Study of Tropospheric Warming and Stratospheric Cooling using GPS RO from CHAMP

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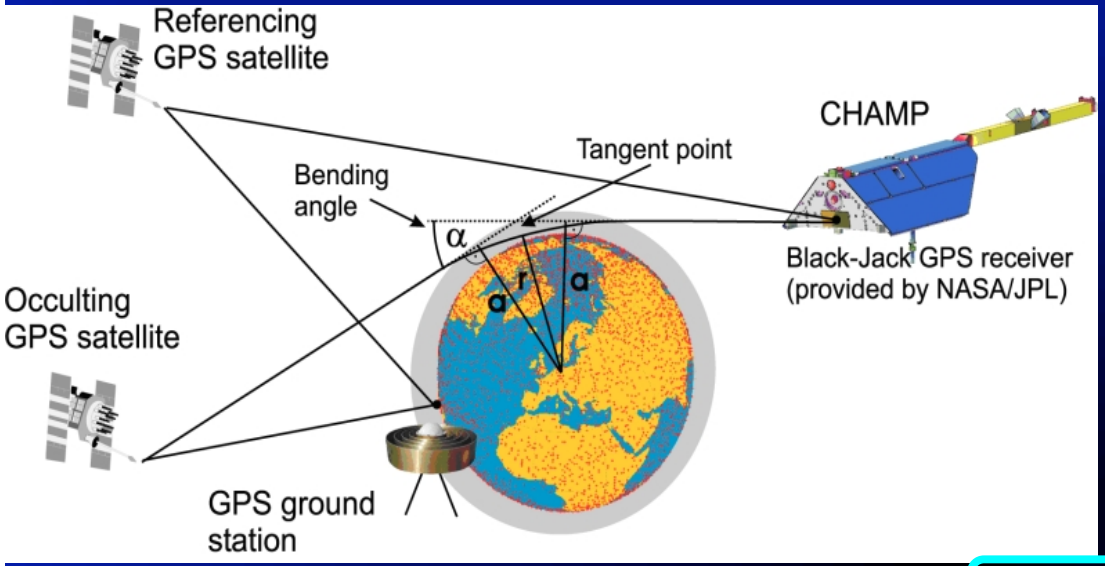
GPS Radio Occultation technique



Abel

$$n(x) = \exp\left(\frac{1}{\pi}\int_x^\infty \frac{\alpha(a)}{\sqrt{a^2 - x^2}}\,da\right)$$

Bending angle profile, α

↓ n α (p / T) + (e / T ²)

Refractive Index Profile, n

(dry atmosphere, Hydrostatic equilibrium)

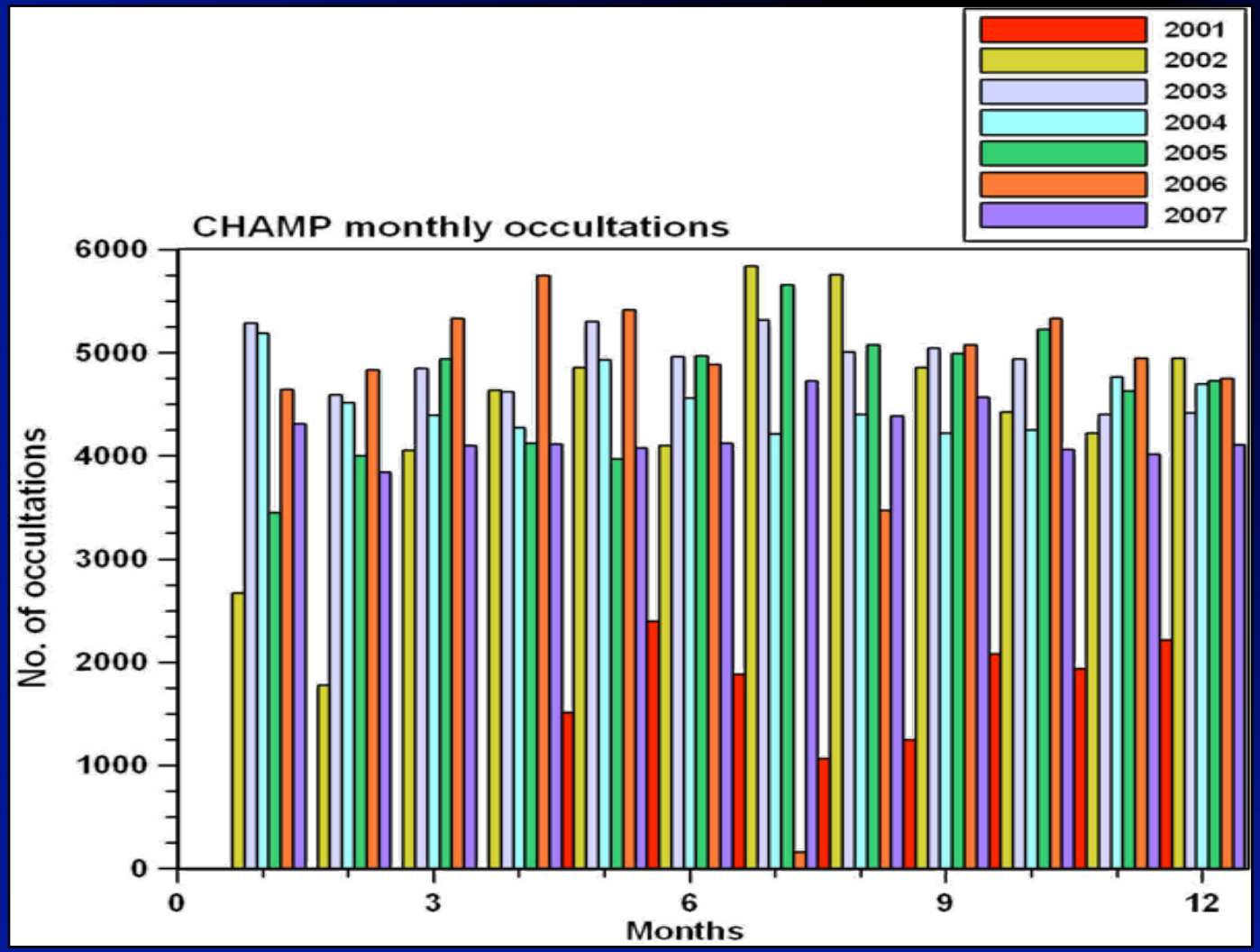
Temperature profile

(apriori temperature information)

