Climate monitoring and modeling: The role of occultation data

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What climate change can we expect this century?
(assuming a further doubling of the greenhouse gases this century)

- **Increase of surface temperature by some +3 °C (1.5 - 4.5°C)**

- **Upper troposphere temperature to increase faster than at the surface** in particular in the tropics

- **Cooling of the lower stratosphere**.

- **Rapidly increasing water vapor** and **precipitation in areas of water vapor convergence** (following Clausius-Clapeyrons relation). Only minor increase in global mean precipitation.

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A climate enigma

- During the last 150 years the climate has warmed by some 0.8 °C

- During the same time the forcing by the greenhouse has increased by 2.8 W/m^2. This corresponds to an increase by CO_2 by more than 3/4.

- **Why is the climate warming so slowly?**

What climate changes have we seen so far?
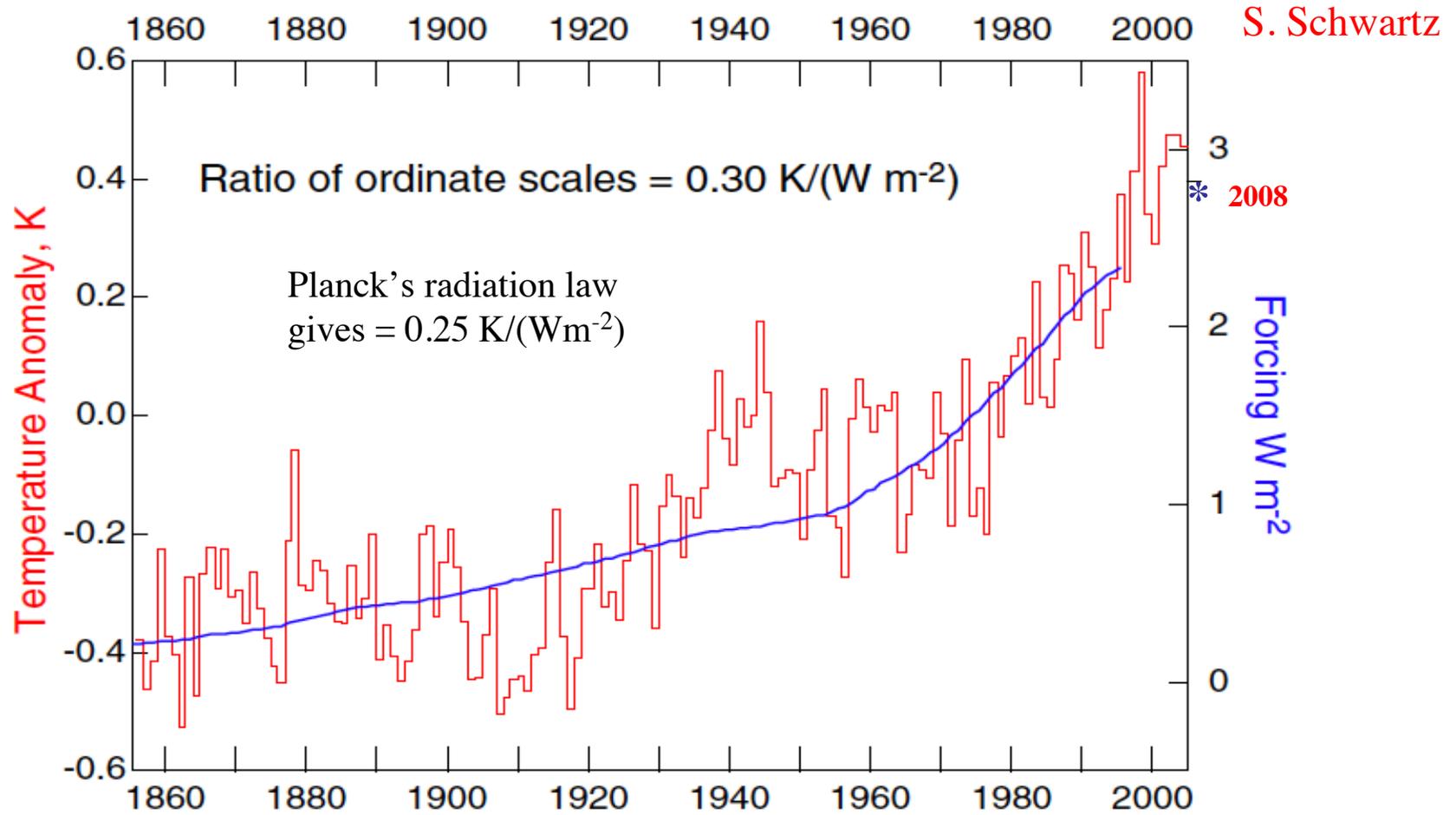## How well is it understood?

