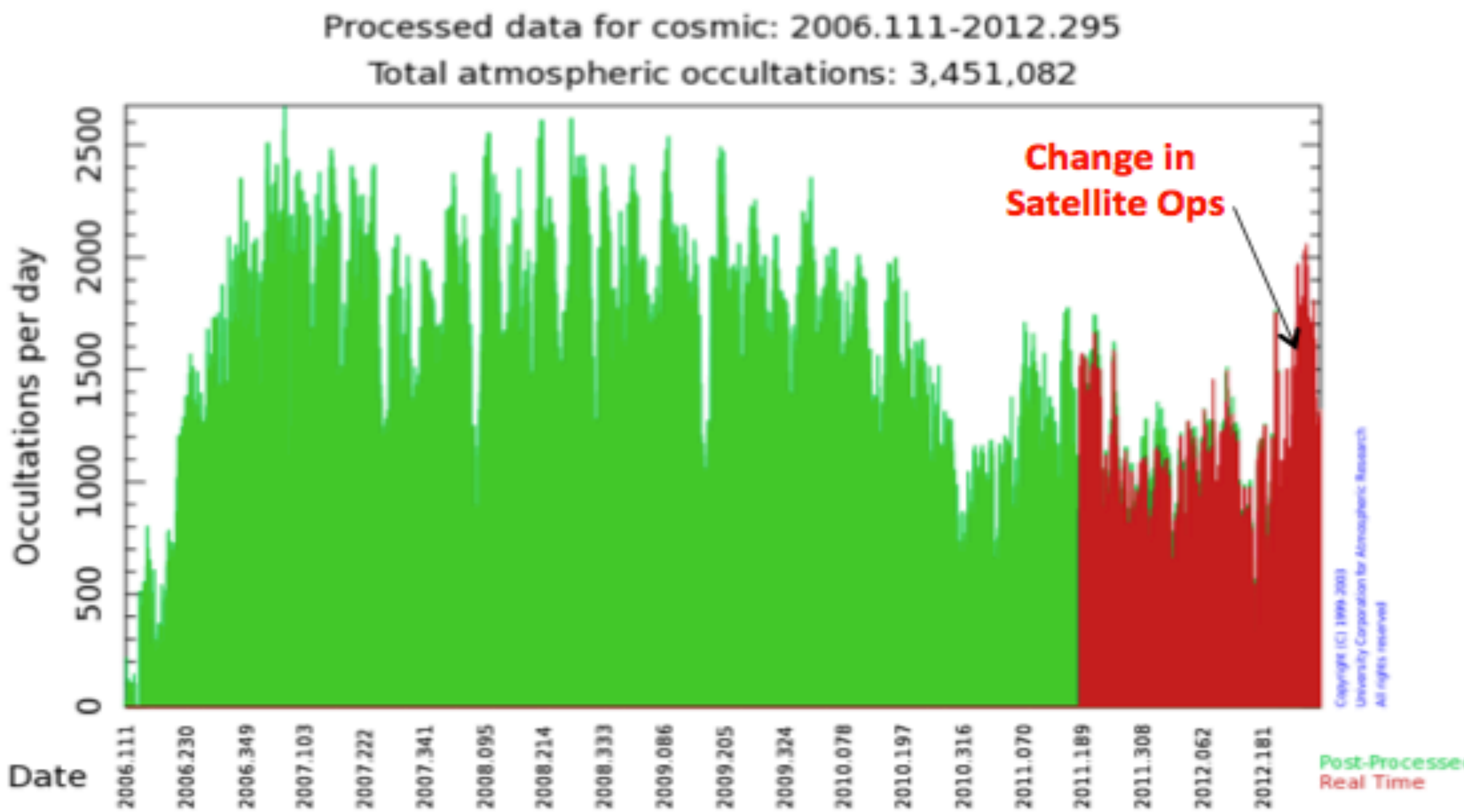
- **Potential applications of COSMIC II data**

> 3.4 Million Profiles in Real Time 4/21/06 – 10/21/2012



As of June 2012, more than 1,900 researchers from 63 countries have become registered users of the data

Outline of Presentation

- **Summary of radio occultation (RO) technique and characteristics of RO observations and data quality**
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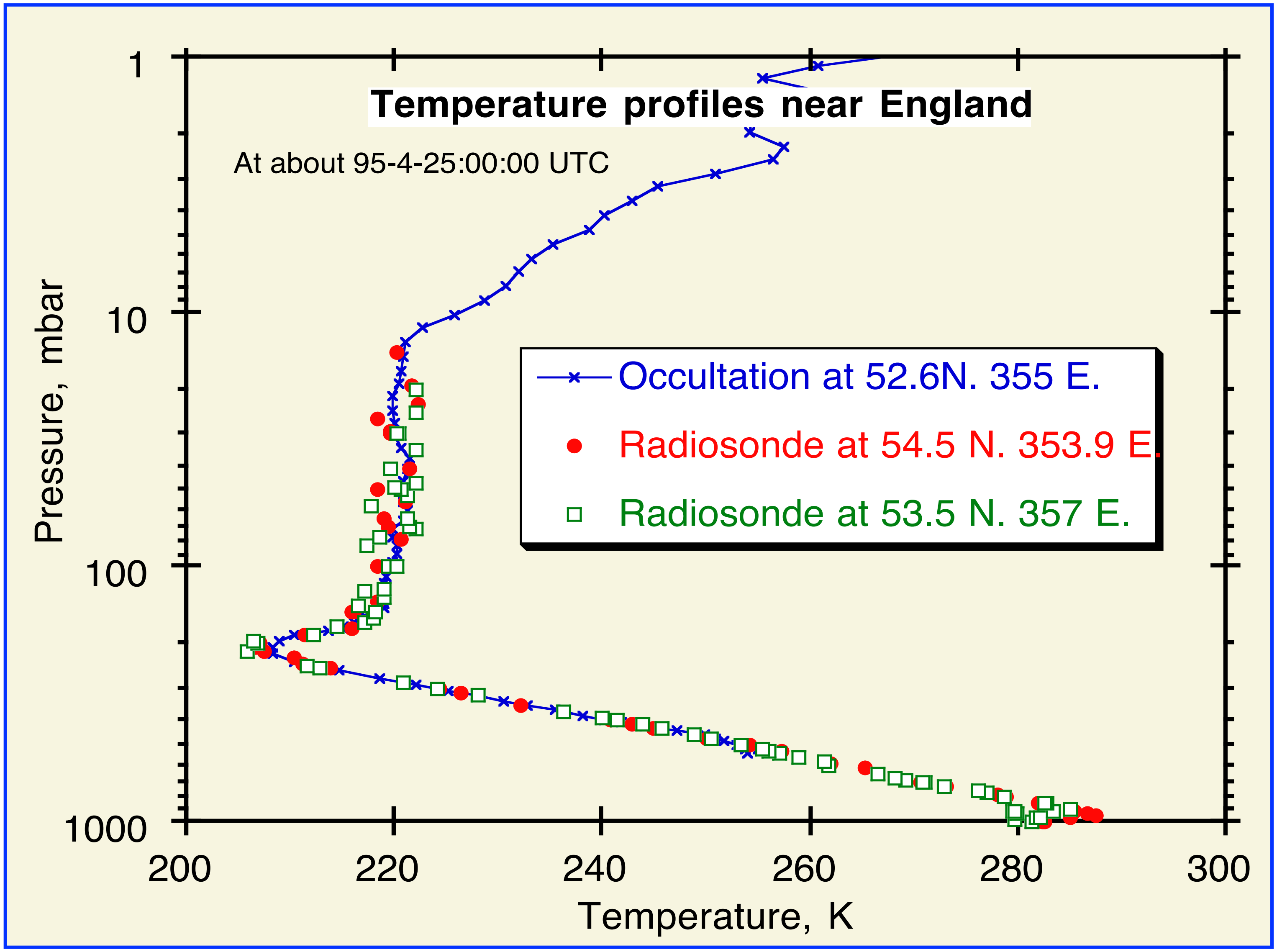
GPS Radio Occultation (RO) Data

- **Climate**
  - Characterize climate, its variability and change
  - Evaluate global climate models and analyses
  - Monitor climate change and variability with unprecedented accuracy- **world's most accurate, precise, and stable thermometer from space!**
- **Weather**
  - Improve global weather analyses, particularly over data void regions such as the oceans and polar regions
  - Improve skill of global and regional weather prediction models
  - Improve understanding of tropical, midlatitude and polar weather systems and their interactions
- **Ionosphere and Space Weather**
  - Characterize global electronic density distribution
  - Observe the interactions among the upper stratosphere, mesosphere and ionosphere
  - Improve the analysis and prediction of space weather.

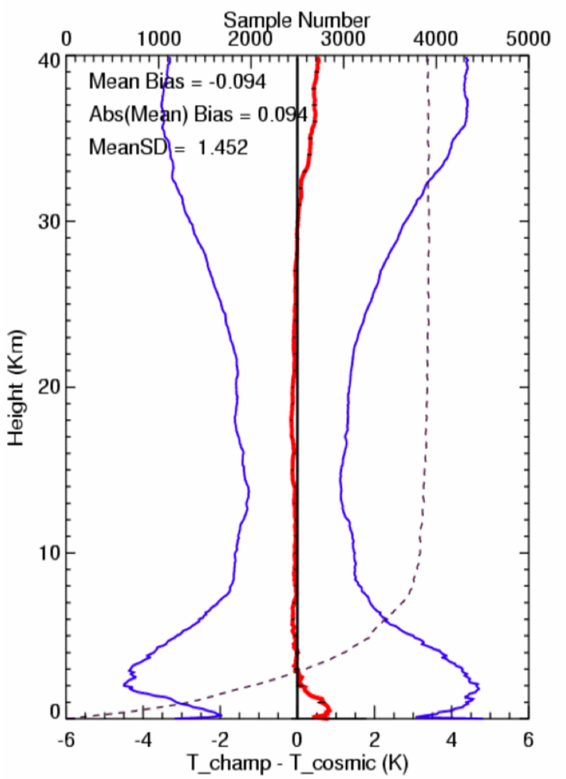


A typical RO sounding showing very sharp tropopause. No other instrument from space can provide such high vertical resolution.

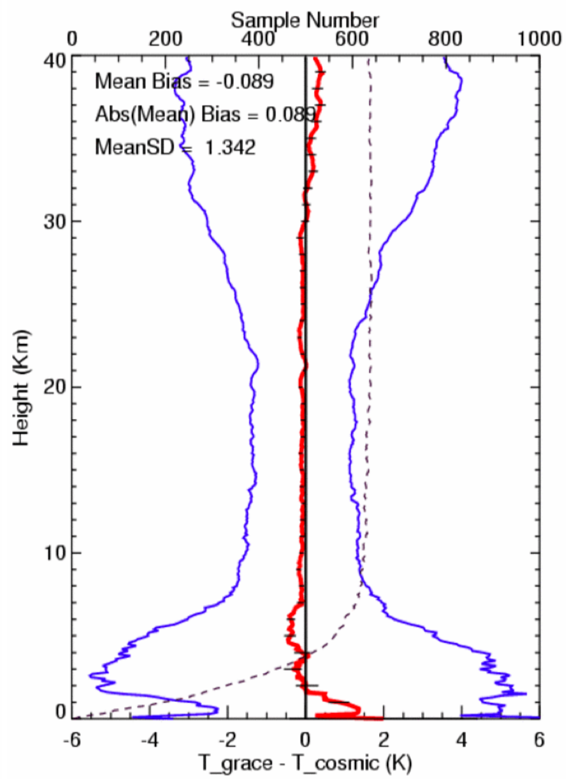
1) Precision/Accuracy/Stability of RO data

Global COSMIC, CHAMP, SAC-C, GRACE-A, Metop/GRAS Comparison

Within 60 Mins, and 50 Km



CHAMP-COSMIC
2007-2008



GRACE-COSMIC
2006

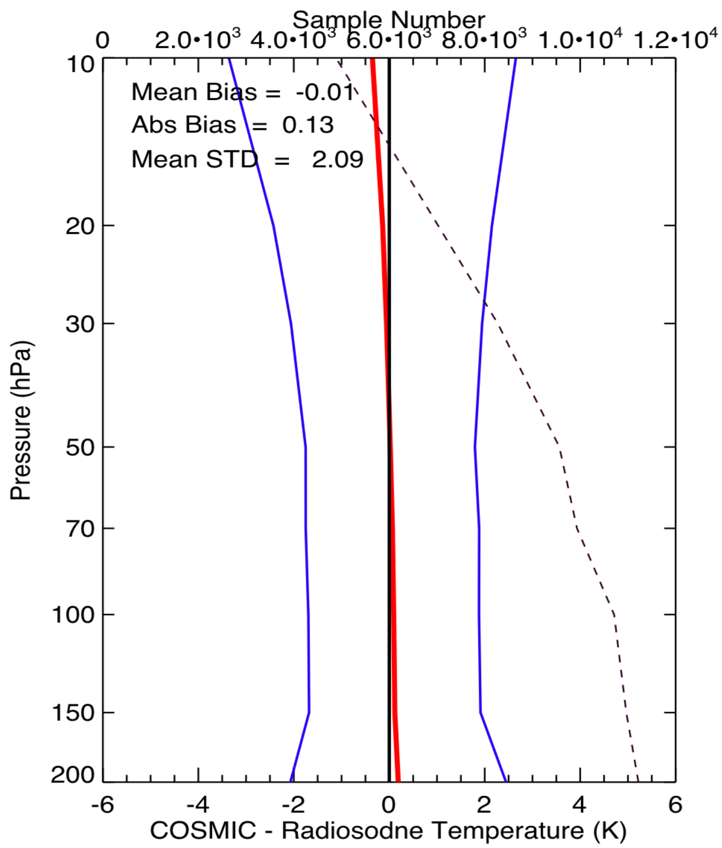
- Comparison of measurements between old and new instrument
- CHAMP launched in 2001
- COSMIC launched 2006
- GRACE launched 2002

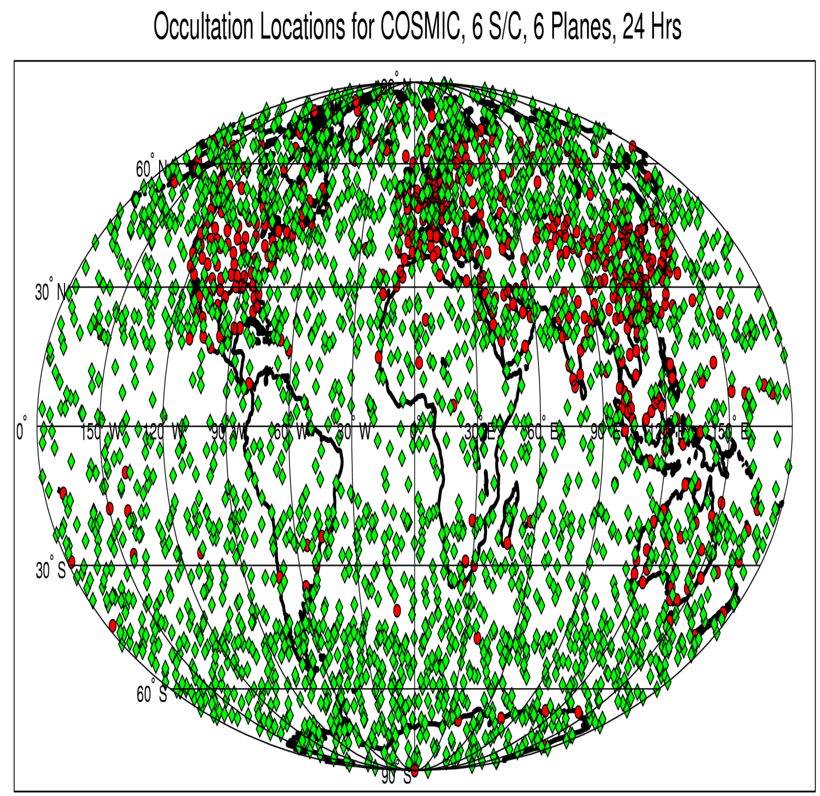
Don't need to have stable calibration reference

(Ho et al., 2013 JGR)