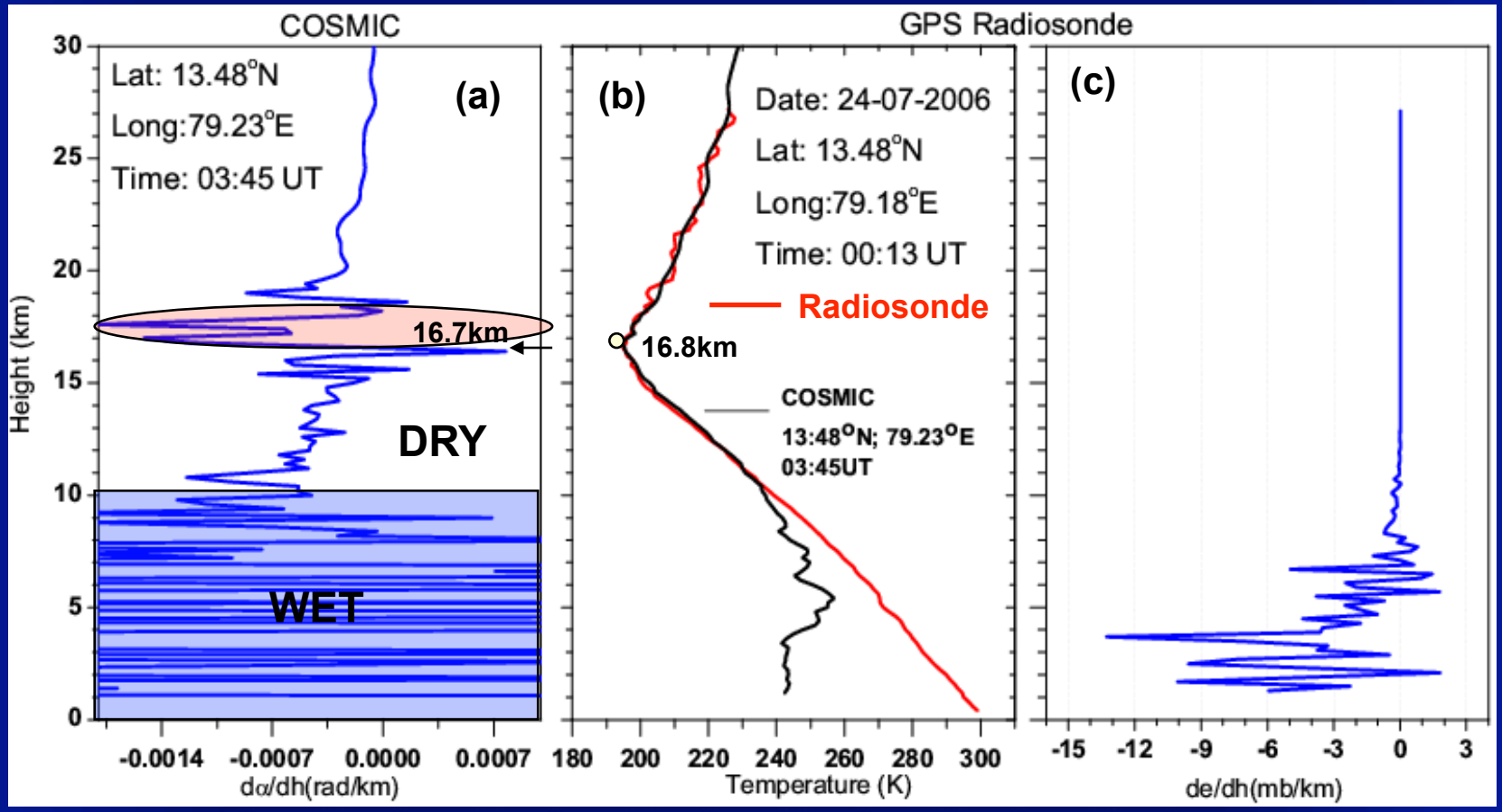
Humidity profile

Jens Wickert et al., JMSJ, 2004

CHAMP monthly occultations



Identification of Tropopause using Bending Angle profile from GPS Radio Occultation (RO): A Radio Tropopause



Vertical Profiles of
(a) Bending angle gradient observed by COSMIC,
(b) Temperature profile observed by Radiosonde and COSMIC, and
(c) Gradient of water vapor partial pressure from the GPS radiosonde measurement over Gadanki on 24 July 2006

Narayana Rao et al., GRL, 2007

Radio Tropopause: Definition

After a careful examination of the vertical profiles of the Bending Angle Gradient ($d\alpha/dh$), the following criterion is arrived at to identify the Radio Tropopause:

Above the altitude range of moist atmosphere, the altitude at which the gradient of the Bending Angle is maximum (taking sign into account) and above which it decreases for at least 1 km is defined as Radio Tropopause.

At polar latitudes, where it is often difficult to identify the tropopause altitude from temperature profiles, the present method is a more reliable means of identifying the tropopause.

Narayana Rao et al., GRL, 2007

Radio Stratopause: Definition

From an examination of a number of profiles of the gradient of the bending angle, the following criterion is evolved for identification of stratopause.