- Long-term surface observational records suggest that the climate system is warming rather slowly with a long-term **climate sensitivity** of **0.3 K/Wm^{-2}**.

  Climate sensitivity, **S**, is a suitable measure how the climate system responds to a change in the radiation balance, **dQ**. Such a change can be due to solar variations, volcanic eruptions emitting aerosols to the upper atmosphere or changes in greenhouse gases or aerosols. We can write **dT= SxdQ**

  This is smaller than suggested from climate models. (0.39-0.83, with a mean value of 0.49) This suggest either a **compensating effect** such as from cooling aerosols or that the **climate models have systematic errors** with an overly strong positive feedback.

- There is an indication that climate models warm the upper tropical troposphere more than what is indicated from observations.

- The Northern Hemisphere has warmed more than the Southern Hemisphere in spite of the fact that the compensating cooling from aerosols would have had the opposite effect. We might assume that this is due to an effective mixing of heat into the Southern Oceans.

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Global mean surface temperature and forcing by well mixed greenhouse gases, CO_2, CH_4, N_2O and CFC

S. Schwartz

Ratio of ordinate scales = 0.30 K/(W m^{-2})

Planck's radiation law gives = 0.25 K/(Wm^{-2})

* 2008

Temperature Anomaly, K

Forcing W m^{-2}

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Model simulation of the global surface temperature of the last century
(include ant. greenhouse gases and aerosols and volcanic aerosols)
Top: natural and anthropogenic effects. Below: natural effects only (IPCC, 2007)