Accuracy of RO derived variables

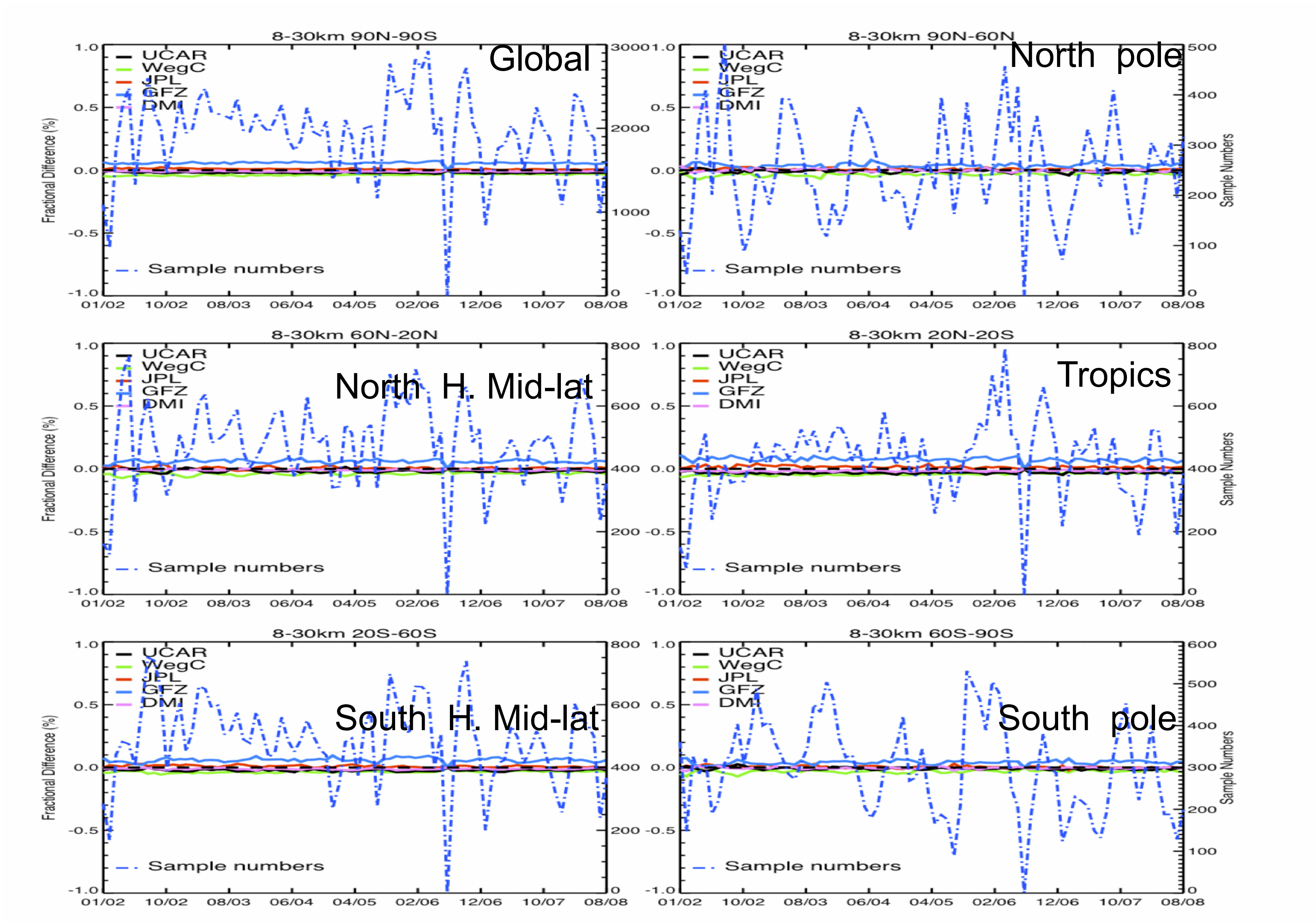
COSMIC





Ho et al., BAMS 2010

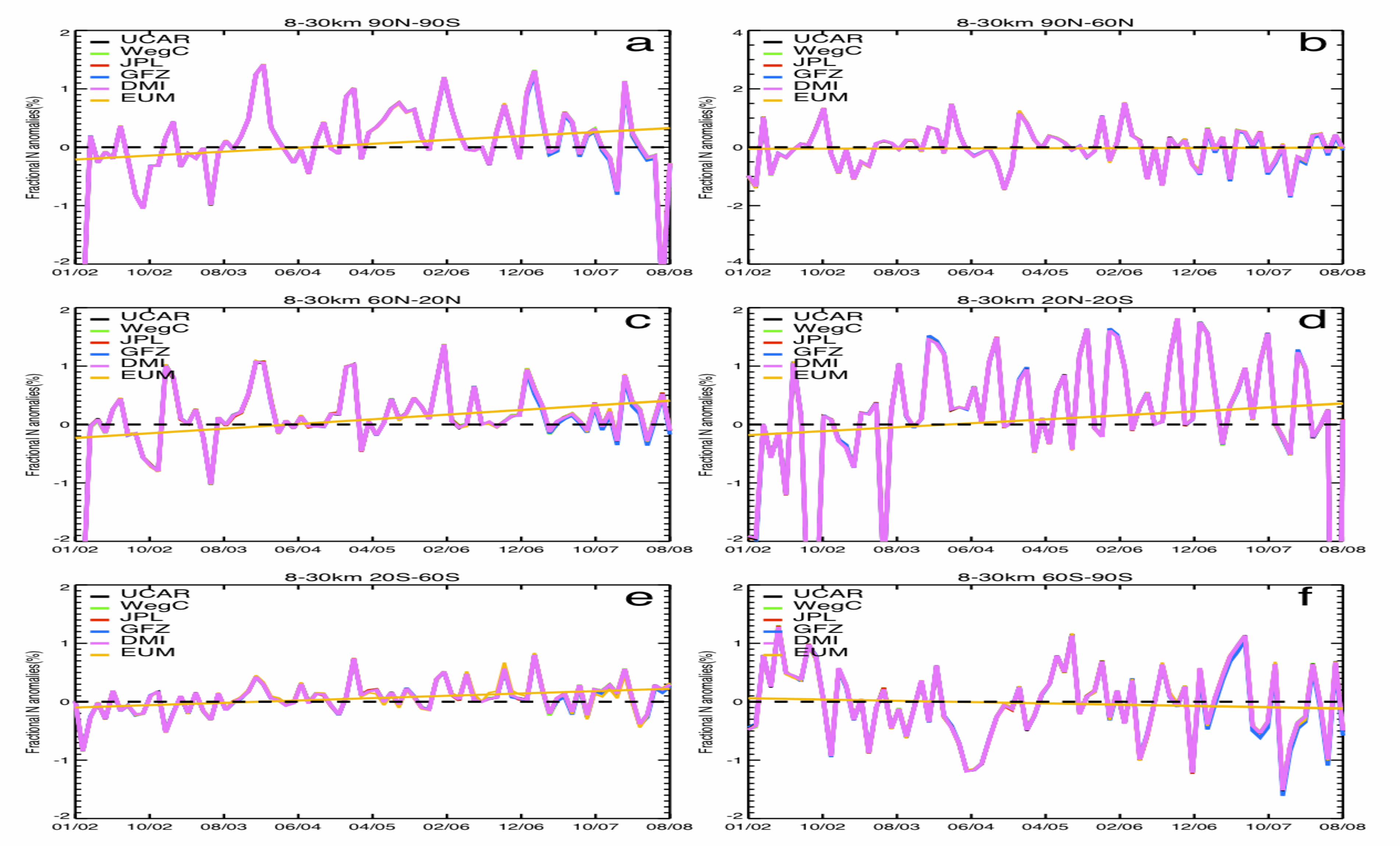
Quantify the quality of RO data among different centers



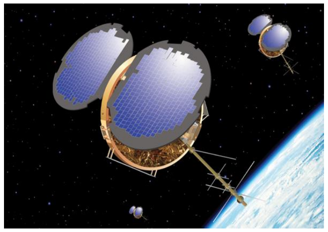
8-30 km (Ho et al., 2009, 2012 JGR)

Comparing RO data from different centers

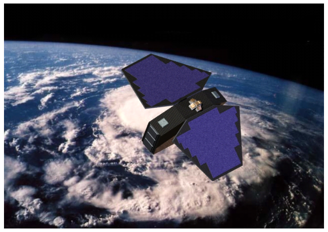
8-30 km



(Ho et al., 2009, 2012 JGR)



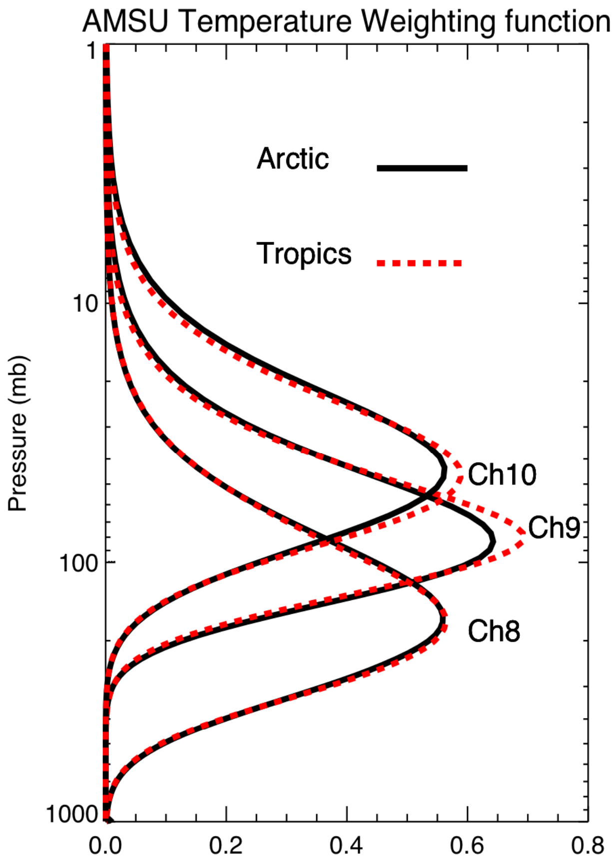
2) Construction of a consistent RO and MSU/AMSU Temperature Climate Data Records



1. Data:
COSMIC from 200606 to 200912
CHAMP from 200106 to 200806
RSS V3.2 200106-200912
UAH V5.1 200106-200812
SNO V2.0 200106-200912

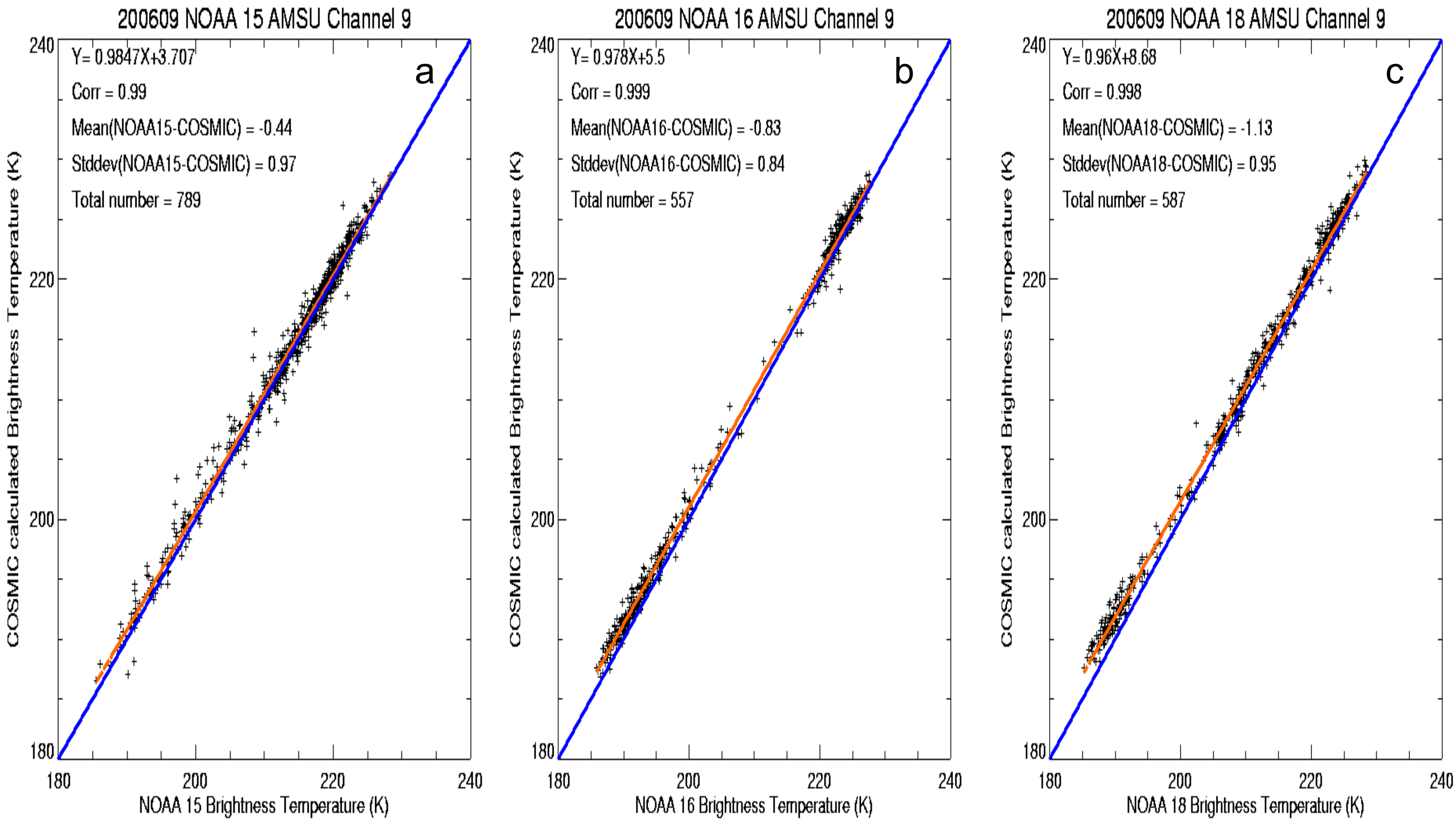
2. Apply CHAMP and COSMIC soundings to AMSU forward model to simulate AMSU TLS

3. Match simulated GPS RO TLS to NOAA AMSU TLS within 30 minutes and 0.5 degree to find calibration coefficients for different NOAA satellites so that we can
a. use GPS RO data to inter-calibrate other NOAA satellite
b. use the NOAA satellite measurements calibrated by GPS RO data to calibrate multi-year AMSU/MSU data and generate consistent RO and MSU/AMSU TLS climate data records

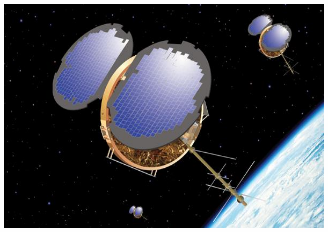


Can we use RO data to calibrate other instruments ?

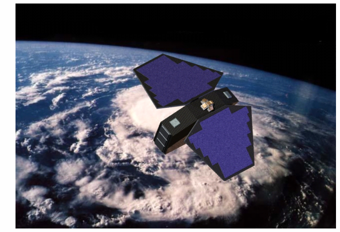
200609

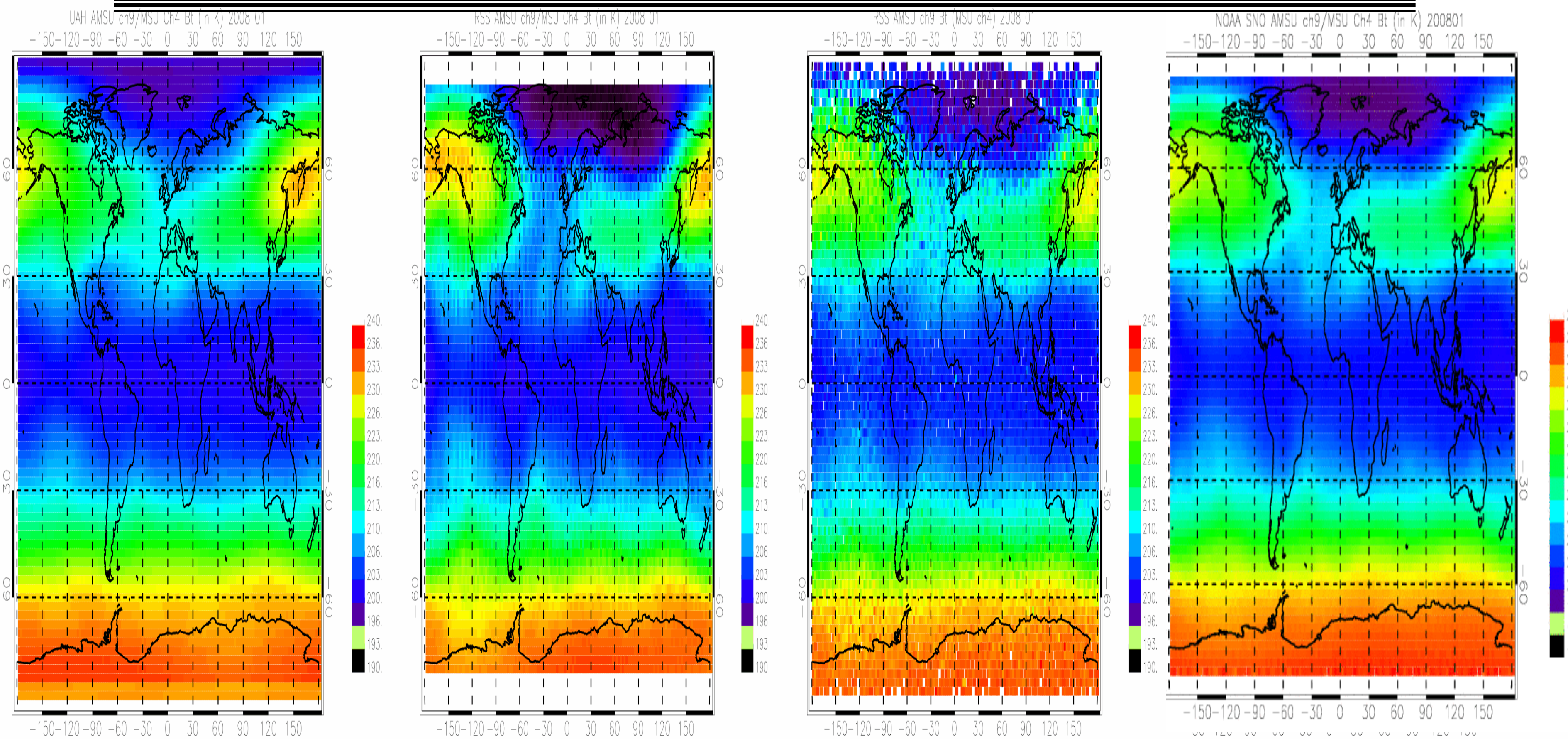


N15, N16 and N18 AMSU calibration against COSMIC



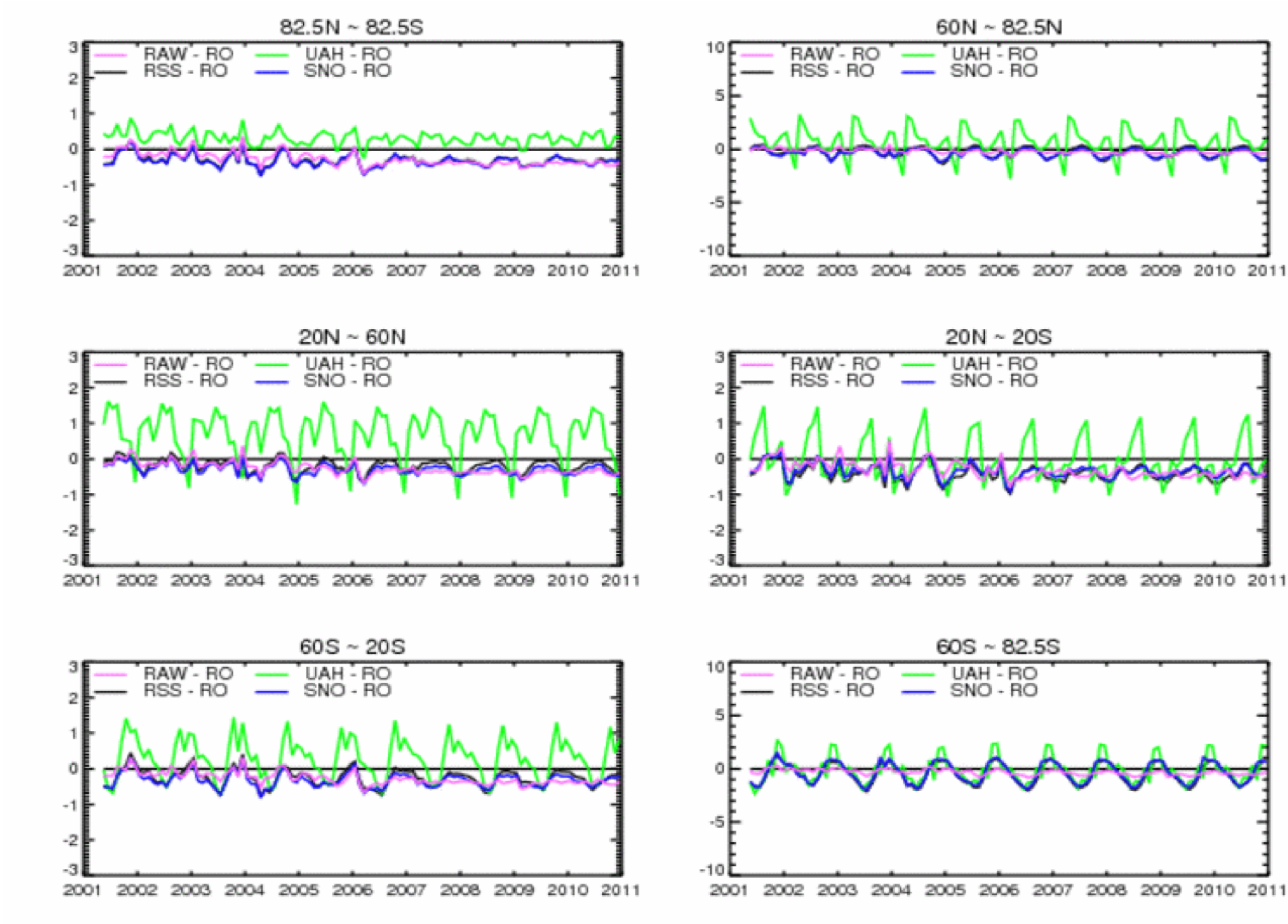
Comparisons of RO-calibrated AMSU with those from RSS, UAH, and SNO