The altitude, in the height range of 40-60 km, at which the gradient of the bending angle,'α', approaches close to zero and remains close to zero for about 1-2 km is defined as stratopause altitude.

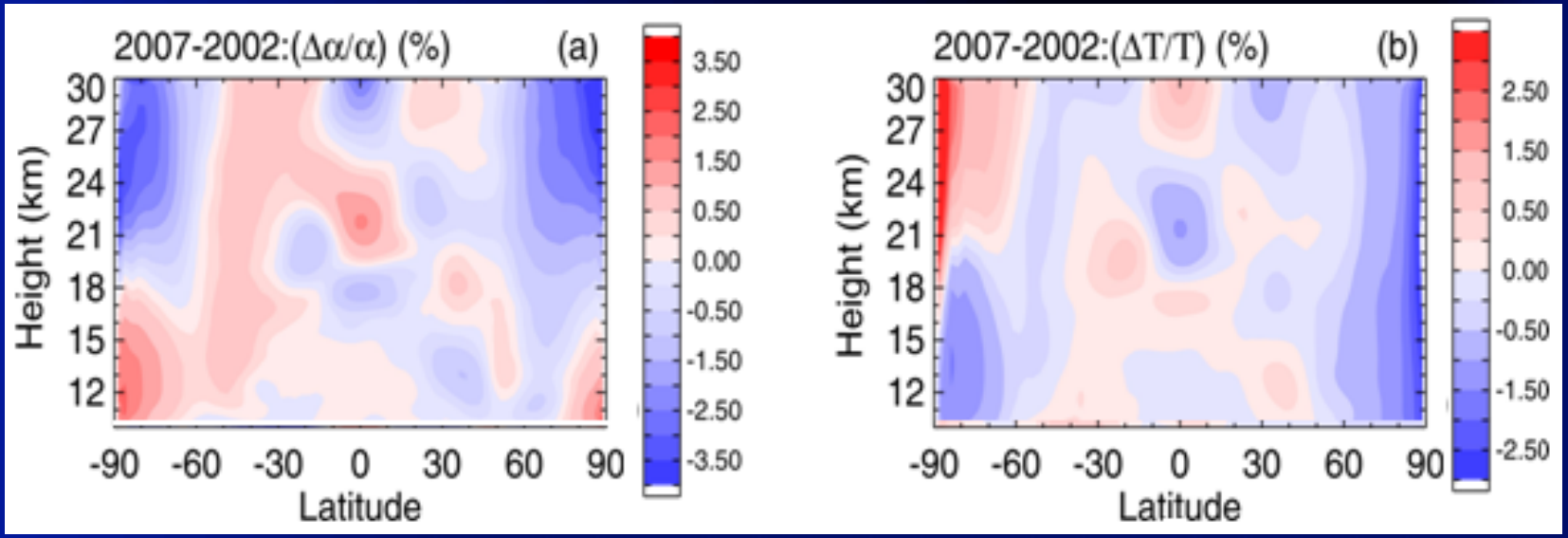
The stratopause identified in this manner from the profile of the gradient of the bending angle (α) is defined as Radio Stratopause, RSP.

Narayana Rao et al., GRL, (communicated)

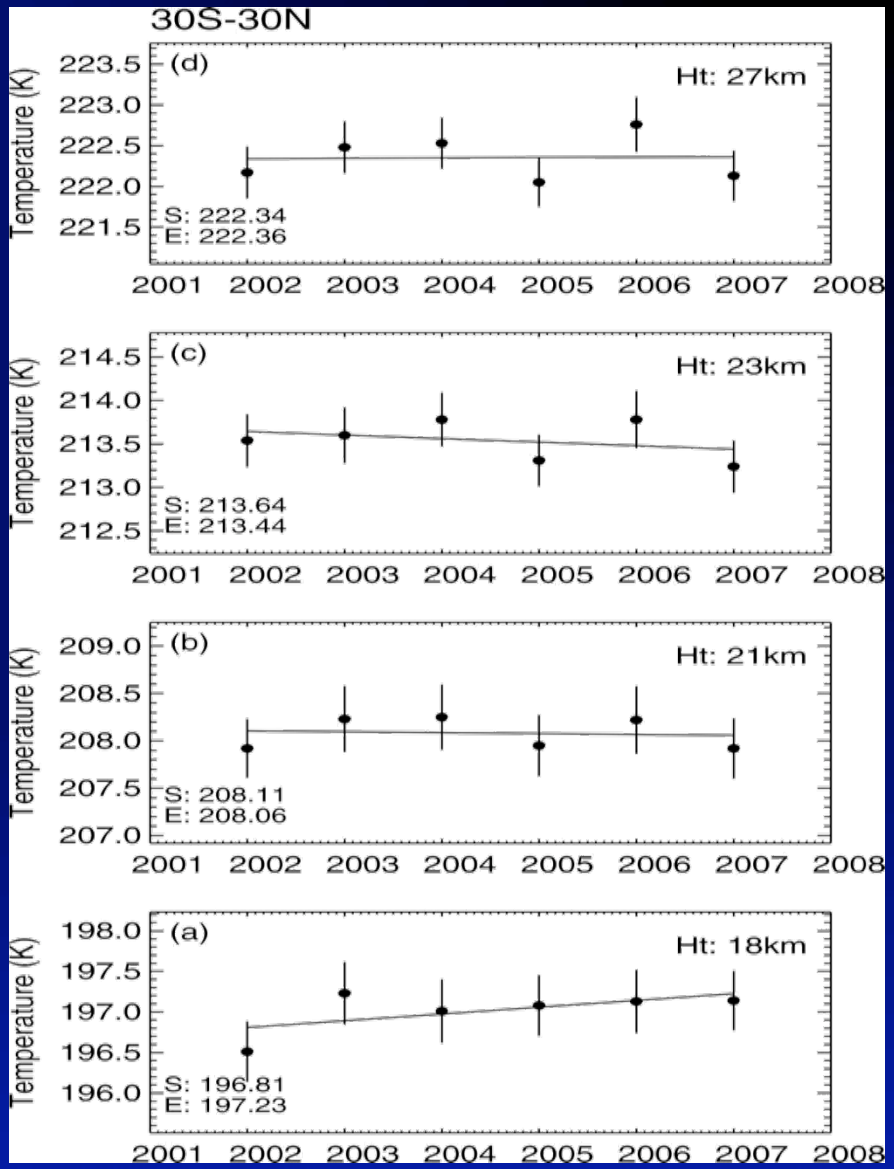
Tropospheric Warming and Stratospheric cooling