Models with high sensitivity had lower forcing and vice versa

Model sensitivity, **S** is 0.35-0.83

S(mean)=**0.49**
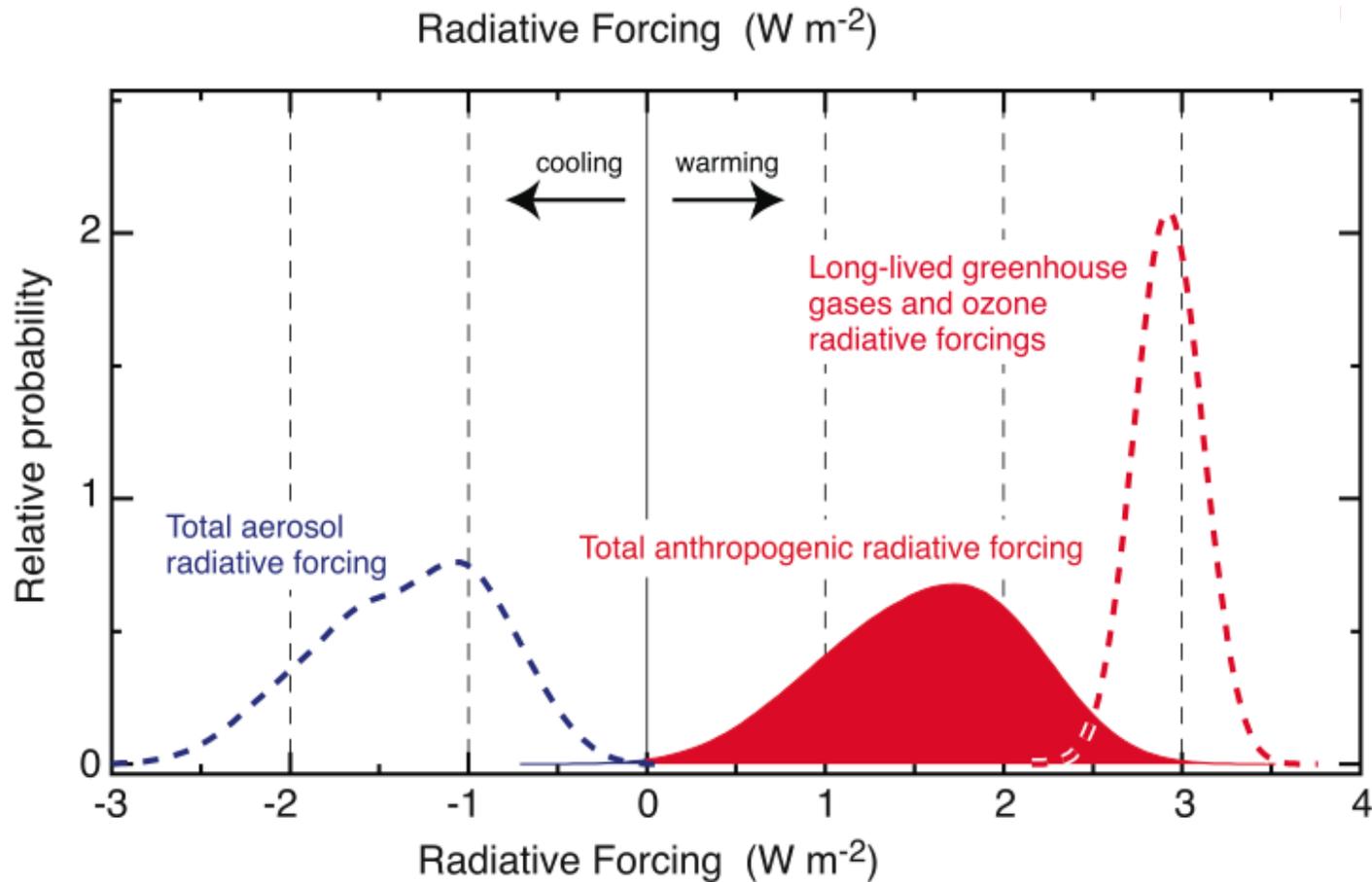
Models have been tuned by aerosols
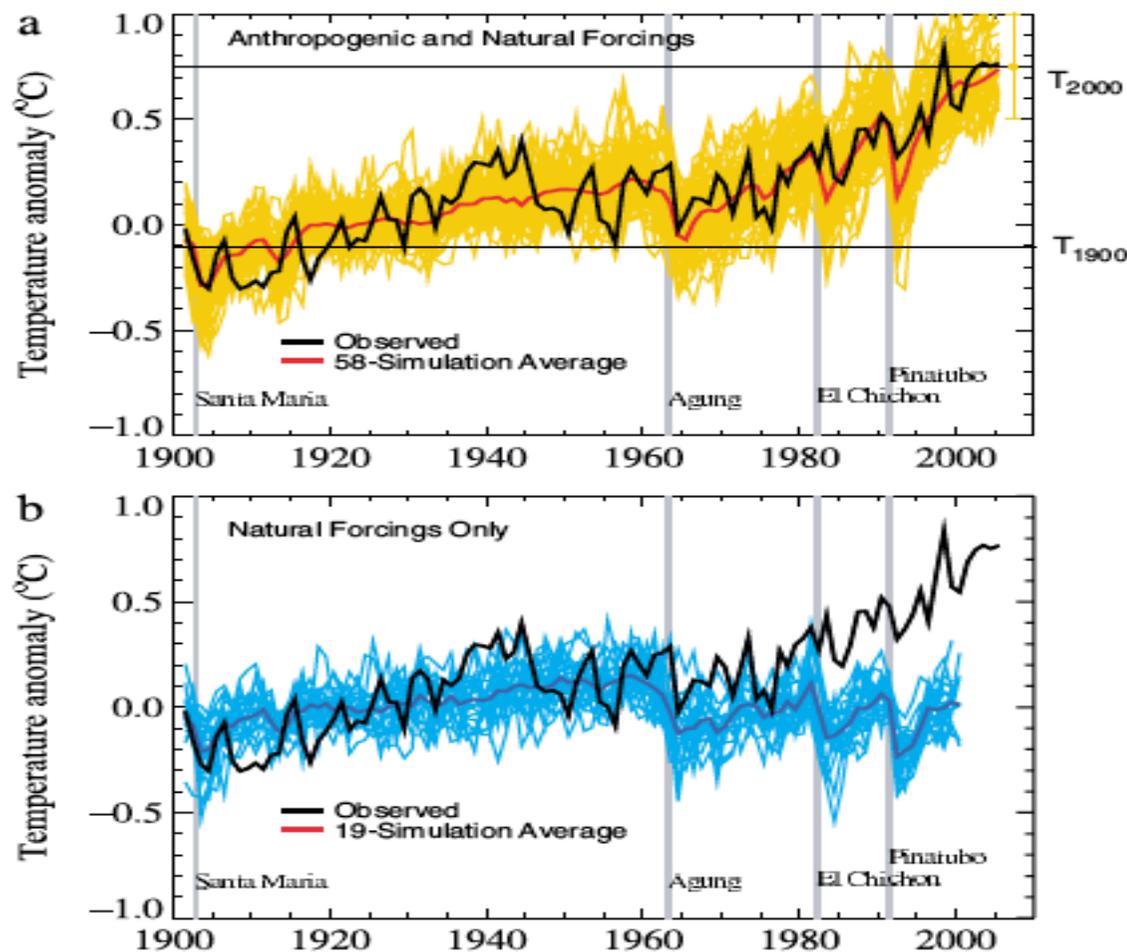
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Anthropogenic perturbations to the climate system