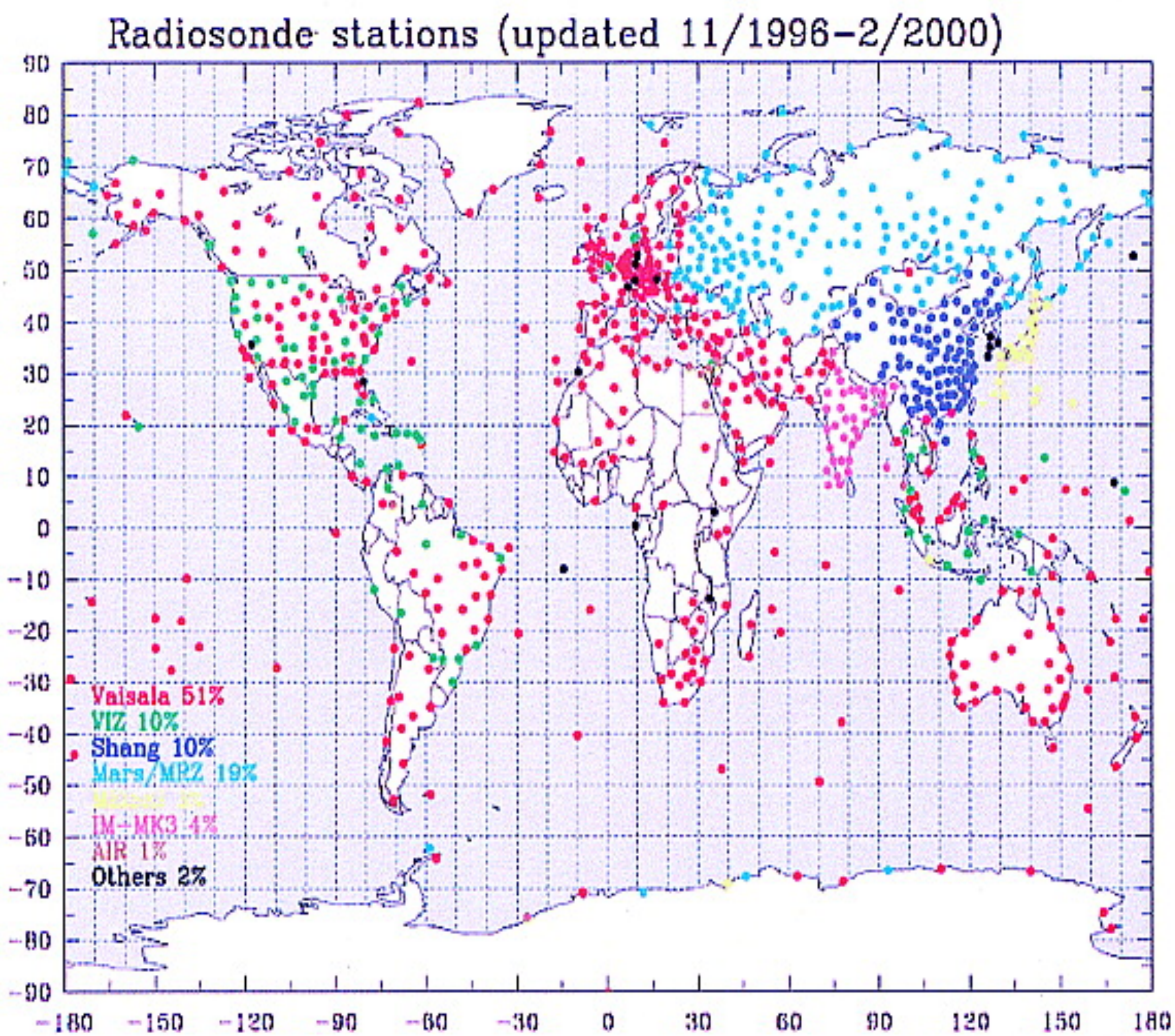
UAH RSS RO_AMSU SNO

200801



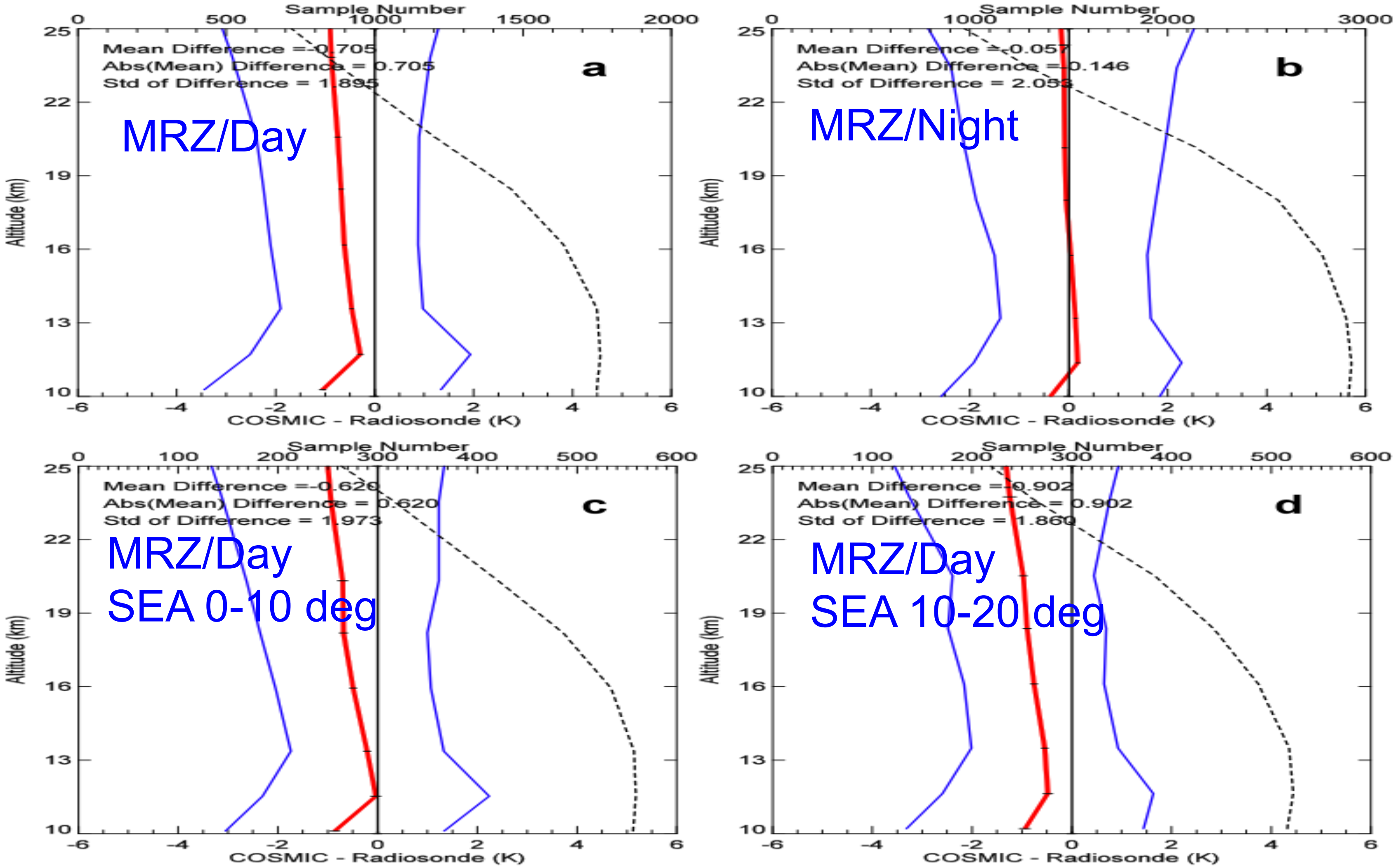
(Ho et al., 2007 GRL, 2009a,b, Ho et al., 2013a JGR)

3) Using RO data to assess the quality of radiosonde data

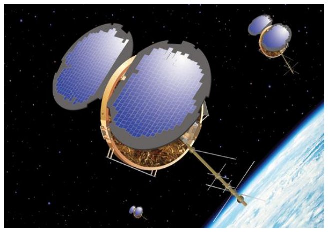


Region	Sonde Type	Matched Sample
Russia	AVK-MRZ	2000 (20%)
China	Shang	650 (6.1%)
USA	VIZ-B2	600 (5.9%)
Others	Vaisala	3140 (30%)

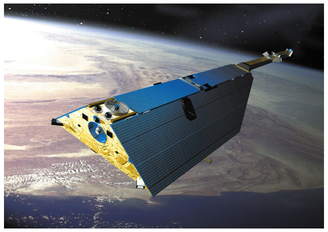
Using RO data to assess the quality of radiosonde data



(He and Ho, GRL 2009)



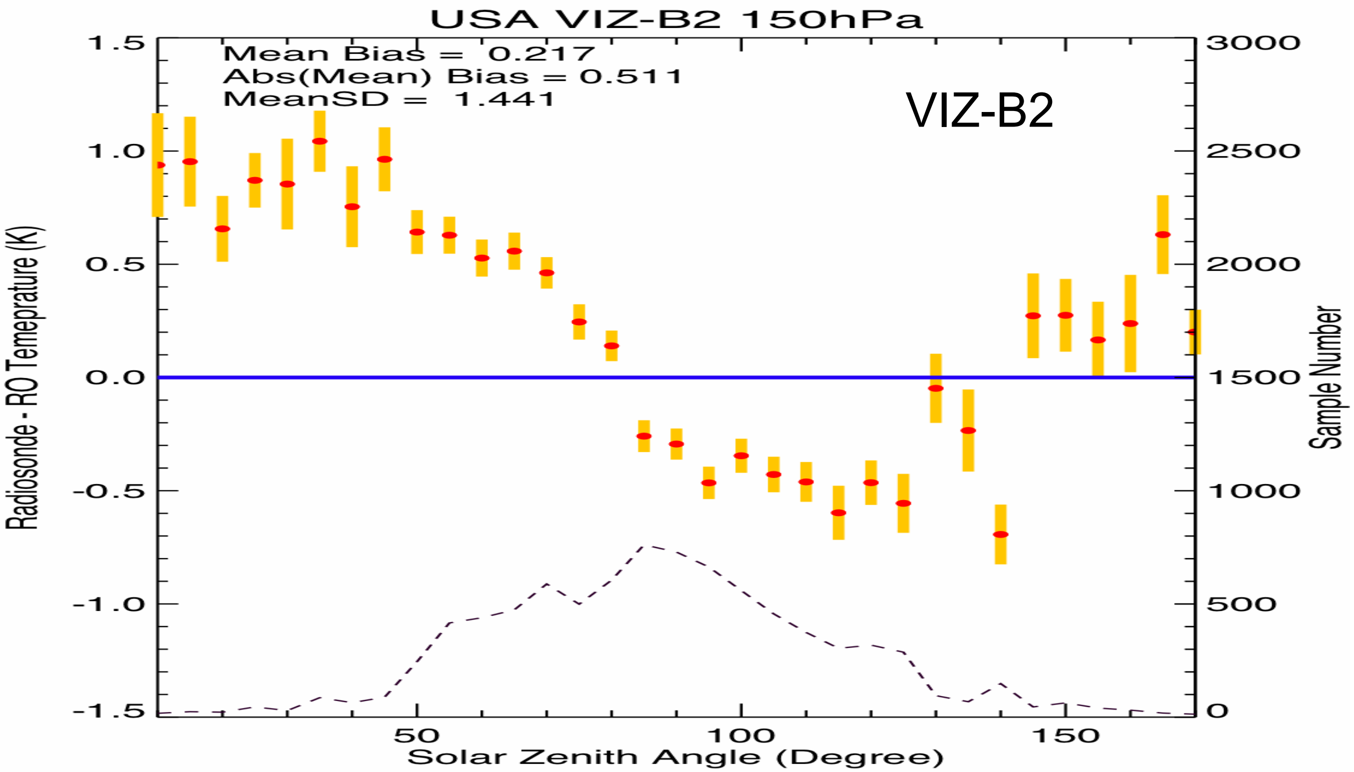
Using RO data to Correct Diurnal variation of Radiosonde Temperature Anomalies



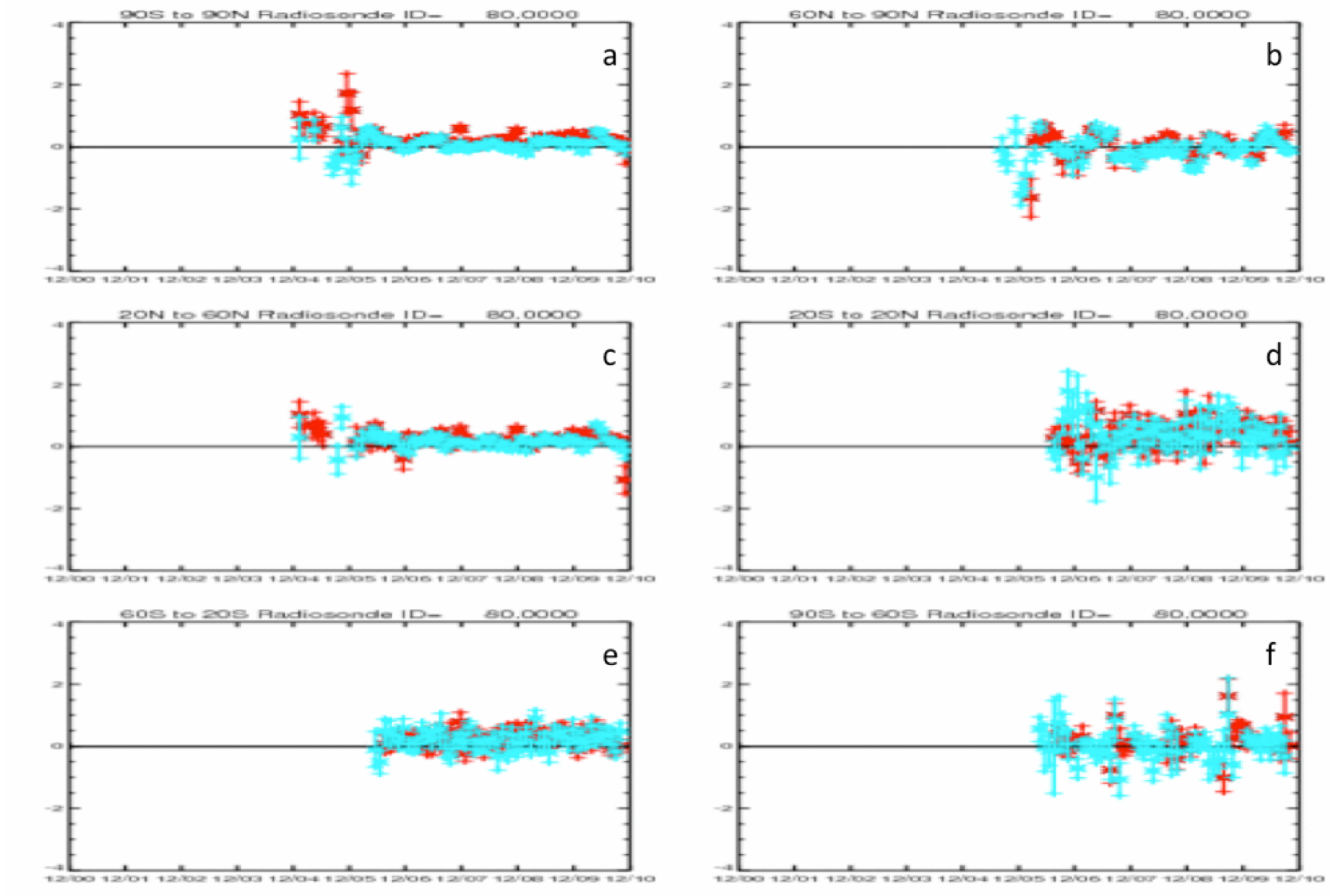
Solar absorptivity = 0.15
IR emissivity = 0.85