- Radiosondes
- Satellite-borne Microwave Sounders
- Rockets
- Lidars
- GPSRO

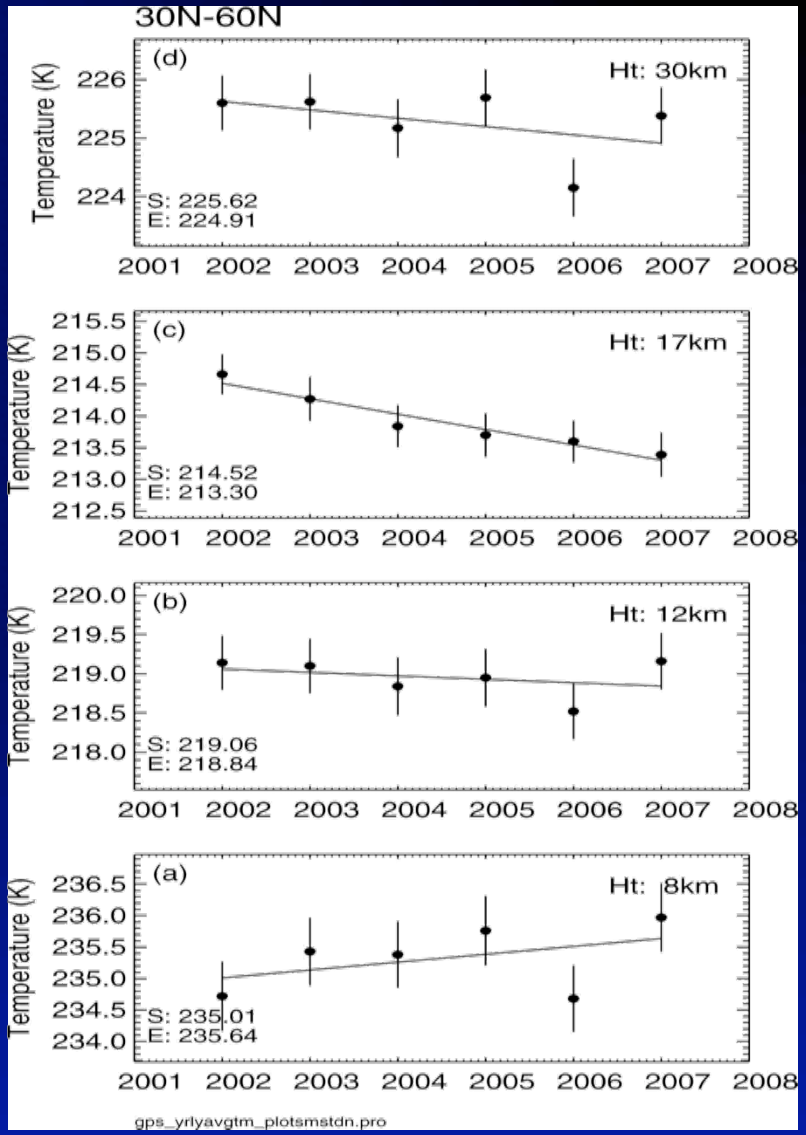
Annual variation of bending angle and temperature



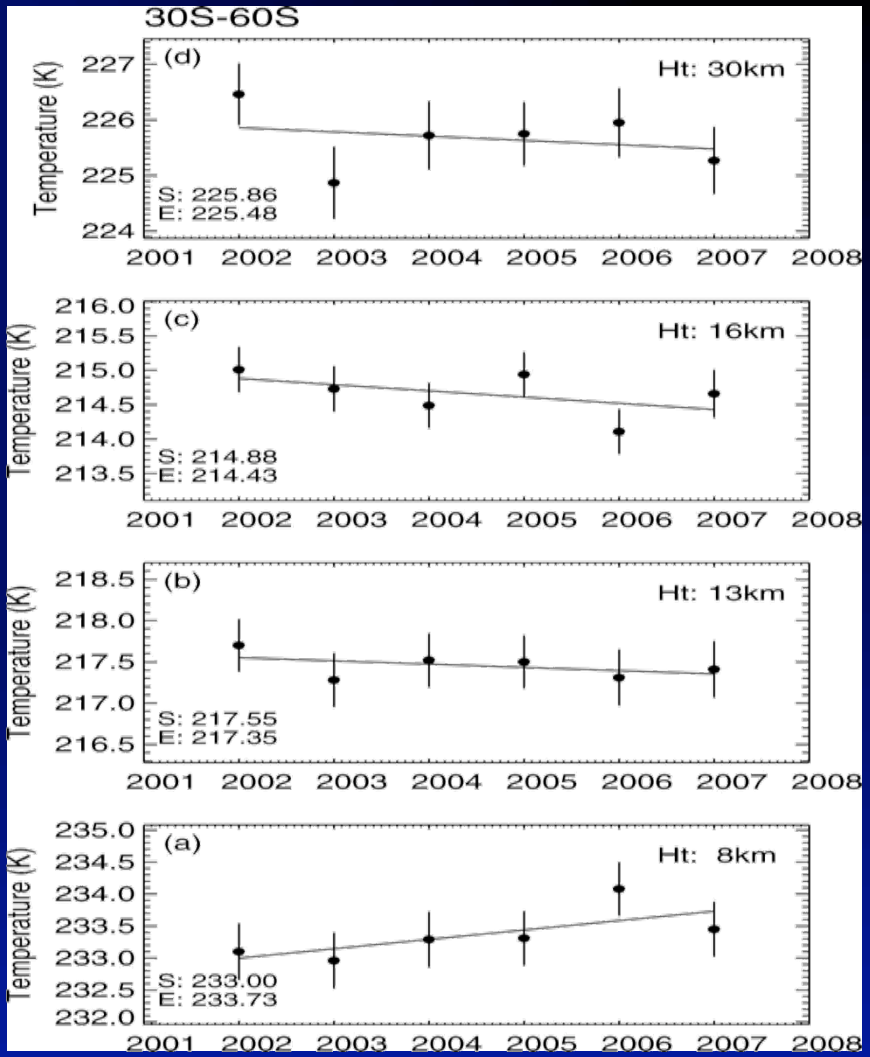
Annual mean temperature trends: 30S – 30N