150 hPa

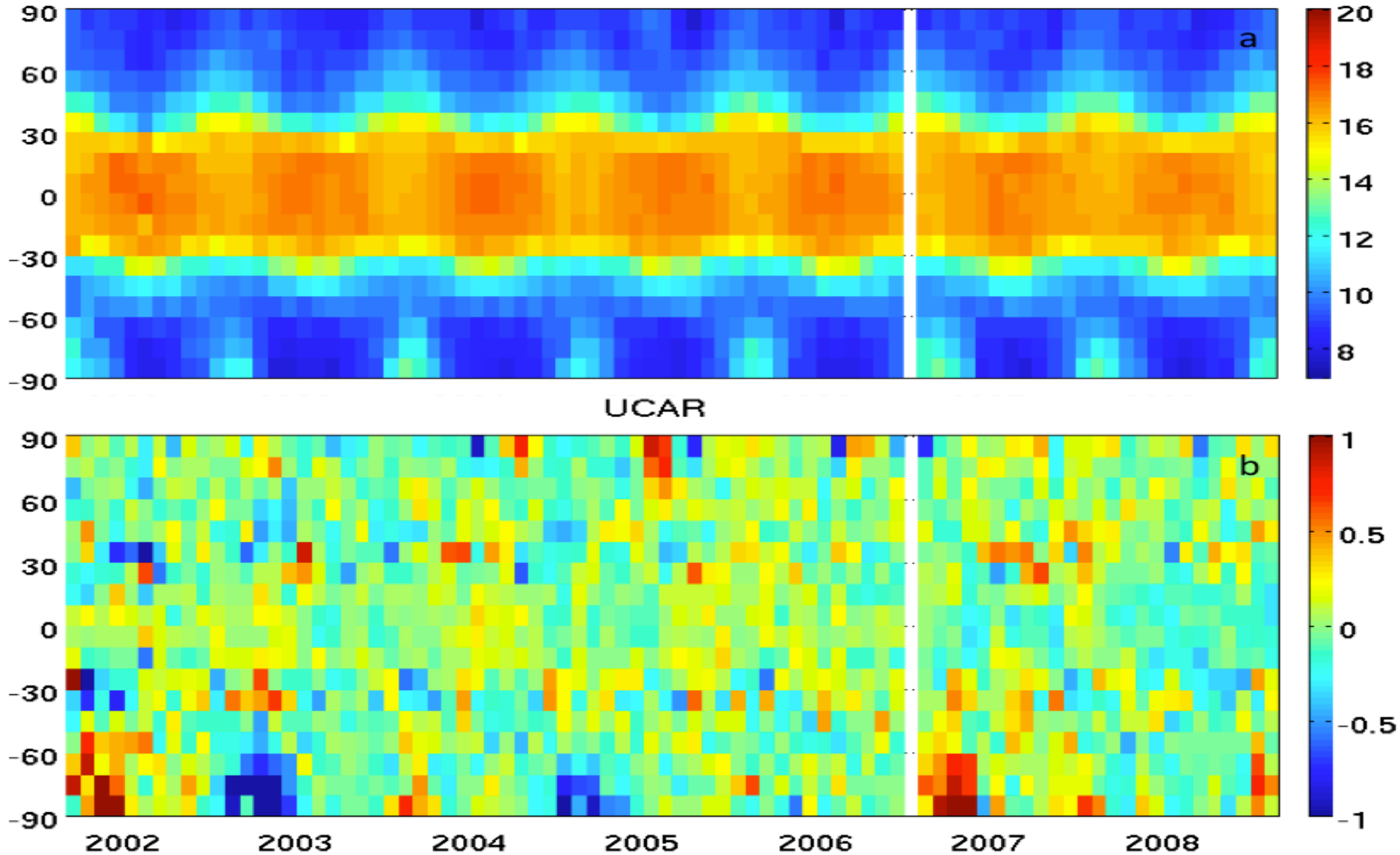
COSMIC from 2006 to 2009
CHAMP from 2001 to 2008
Radiosodne data DS351.0 from NCAR



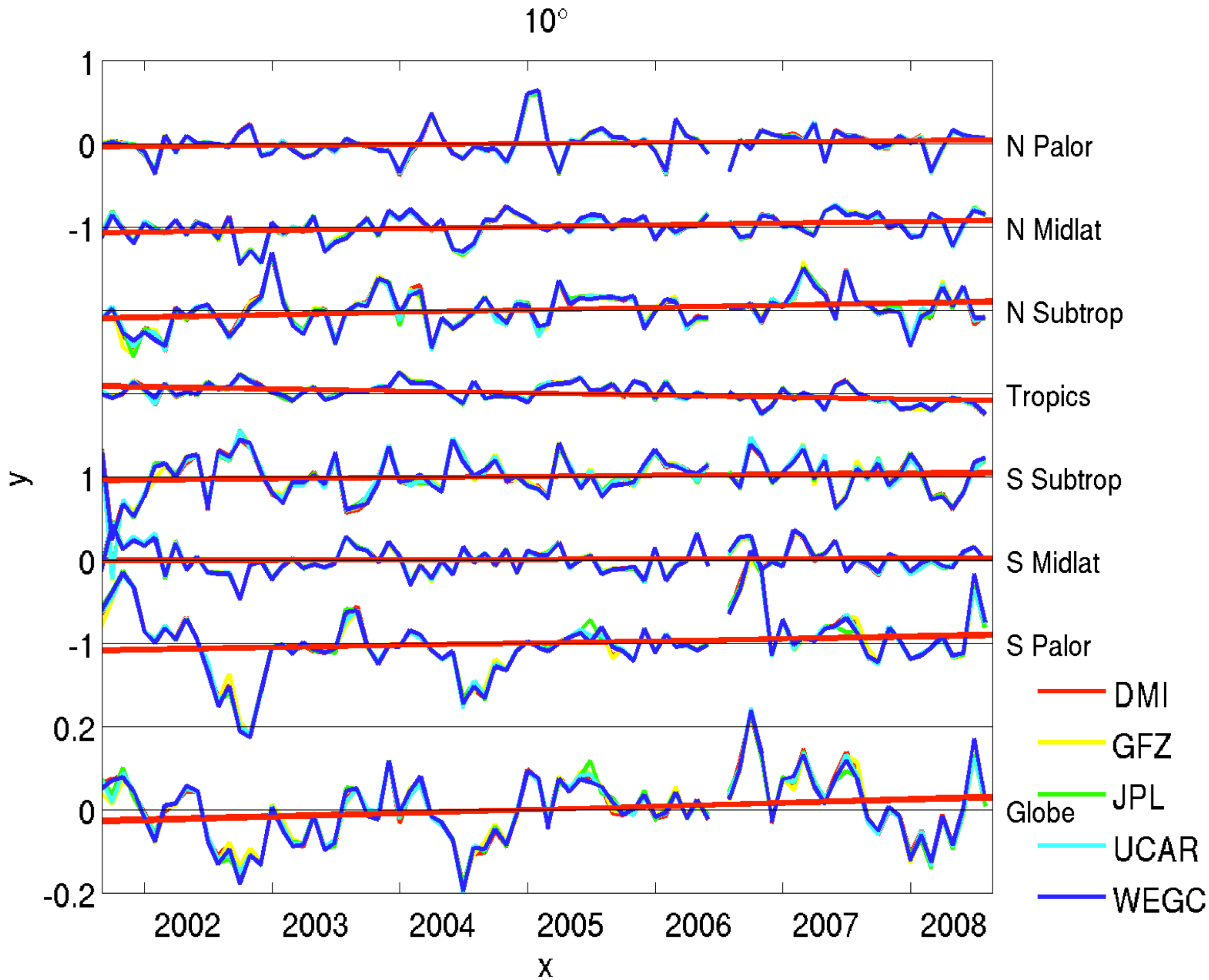
(Ho et al., 2013b JGR, in preparation)


90S to 90N Radiosonde ID= 80,0000
a
60N to 90N Radiosonde ID= 80,0000
b
20N to 60N Radiosonde ID= 80,0000
c
20S to 20N Radiosonde ID= 80,0000
d
60S to 20S Radiosonde ID= 80,0000
e
90S to 60S Radiosonde ID= 80,0000
f

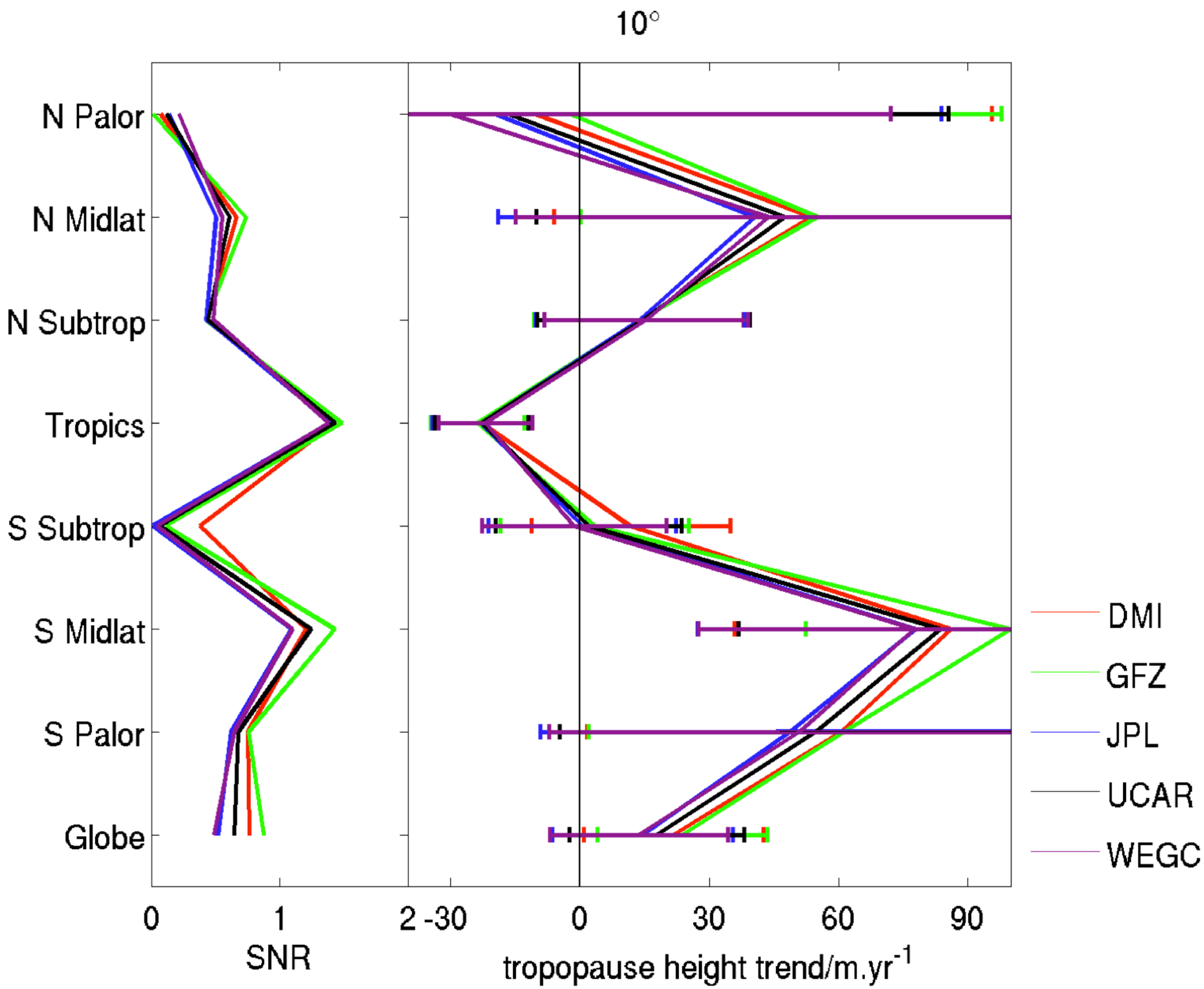
4) Construction of a consistent RO tropopasue height climatology



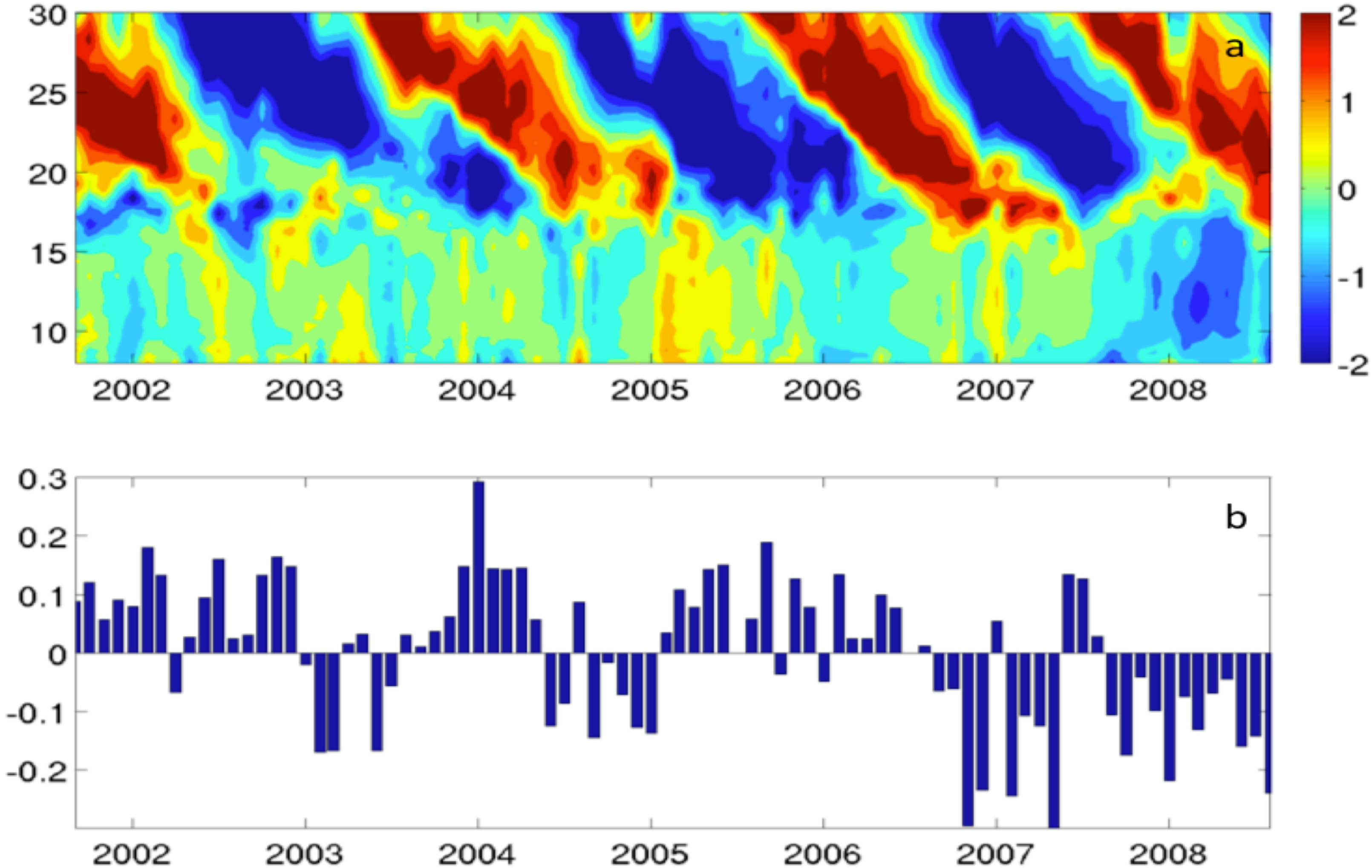
a) the mean tropopause height climatology (in km) generated by using CHAMP data from June 2001 to August 2008, and b) the corresponding monthly tropopause height anomalies (in km).



The LRT time series from October 2001 to October 2008 for DMI, GFZ, JPL, UCAR and WEGC for different latitudinal zones.

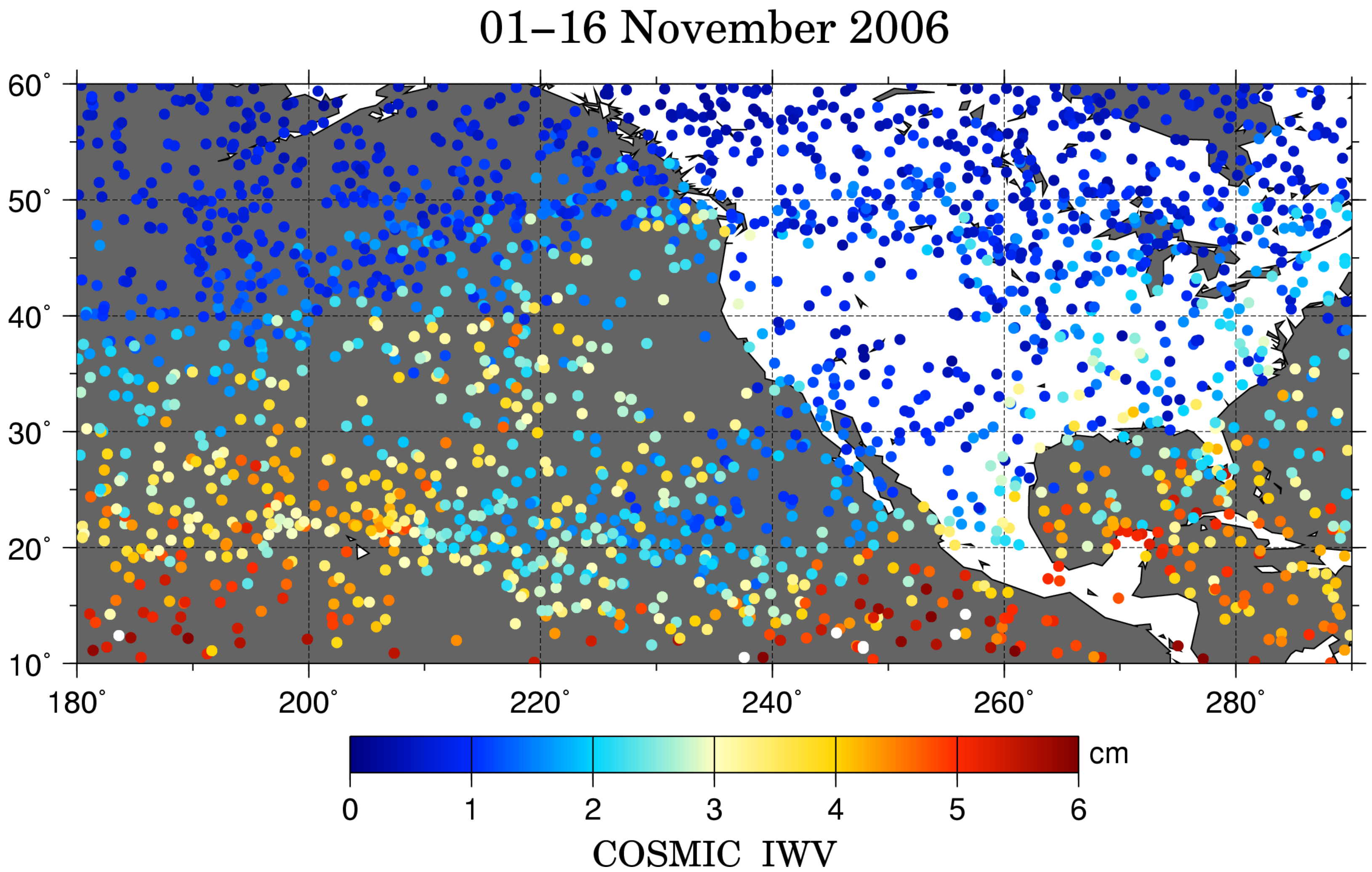


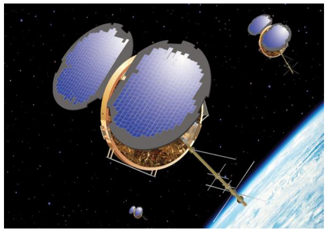
The LRT trends (meter/yr) from October 2001 to October 2008 for DMI, GFZ, JPL, UCAR and WEGC for different latitudinal zones.



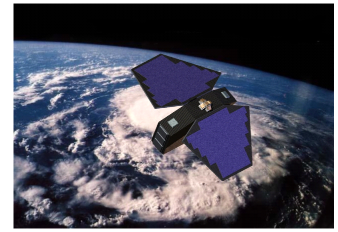
a) the time series of temperature anomalies (in K) from 8 km to 30 km in height and from 10 degree N to 10 degree S that are constructed by using UCAR CHAMP data, and b) the corresponding time series of the trend of tropopause height (in km/year) also computed by using UCAR CHAMP data.

5) Precipitable Water (PW) from COSMIC data

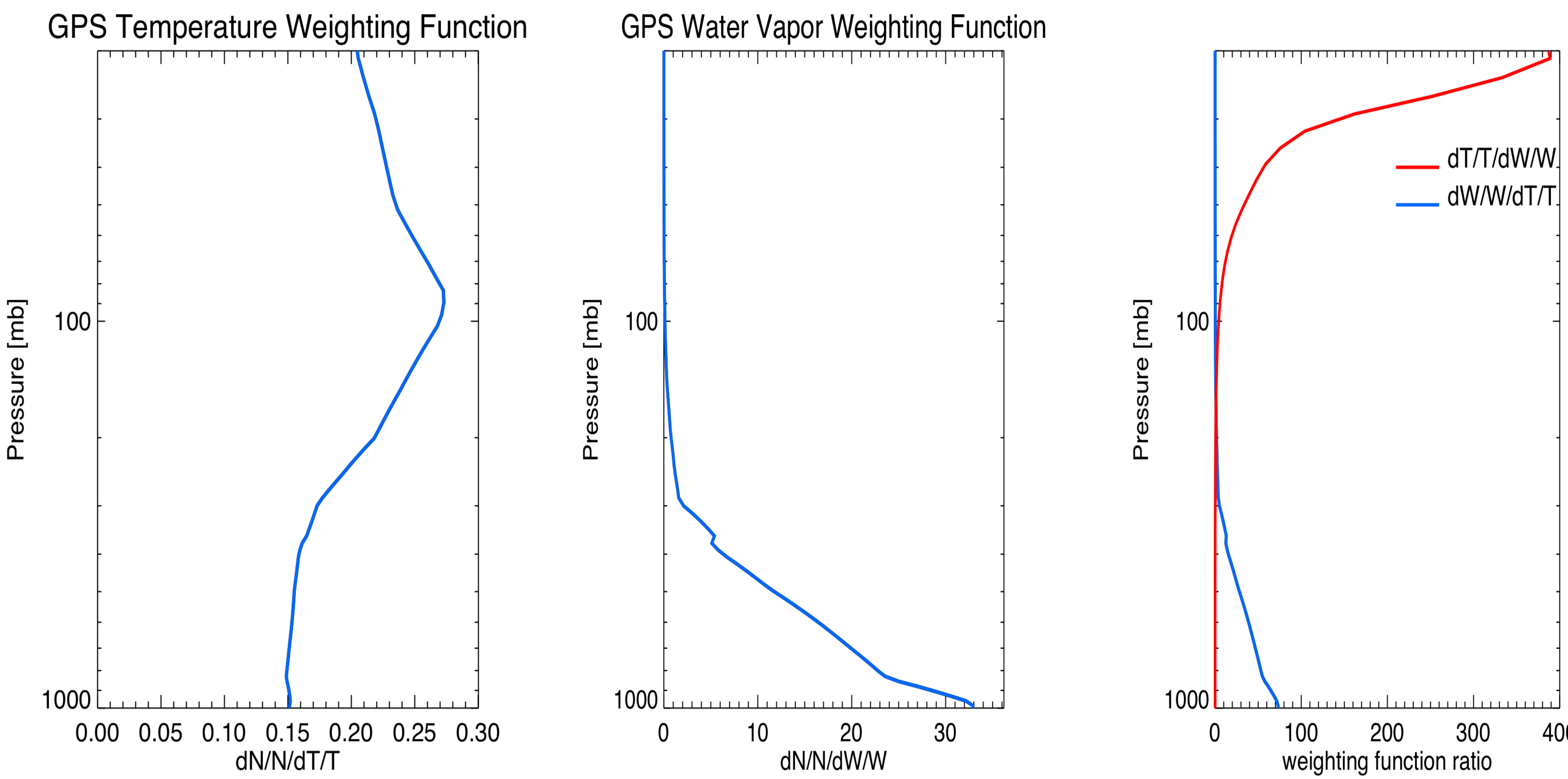




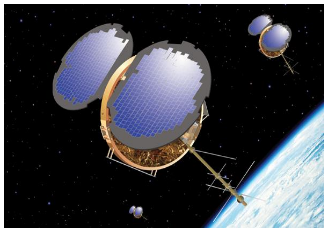
No Ambiguity of the Sensitivity of Refractivity to T and W



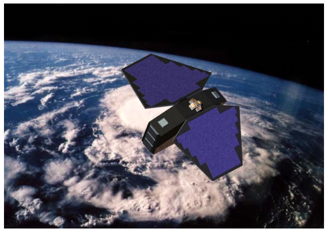
$$N = 77.6\frac{P}{T} + 3.73\times10^{5}\frac{P_W}{T^2}$$



Shu-peng Ben Ho, UCAR/COSMIC

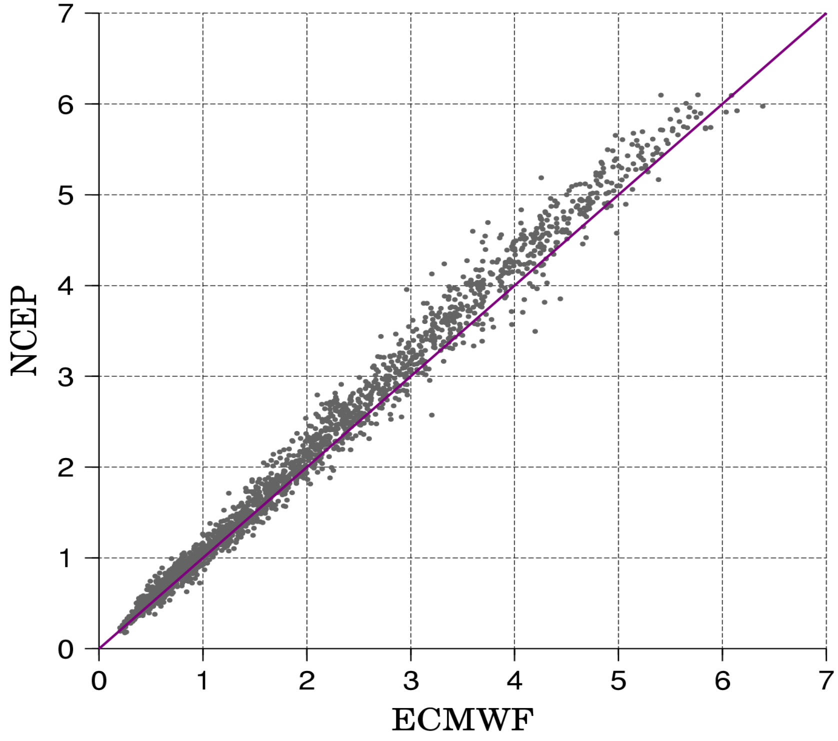


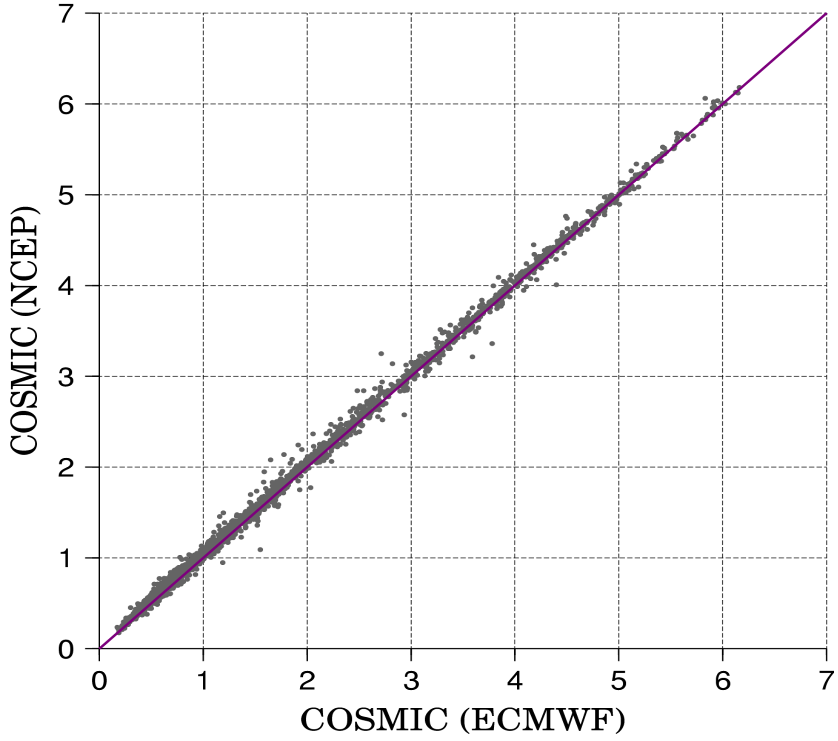
Does 1D-var WV results depend on initial WV ?



PW derived from NCEP or ECMWF analyses

PW retrieved from COSMIC GPS RO data using NCEP or ECMWF analysis as first guess

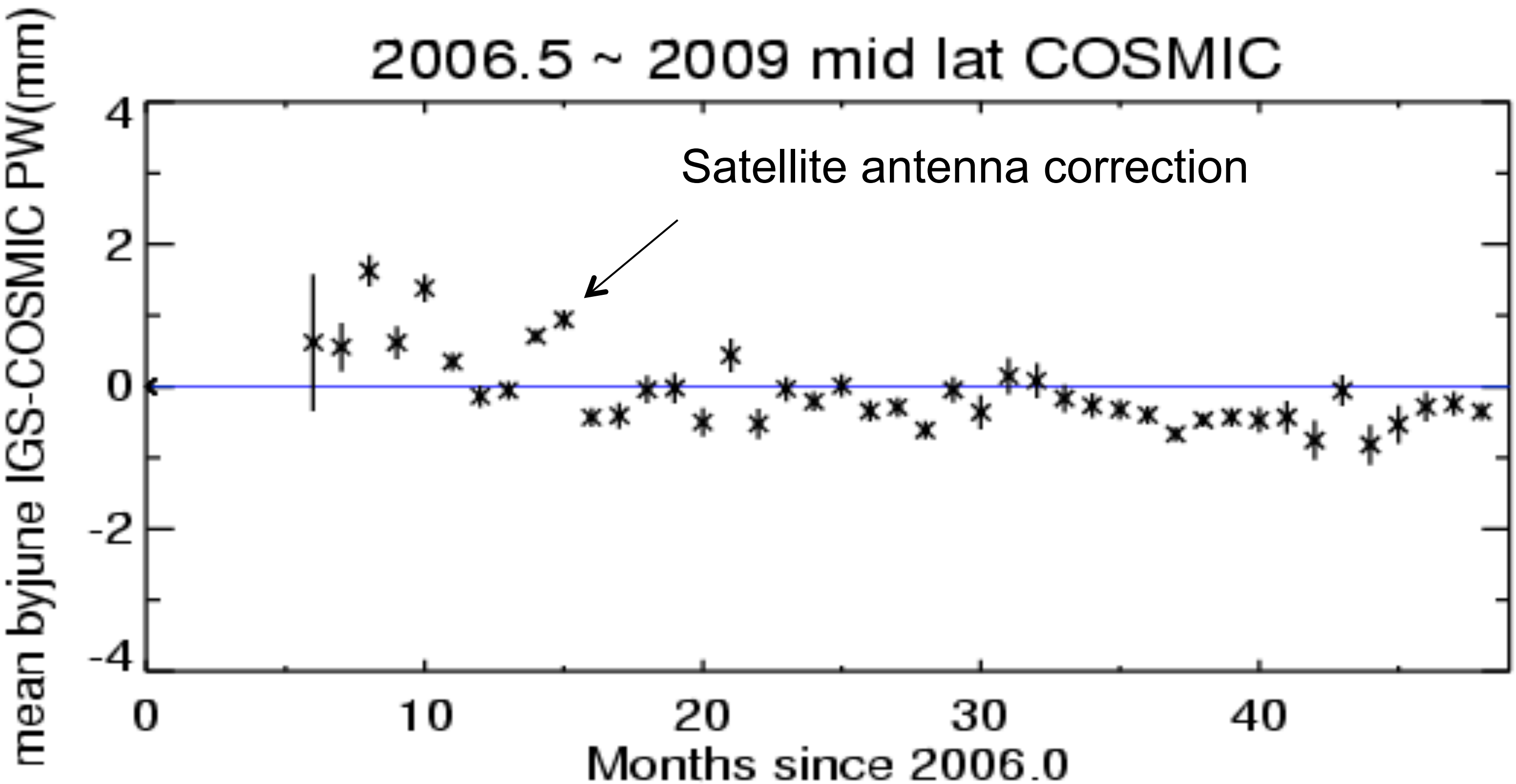


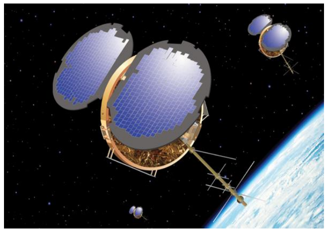


From: Wee and Kuo (2007)

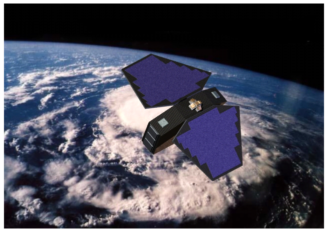
Comparison of PW data from COSMIC and global analyses

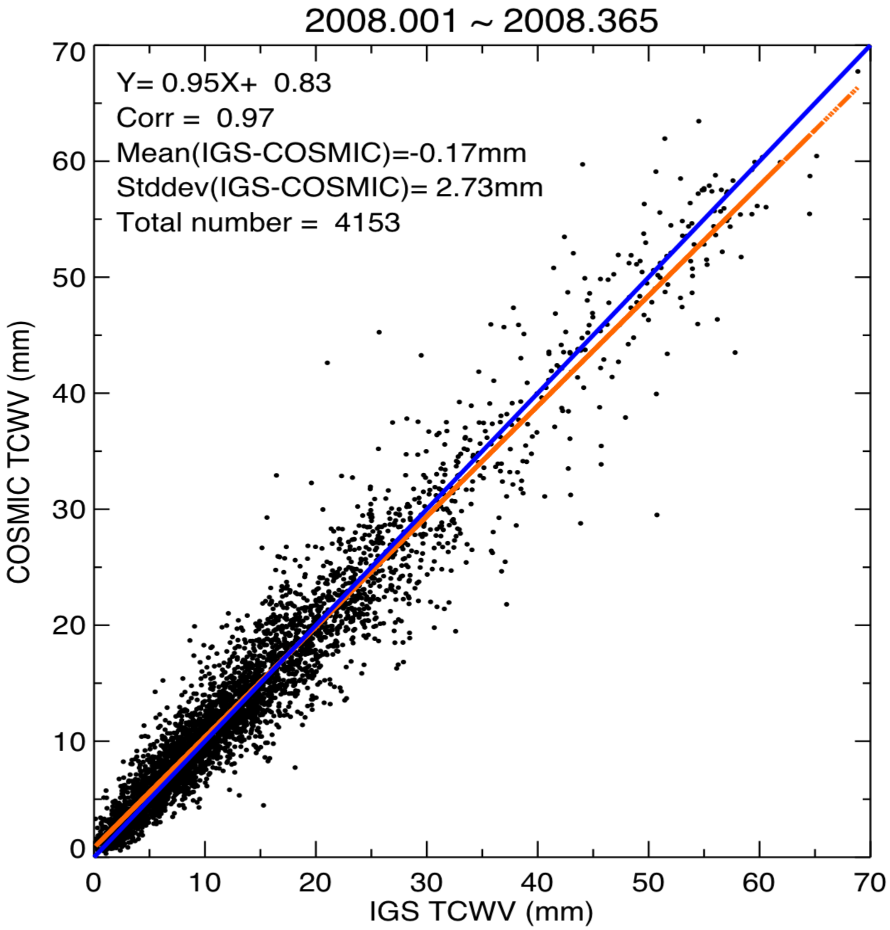
Time series of IGS-COSMIC TPW (mm)