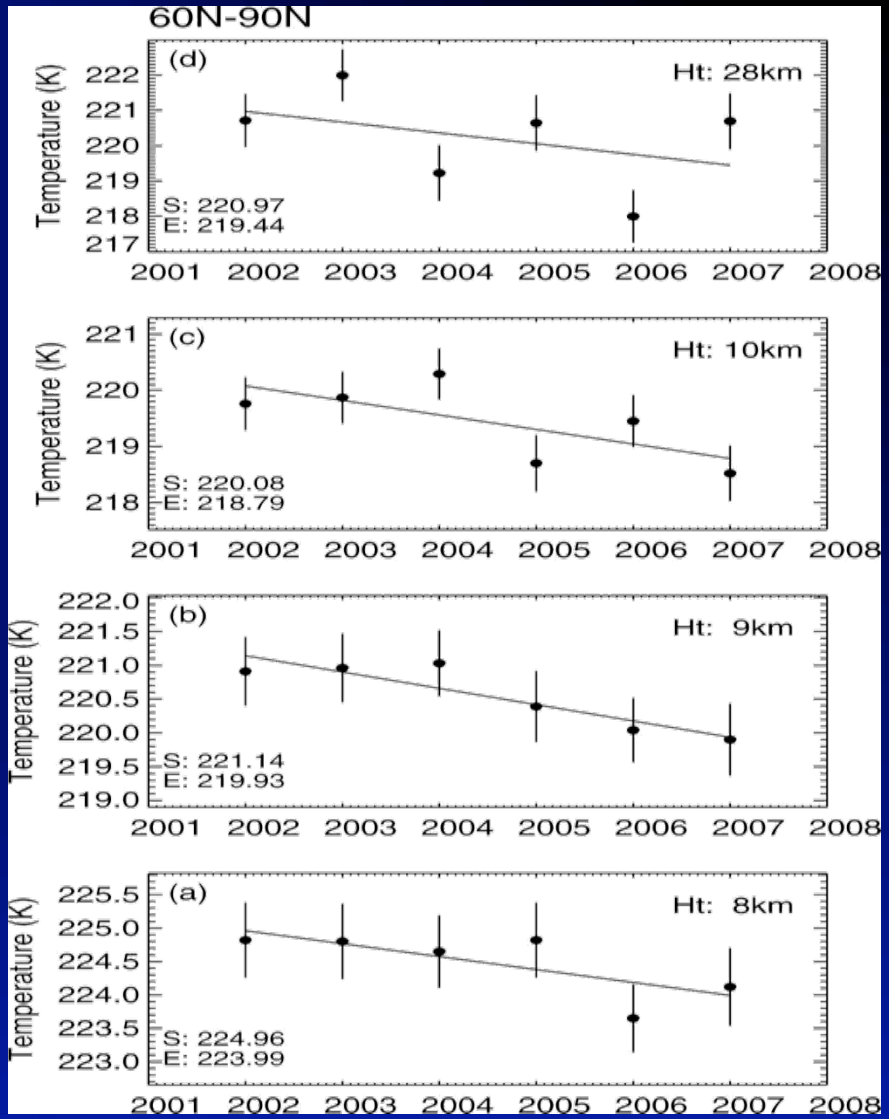
Annual mean temperature trends: 30N – 60N