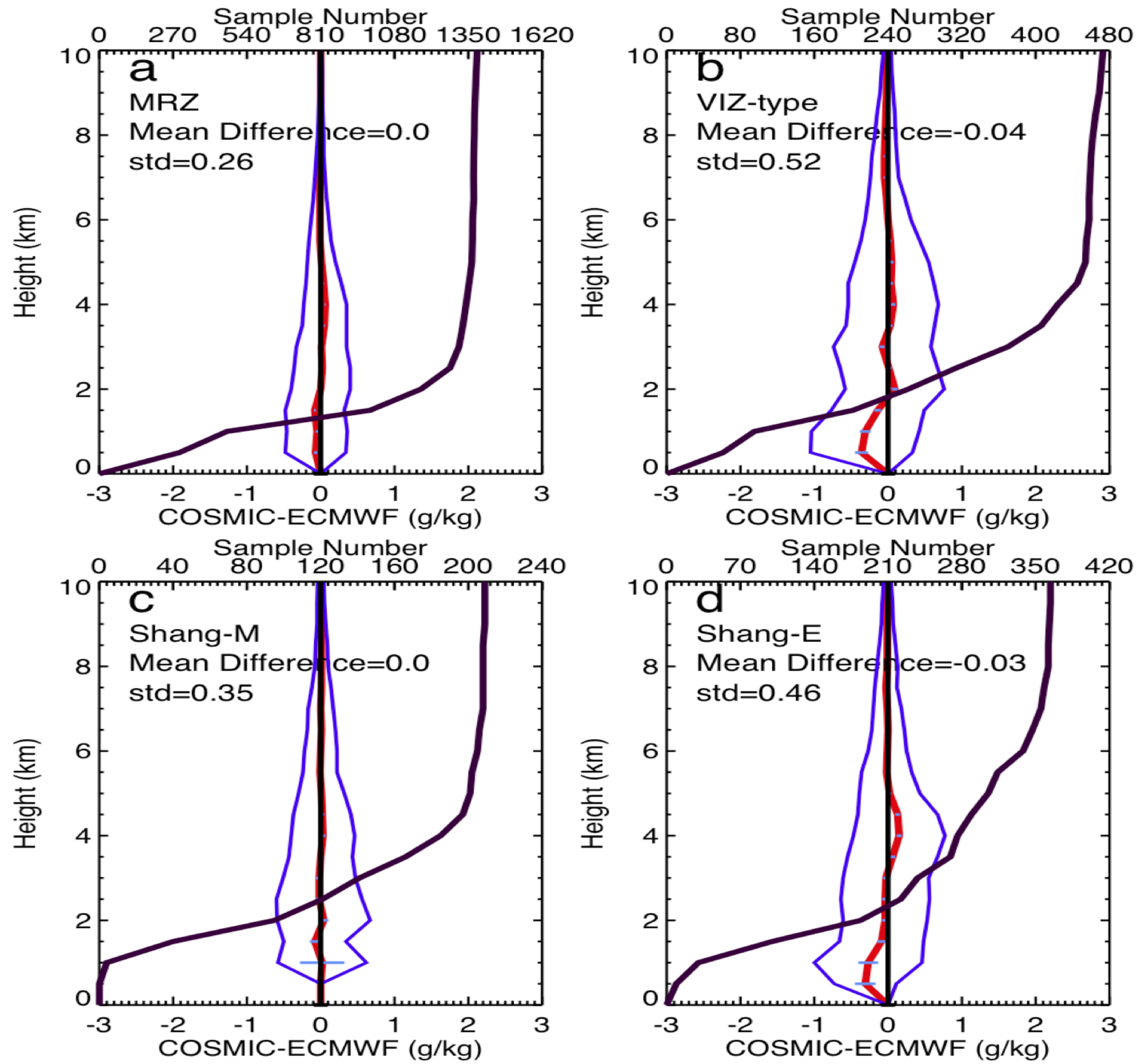
Using GPS RO Water vapor to assess systematic Radiosonde water vapor Biases





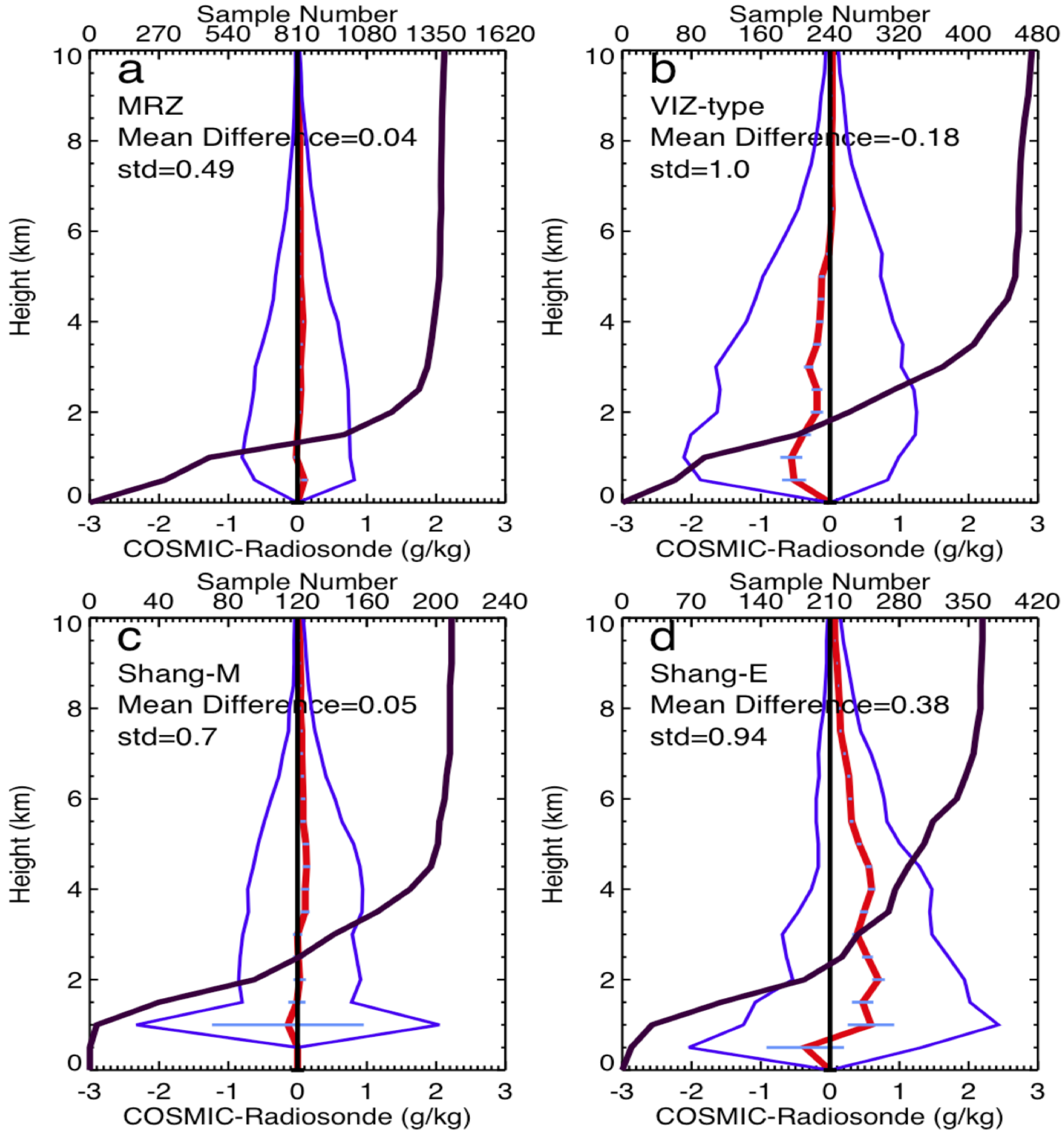
(Ho et al., 2010 BAMS)

6) Assessment of radiosonde water vapor bias using RO WV profiles



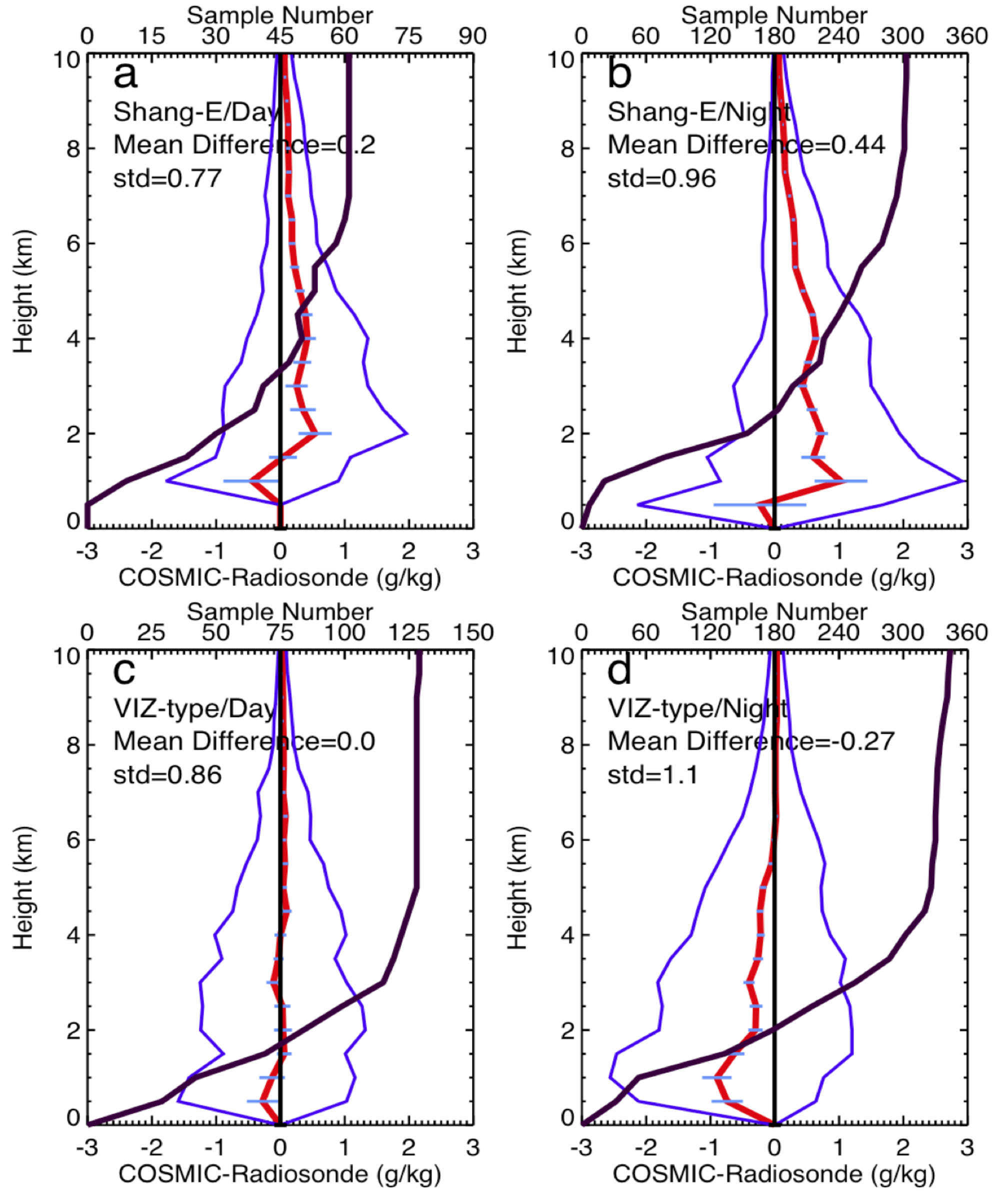
COSMIC-ECMWF Water vapor (g/kg)

(Ho et al., 2010, Remote Sensing)



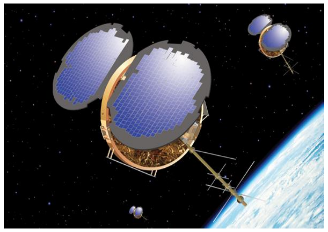
COSMIC-Radiosonde Water vapor (g/kg)

(Ho et al., 2010, Remote Sensing)

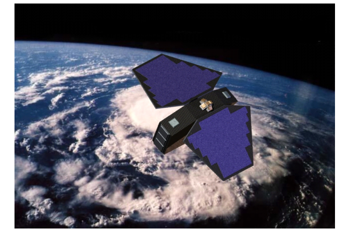


(Ho et al., 2010, Remote Sensing)

COSMIC-Radiosonde Water vapor in day and night (g/kg)



Using GPS RO Total Water Vapor Column to detect ENSO signals

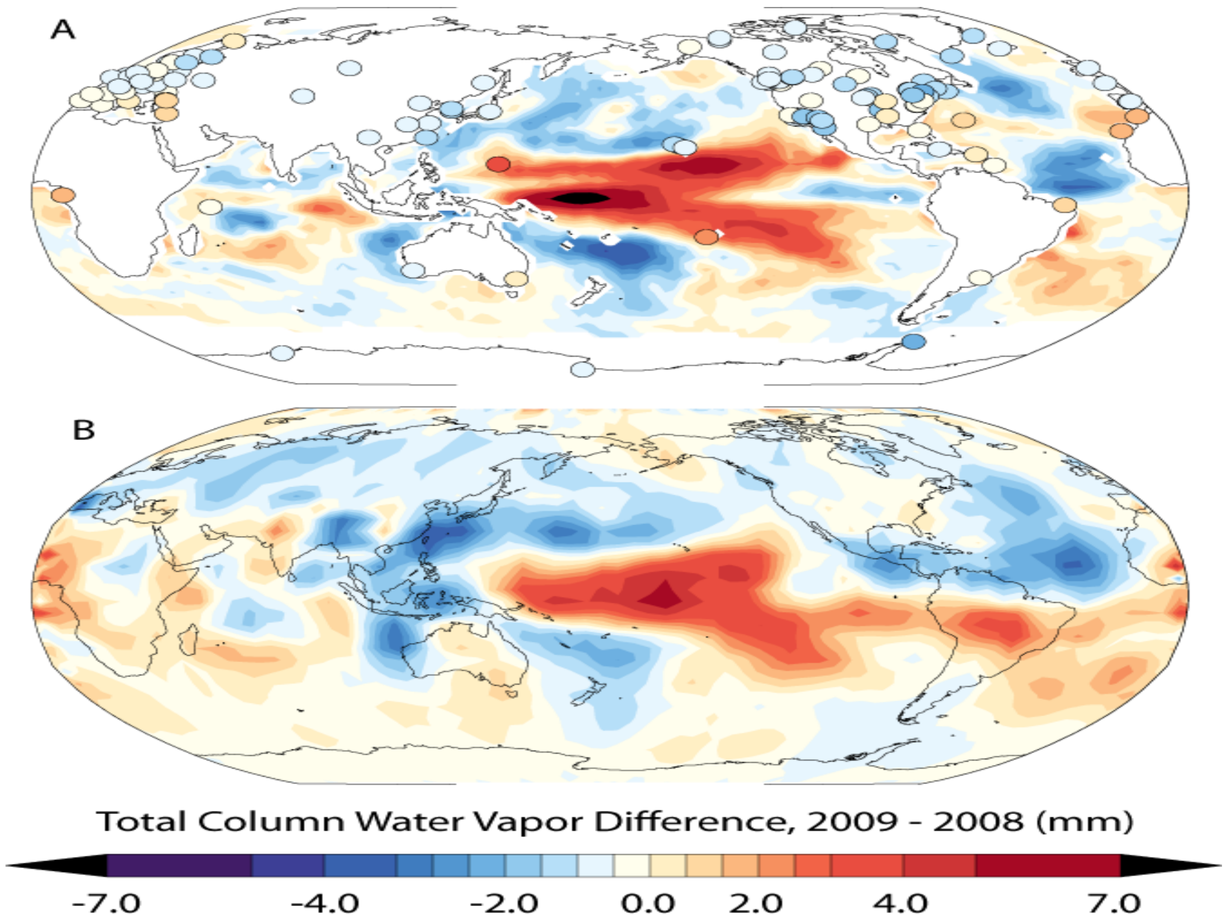


TWP 2009-2008

GB-GPS

AMSR-E

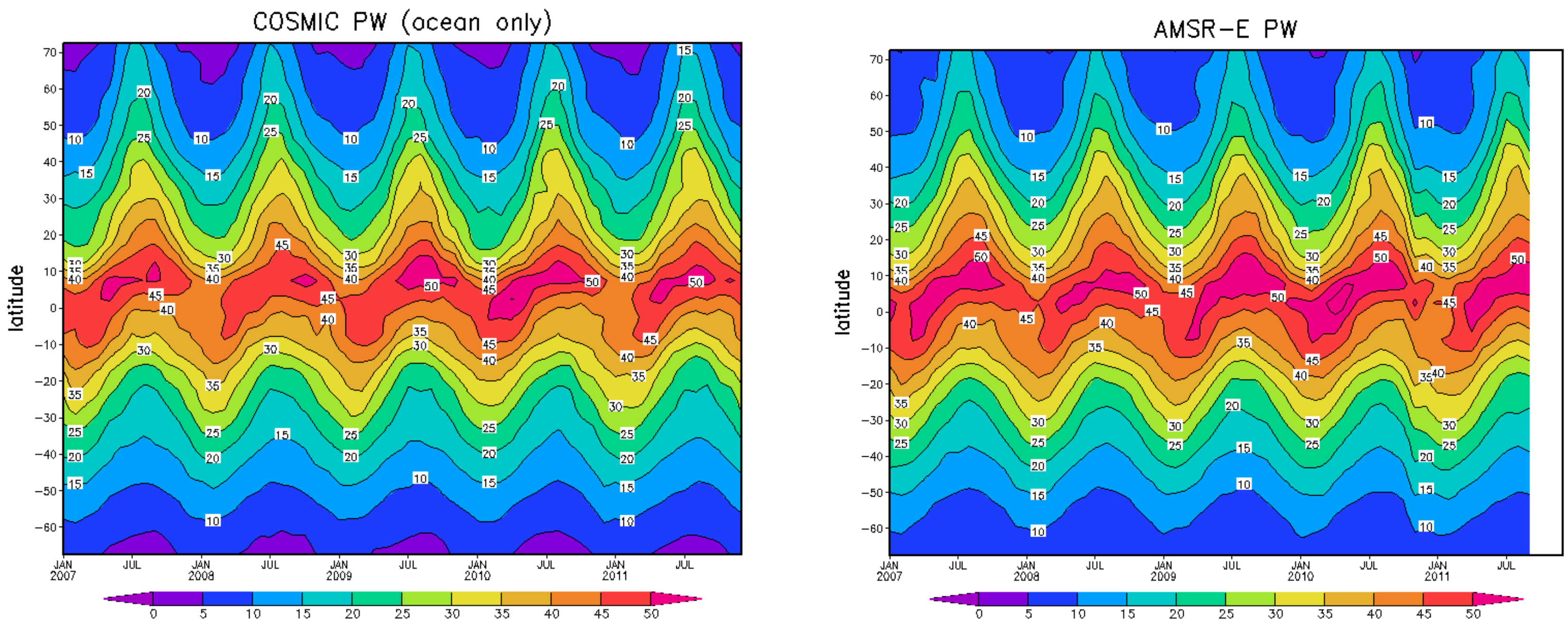
COSMIC



(Mears, Ho et al., 2010, 2011 BAMS)

7). Using RO data to study modes of variability including variability of tropopause, PBL, TLS temperature anomalies, water vapor feedback, MJO, and ENSO

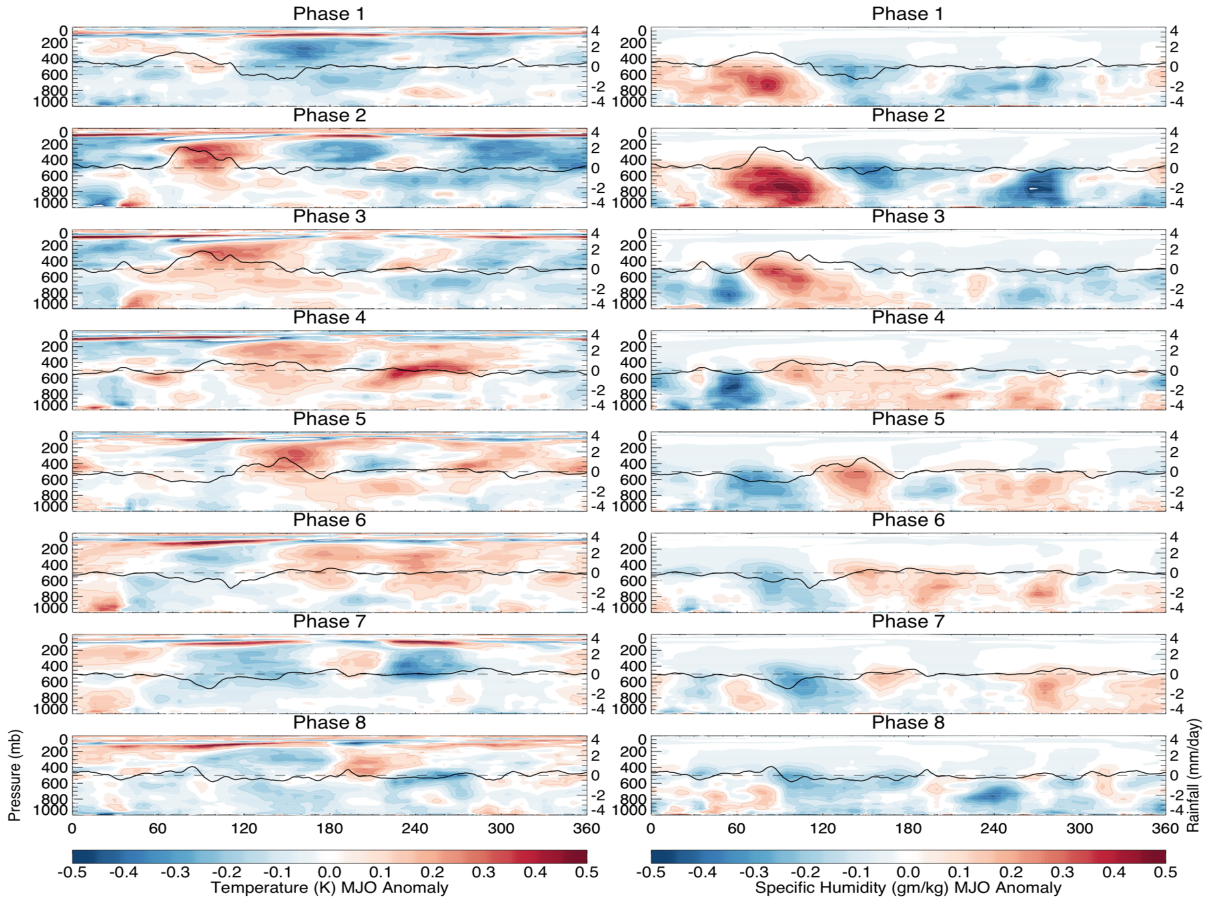
a. Using COSMIC data to quantify characteristics of global precipitable water in ENSO events



Latitudinal variations of monthly mean PW (mm) in 2007-2011 for COSMIC (left panel) and AMSR-E (right panel)

Wen-Hsin Teng, Ching-Yung Huang, **S.-P. Ho**, Ying-Hwa Kuo, and Xin-Jia Zhou, Characteristics of Global Precipitable Water in ENSO Events Revealed by COSMIC Measurements, *J. Geophy. Research,* 2012 (accepted)

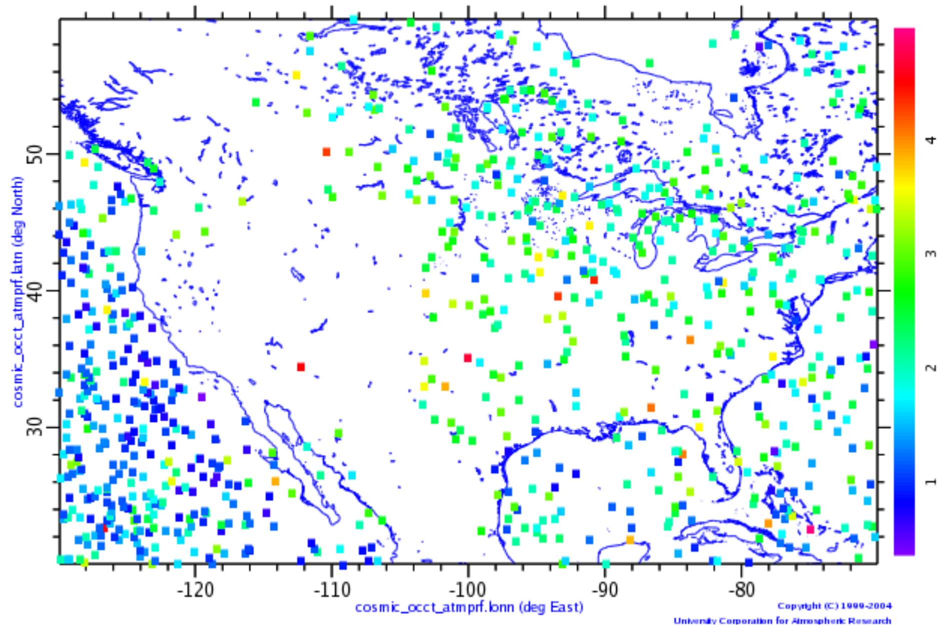
8). Using RO data to study the Structure and Evolution of Madden Julian Oscillation from COSMIC



Vertical structures of RO temperature (left) and specific humidity (right) anomalies (shading) averaged over 8°S-8°N for a composite cycle (8 phases) duing a MJO event. The overlaid solid black lines are TRMM rainfall anomalies (scale at right) for the same period of COSMIC RO data.

Zeng, Zhen, **S.-P. Ho**, S. Sokolovskiy (2012), The Structure and Evolution of Madden- Julian Oscillation from FORMOSAT-3/COSMIC Radio Occultation Data, *J. Geophy. Research* (accepted).

9) Distribution of heights of strong inversion layers (BAL > 1E-2 rad) over North America

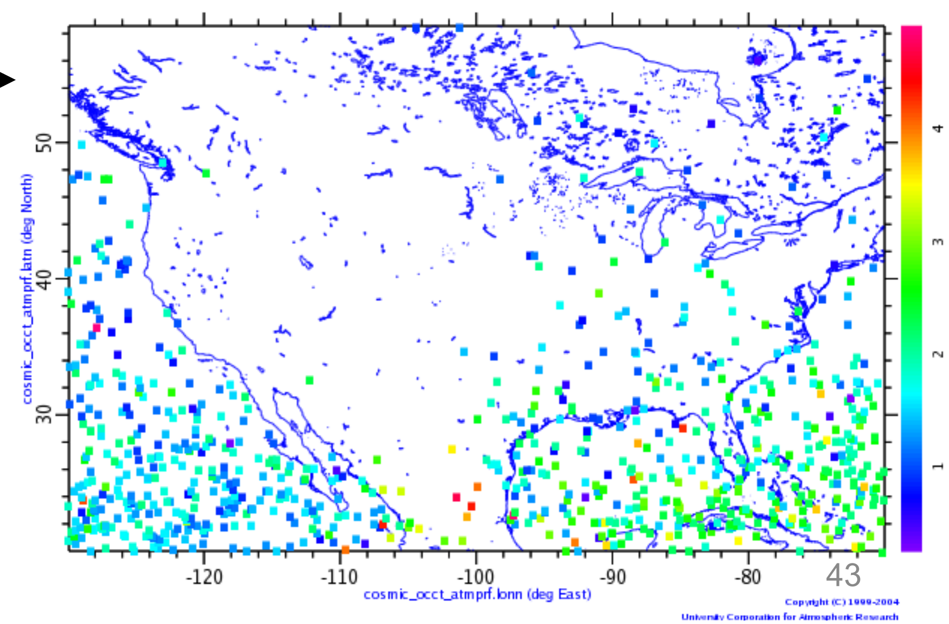


Summer:

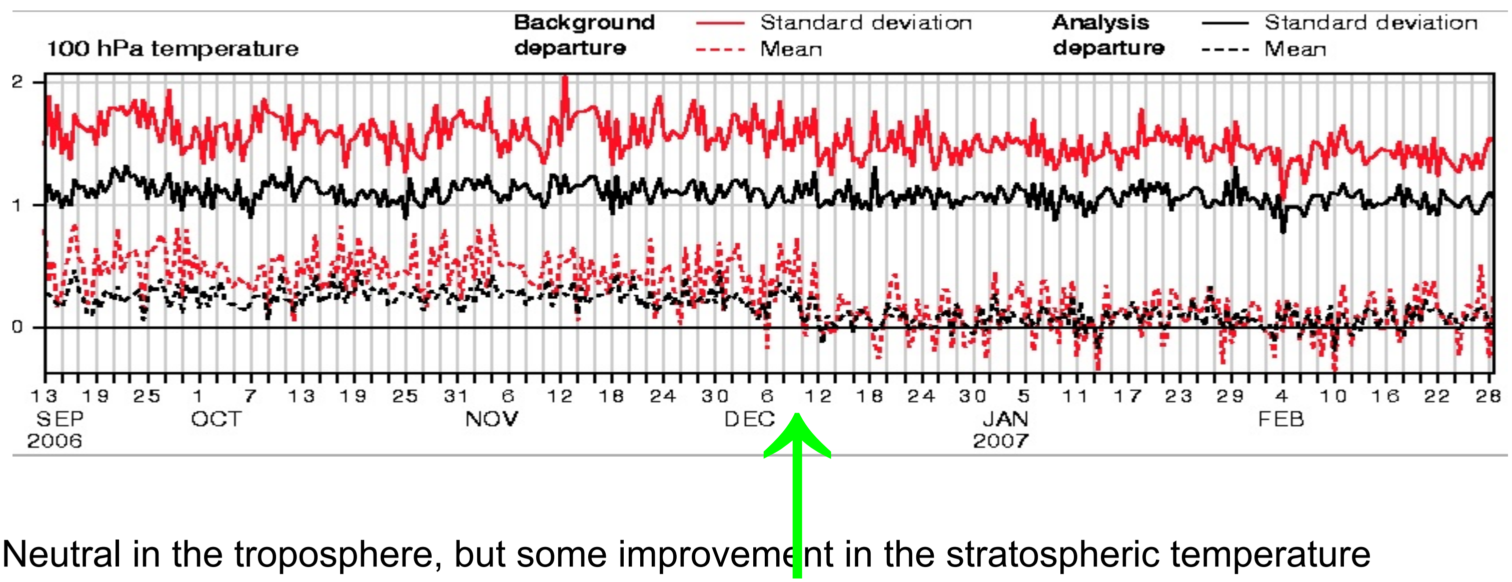
most sharp inversion layers (pronounced ABL top) over the ocean and plains; less over mountains

Winter:

- fewer strong inversion layers over continent, more over the ocean southwards
- shallower ABL over continent
- deeper ABL over the ocean than in Summer



10) ECMWF Operational implementation of GPSRO on Dec 12, 2006

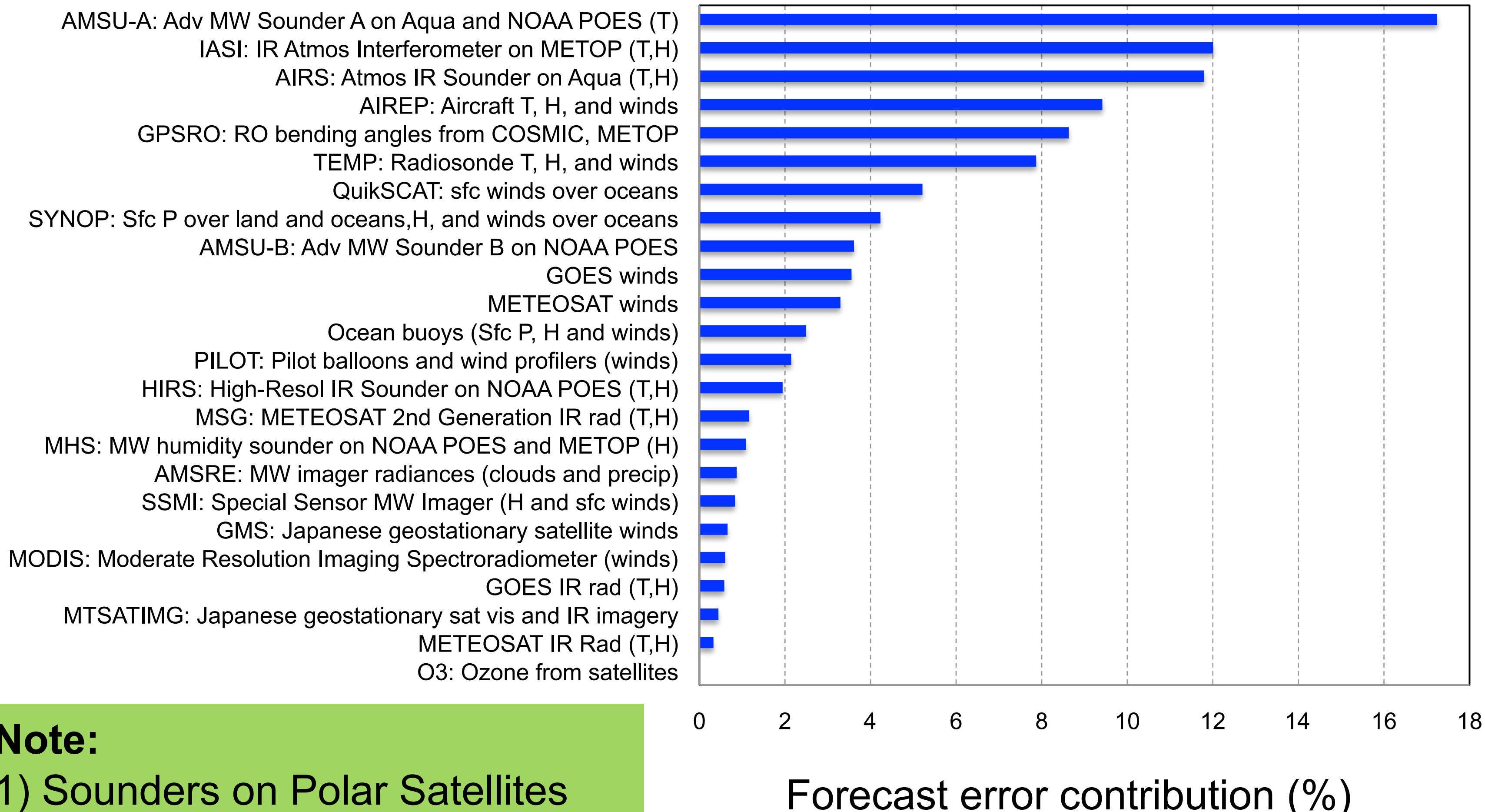


Neutral in the troposphere, but some improvement in the stratospheric temperature scores. **Obvious improvement in time series for operational ECMWF model**.

Dec 12, 2006 Operational implementation represented a quite conservative use of data. No measurements assimilated below 4 km, no rising occultations.

Nov 6, 2007 Operational assimilation of rising and setting occultations down to surface

11) Operational ECMWF system September to December 2008. Averaged over all model layers and entire global atmosphere. % contribution of different observations to reduction in forecast error.