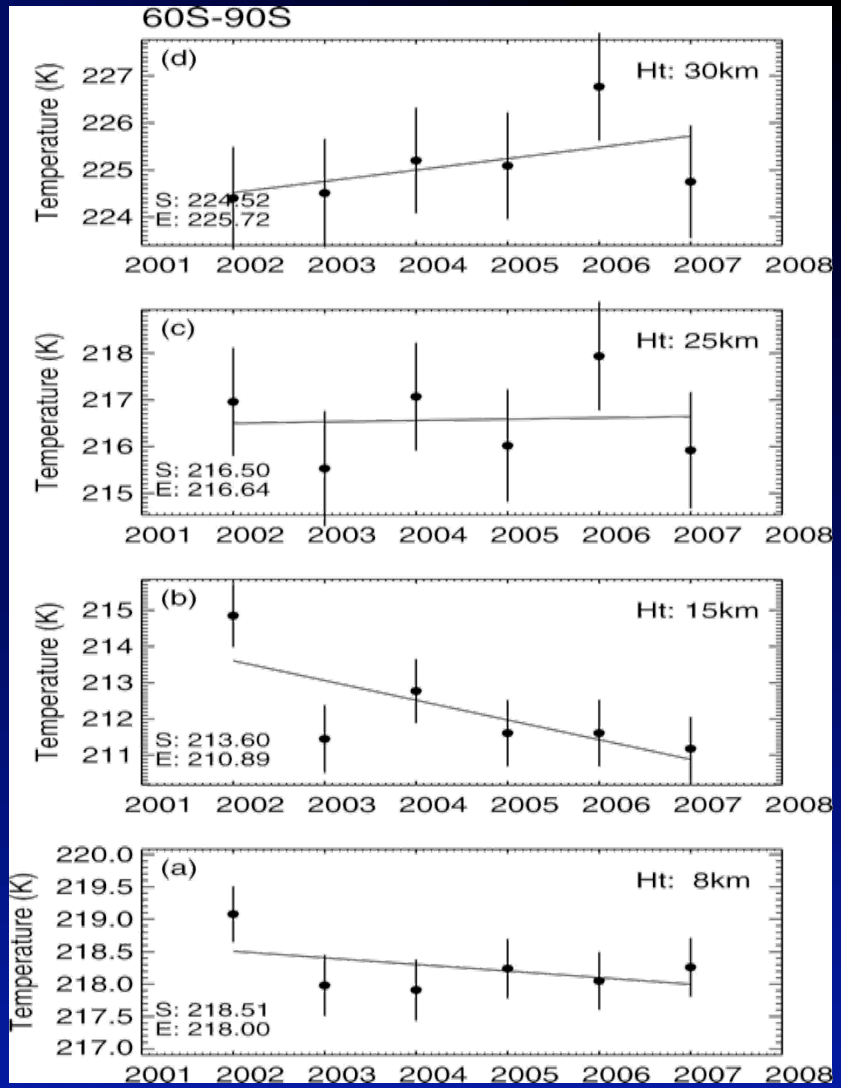
Annual mean temperature trends: 30S – 60S



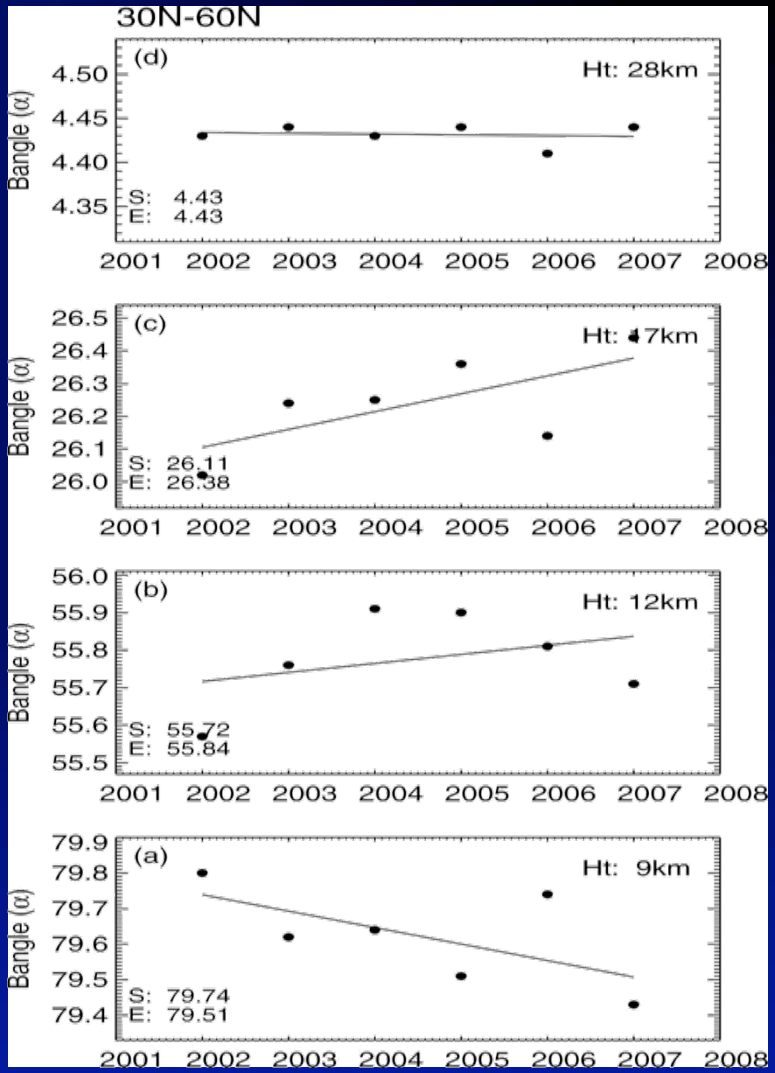
Annual mean temperature trends: 60N – 90N



Annual mean temperature trends: 60S – 90S



Annual mean Bending Angle trends: 30N – 60N



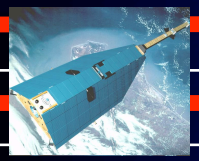
GPS RO occultation missions – Then and Existing

1995 - 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008

GPS/MET — UCAR, Apr 95-Feb 97

SUNSAT — S. Africa, Feb. 99

ORSTED — Denmark, Feb.99



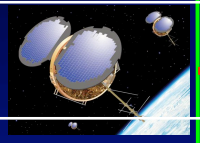
CHAMP — GFZ, July 2000

SAC-C — Argentine + JPL, Nov 2000

IOX — DoD, JPL, Sep. 2000

GRACE — DLR, NASA, Mar. 2002

COSMIC — UCAR + Taiwan-NSPO, 6 LEO satellites, Apr. 2006

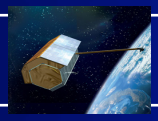


Data rate 2500/day

GPS RO occultation missions – forthcoming

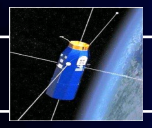
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014