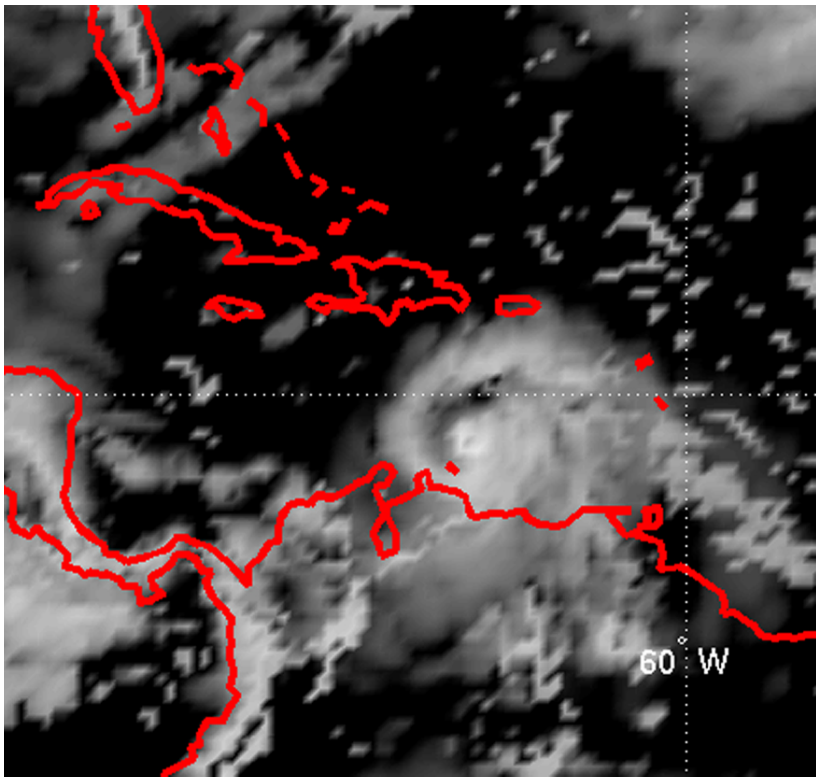


Note:
1) Sounders on Polar Satellites reduce forecast error most
2) Results are relevant for other NWP Centers, including NWS/ NCEP

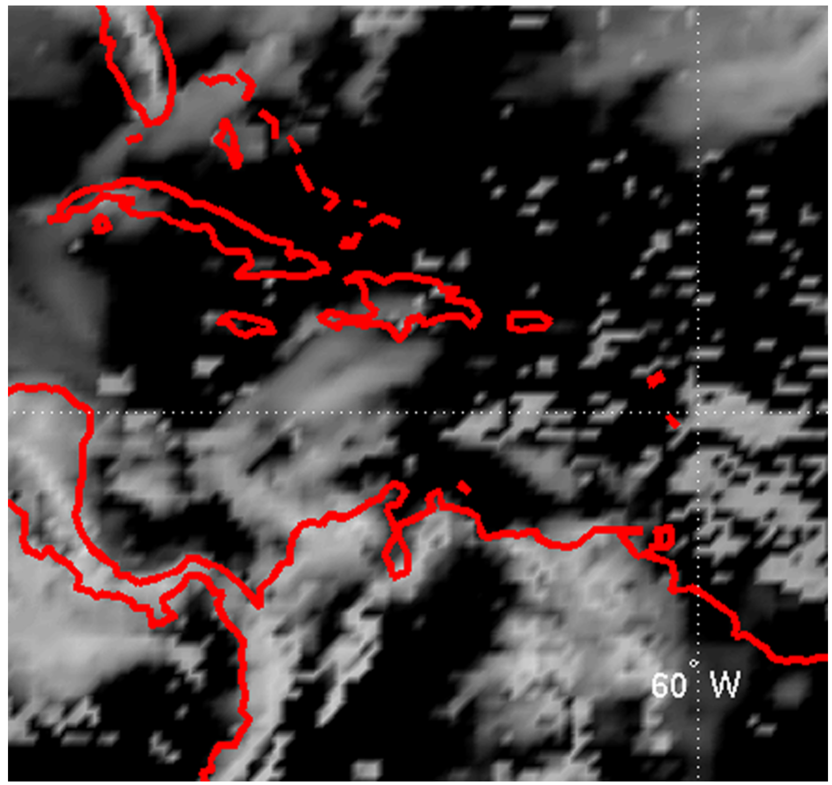
Courtesy: Carla Cardinali and Sean Healy, ECMWF

12) Impact of COSMIC on Hurricane Ernesto (2006) Forecast

With COSMIC



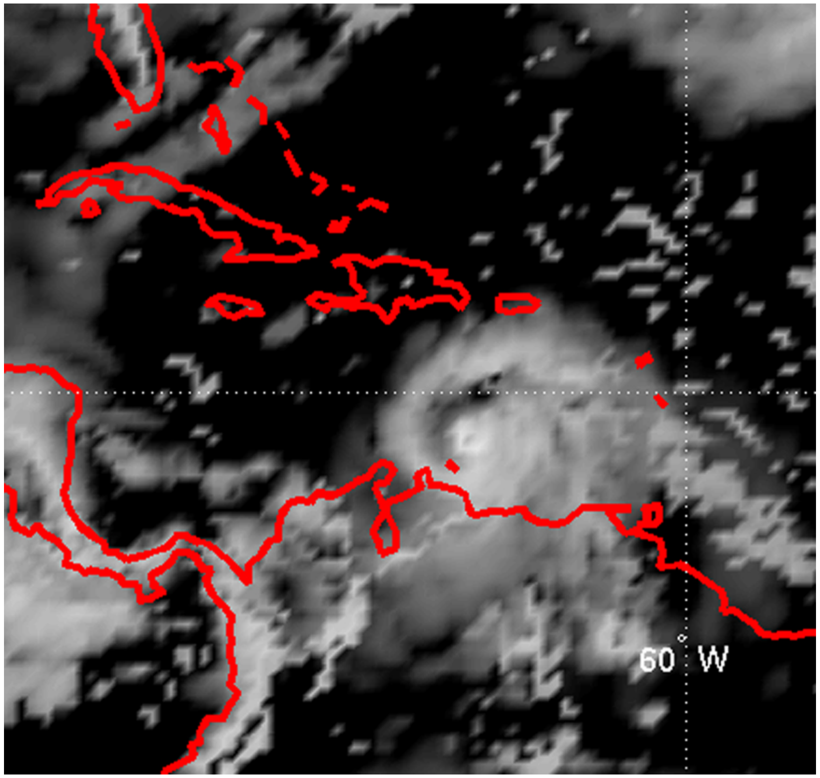
Without COSMIC



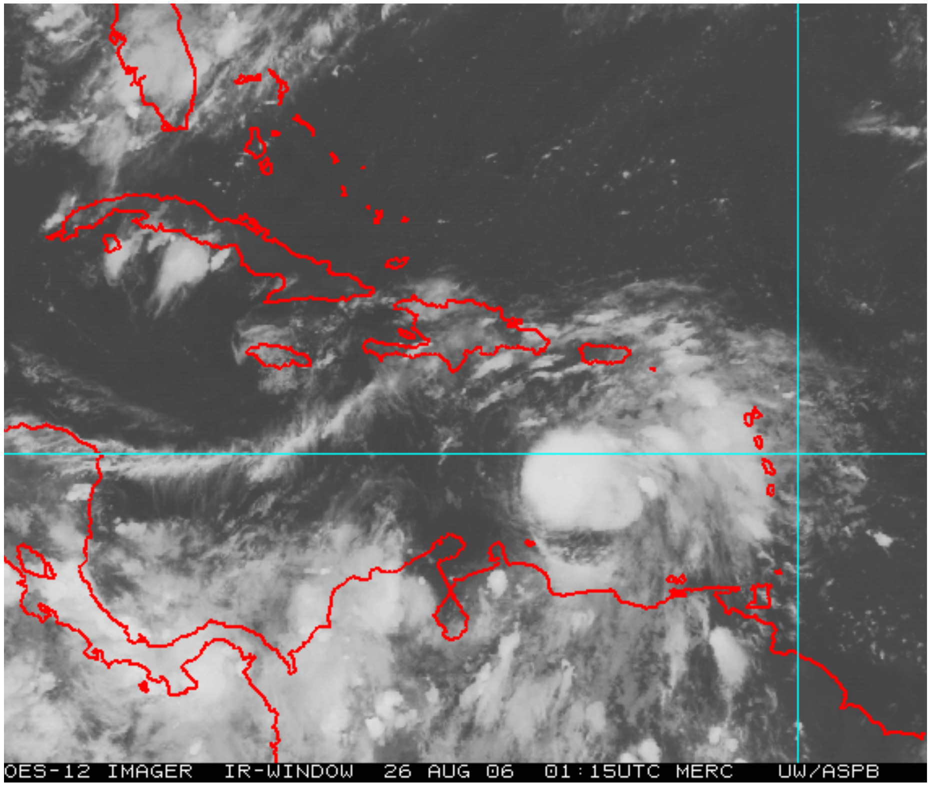
Results from Hui Liu, NCAR

Impact of COSMIC on Hurricane Ernesto (2006) Forecast

With COSMIC



GOES Image

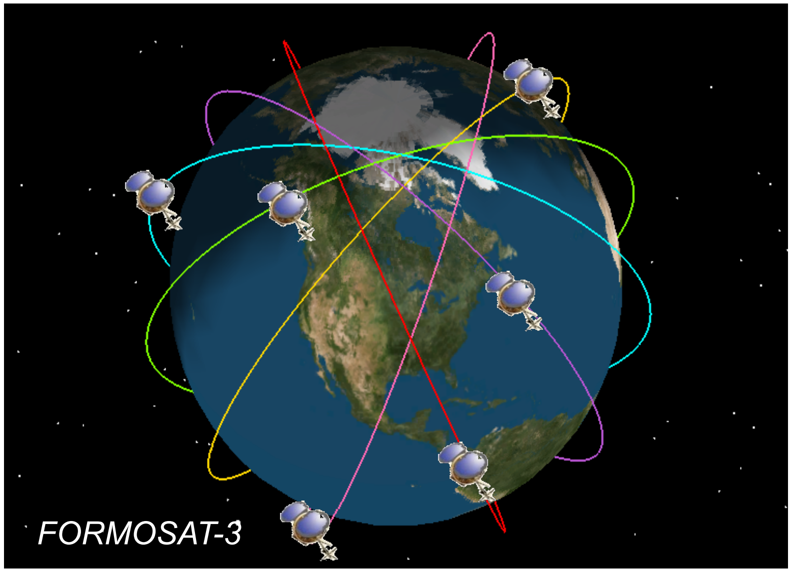


GOES Image from Tim Schmitt, SSEC

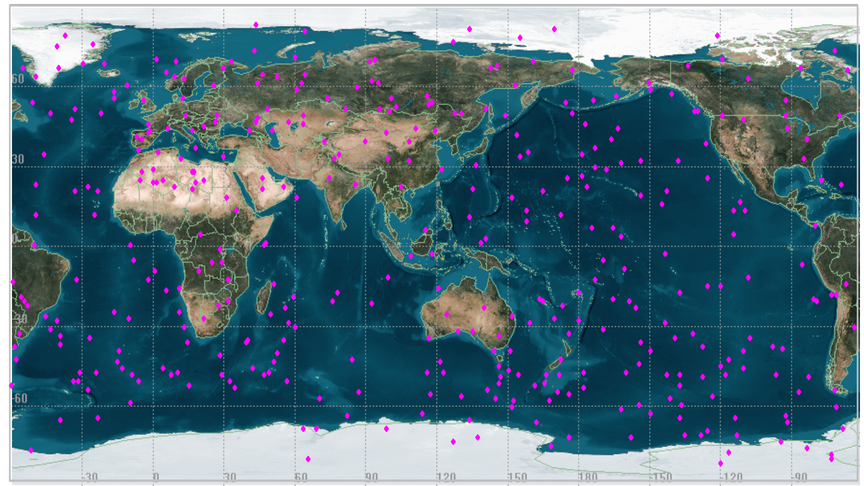
Outline of Presentation

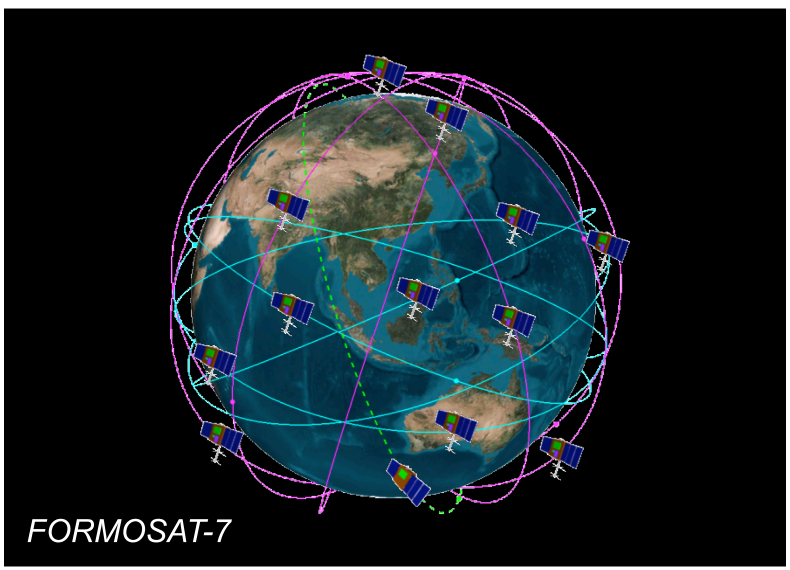
- **Summary of radio occultation (RO) technique and characteristics of RO observations and data quality**
- **Summary and status of COSMIC**
- **Highlights of COSMIC results from Troposphere to Stratosphere**
- **Potential applications of COSMIC II data**

COSMIC and COSMIC-2

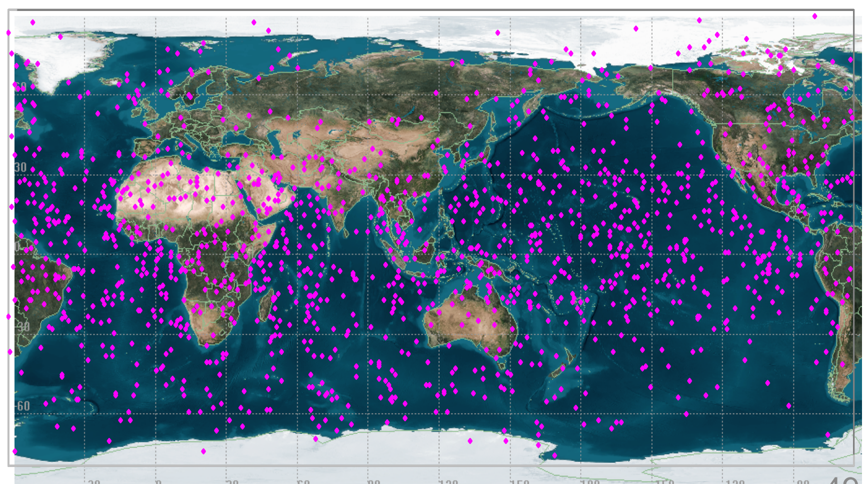


FORMOSAT-3 Occultations – 3 Hrs Coverage



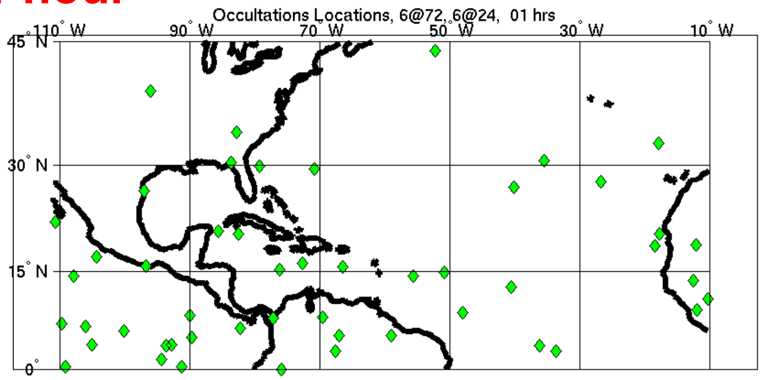


FORMOSAT-7 Occultations – 3 Hrs Coverage

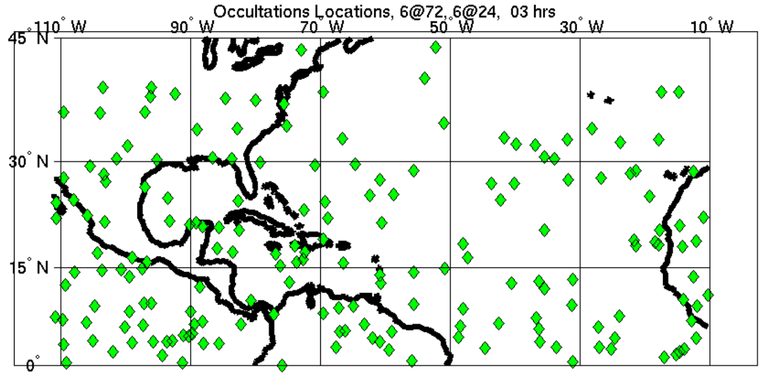


FORMOSAT-7/COSMIC-2 Soundings
GPS and GLONASS
(6@72°, 6@24°)

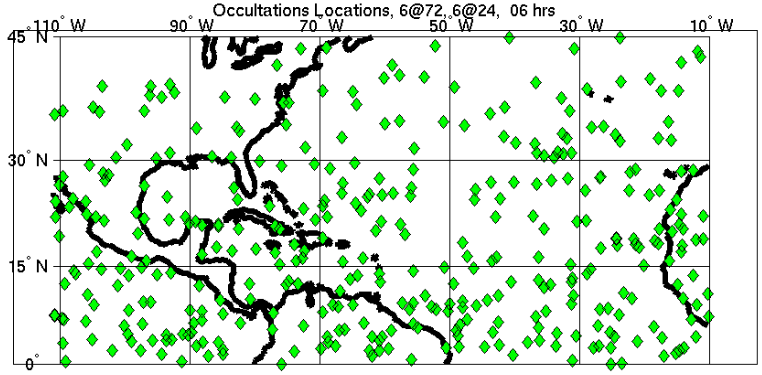
1 hour



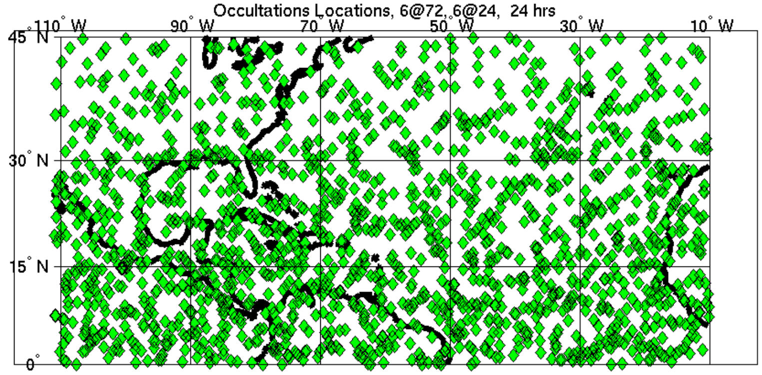
3 hour



6 hour



24 hour



The potentially new Meteorology/Weather Forecast applications that can be explored using COSMIC II data

- With significantly increased data density and quality, COSMIC-2 will provide significant data set to support science and operations.
- Deep penetration of tropical lower troposphere with high accuracy and high density will provide high-quality moisture observations under clouds, which is very important for a variety of studies:
  Tropical cyclone analysis and prediction,
  Global and regional PBL structures, etc.
- With less COSMIC RO data available daily, their impacts on NWP degrade. COSMIC-II shall dramatically boost the impact level of RO data on global and regional NWP.

The potentially new climate applications that can be explored using COSMIC II data: summaries from the COSMIC workshop

- With increase data density and quality, COSMIC-2 will provide significant data set to support science and operations
- Study of hydrological processes over the tropics
- Evaluation of climate prediction models – Assess their ability to capture climate processes
- Calibration of other satellites measurements – to build long-term climate records
- Improve accuracy and quality of global re-analyses

- Better resolving dynamical scales (gravity waves etc)
- Modes of variability
  - ENSO - enhanced density from COSMIC2, towards more of a gridded product with better time resolution
  - MJO
  - Equatorial Waves
  - QBO
- Structure of tropic storms:
- (Marine) PBL: height, structure, seasonal and diurnal behavior
- Combine with other datasets: TRMM, CloudSat, AIRS to study moisture, stability, cloud and precipitation
- Be part of a longer data record for defining the climate state and monitoring its changes

Closing comments

- Accurate, vertically resolved information about temperature and water vapor is fundamental requirements for detecting climate change and understanding the processes that shape it.
- The vertical resolution has to be adequate to resolve changes in the tropopause and in the boundary layer
- Clearly GPS has much to offer in understanding important climate processes