Terrasar X, Feb. 2007 Germany



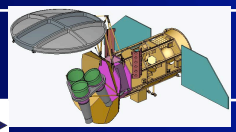
METOP, Oct. 2006 EUMSAT

C/NOFS DoD, USA

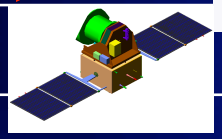


EQUARS (?) Brazil-INPE + RISH, 2007 (20 deg)

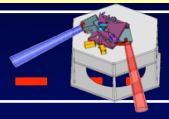
Oceansat-2 India-ISRO+ Italy-ASI, 2008 (polar orbit)



Megha Tropiques India-ISRO+France-CNES, 2009 (20 deg)



SWIFT-ARGO Canada-CSA, 2009 (polar orbit)



Data rate	2,500/day	> 5,000/day

Planned Missions

Name	Receiver	Launch	soundings	Status
OceanSat2	ROSA	2008	300	Planned
Megha Tropiques (India)	ROSA	2009	500(Tropics)	Planned
TANDEM – X	IGOR	~2010	200	Planned
KOMPSAT-5	IGOR	~2010	500	Planned
Aquarius/SAC-D	ROSA	2010	600	Planned
METOP-B	GRAS	2011	600	Planned
CICERO	Pyrix	2011	12,000/24,000 (12/24)	Phase B
EQUARS	Pyrix	2012	500 (Tropics)	Planned
FORMOSAT3-FO (TAIWAN)	Pyrix	2012	10,000 (12)	Planned
Sabrina	ROSA	2012	600	Planned
Iridium	Pyrix?	2013	33,000/66,000 (66)	Proposal
GEMSS (India)	Pyrix?	2012	3000 (6, Tropics)	Proposal
China Earthquake	TBD	2013?	600	Proposal
METOP-C	GRAS	2016	600	Planned

Near Future Indian Plans

Dual frequecny GPS receiver on ROSA (OceanSAT-2)

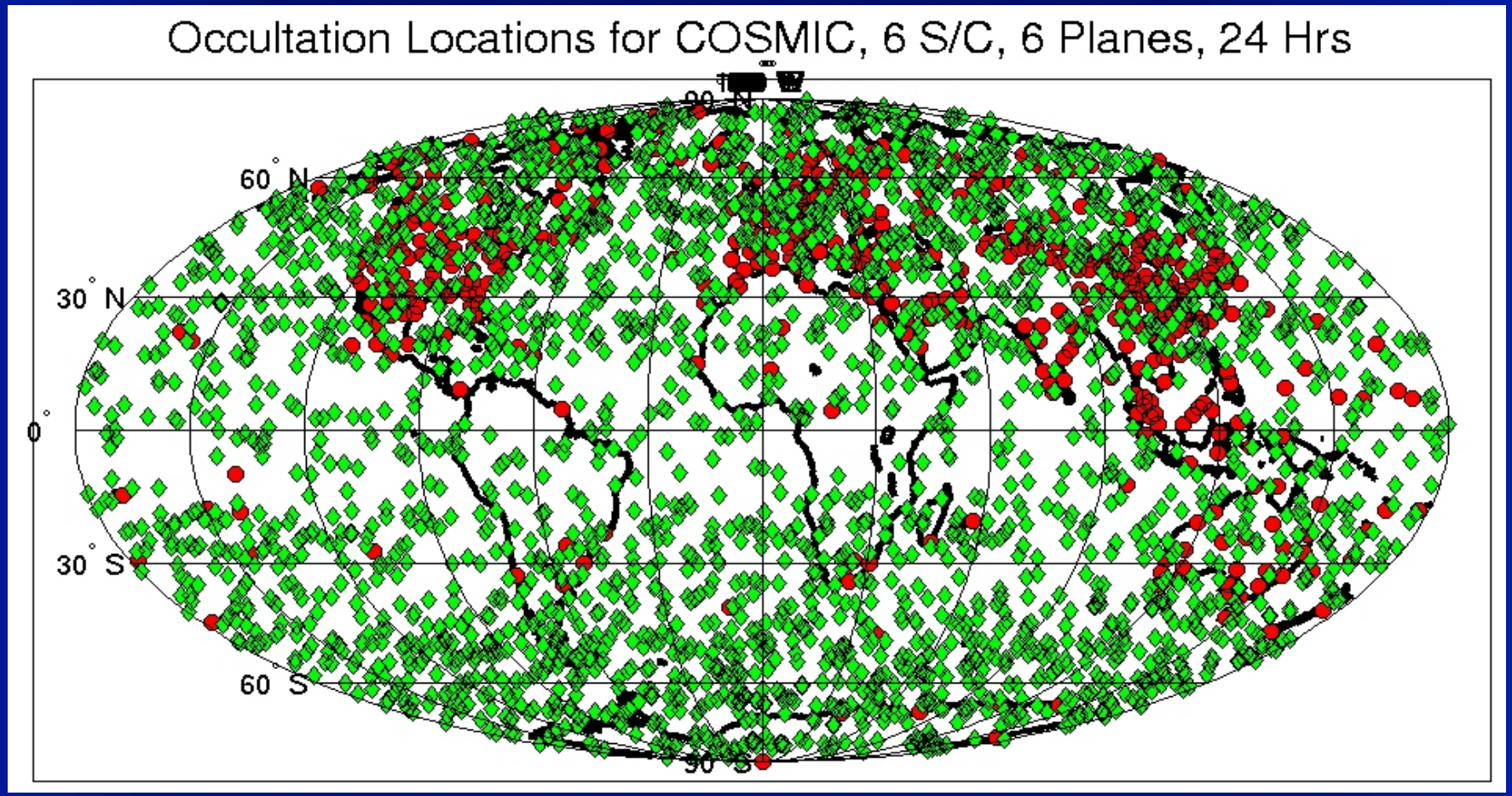
2008

ROSA on Megha Tropiques

2009

Megha Tropquies will be a unique low inclination (20º) LEO satellite having a dual frequency GPS receiver for radio occultation measurements

Simulations of Radio Occultations with COSMIC



GEMSS:

Realizing the potential of GPS RO Technique for operational weather forecast, Atmospheric modeling, Communications, climate studies and also to carry out frontline research in Atmospheric sciences, ISRO has formulated a project, GPS RO based experiments for Meteorology and Space Sciences (GEMSS).

GEMSS will have a Constellation (may be 6) of LEO satellites at Low inclination angle (~20^{o}) to provide adequate number of occultations in the tropical latitudes.

Conclusions

- Temperature profiles obtained from CHAMP during 2002-2007 have been analyzed to study tropospheric warming and stratospheric cooling globally.

- In tropics an increase in temperature is observed in the upper troposphere due to warming and decrease in temperature is obsereved in the lower and mid-stratosphere due to cooling.

- In the tropics, major warming is seen at 18 km and the largest cooling is observed at 23 km. Transition from warming to cooling is seen at 21 km, the region that delineates the warming of the troposphere due to increased green house gases from the cooling of the stratosphere.

- At mid latitudes major warming is seen at 8 km and major cooling is around 16-17 km and transition from warming to cooling is observed at 12-13 km.

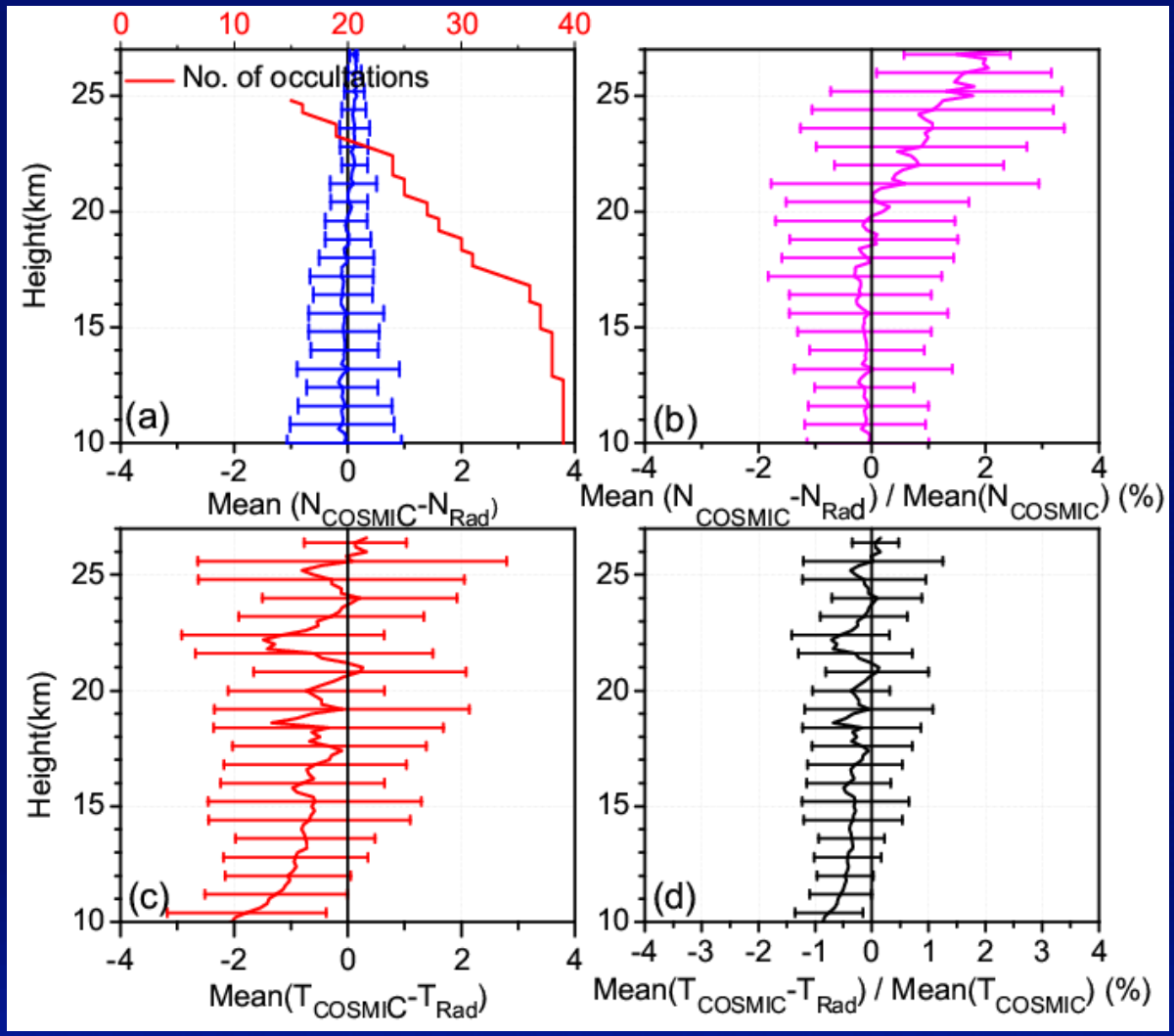
- At northern mid latitudes, the magnitude of tropospheric warming and stratospheric cooling is larger than that observed in tropics. Also , the magnitude of stratospheric cooling at northern mid - latitudes is larger than that at southern mid latitudes.

- It is interesting to note that at SH polar latitudes warming occurs from 25 km onwards with a peak around 29-30 km.

The results suggest that the GPSRO measurements are well suited to study tropospheric warming and stratospheric cooling globally and also to study the height at which the transition from warming to cooling takes place.


Thank You

Statistical Comparison between COSMIC and GPS radiosonde at NARL



Narayana Rao et al., TAO, 2008 (In Press)