Current estimates of anthropogenic radiative forcing:

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[*Intergovernmental
Panel on Climate
Change (IPCC)*, **2007**]

Climate sensitivity from observations

Greenhouse gases and aerosols $\qquad$ **dQ = (1/S)xdT + dF**

dQ (1850-2010) G.house gases	2.8 W/m^2 (CO$_2$ 60%)	dQ (1850-2010) Aerosols 1	-0.5 W/m^2
dT (1900-2007)	0.8 K	S = dT/dQ	**0.4 K/Wm^2**
Deep ocean heat transport	**0.4 W/m^2**	dQ (1850-2010) Aerosols 2	- 1.0 W/m^2
S = dT/dQ	**0.3 K/Wm^2**	S = dT/dQ	**0.6 K/Wm^2**

Content of my talk

- **Assessment of atmospheric temperature changes during the last three decades from present observing systems.**

  - Typical problems-

- **Assessment of water vapour changes from observations and models.**

- **Experience of using GPS occultation and in in-situ measurements and promises for climate monitoring of temperature and water vapour.**

- **Proposals for the future**

  - an integrative approach-

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Atmospheric temperature changes

- Surface temperatures

- Tropospheric and stratospheric temperatures

Present climate monitoring

- Climate monitoring of the temperature of the free atmosphere has so far been obtained from **radiosondes and MSU measurements.**

- Both of these systems suffer from **systematic biases that are changing in time,** that are corrected in different and in somewhat ad hoc ways. They are thus open to criticism.

- Recent reanalyses are starting to provide complementary information but are still **suffering from ongoing changes in the observing systems** and large scale **observational biases**.

- Consequently, the degree and structure of climate change in the atmosphere has been **questioned.**

Satellite microwave soundings are used to measure the atmospheric temperature

- Measurements has been around since 1979 when the first operational polar orbiting satellite system was launched.

- Present instrument use some 20 channels from 21 to 183GHz. The make use of an oxygen resonance band to derive vertical temperature profiles.

- Different problems are due to calibration between satellite unit, satellite drifts etc. and they are still open to interpretations, nowadays more or less overcome.

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Vertical relative weighting functions for each of the radiation channels. The vertical weighting function describes the relative contribution that microwave radiation emitted by a layer in the atmosphere makes to the total intensity measured above the atmosphere by the satellite.
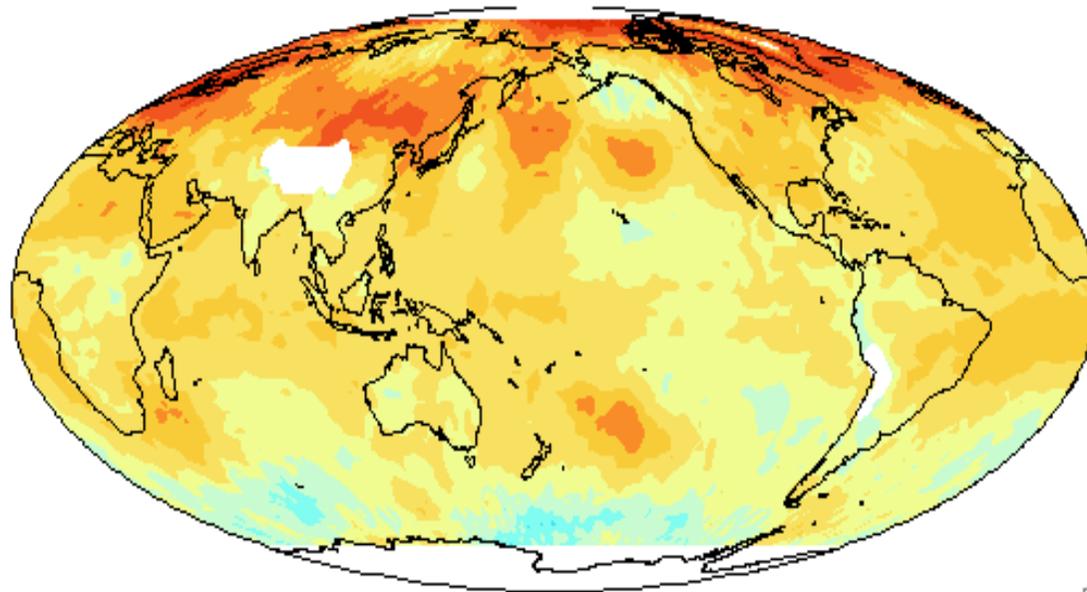
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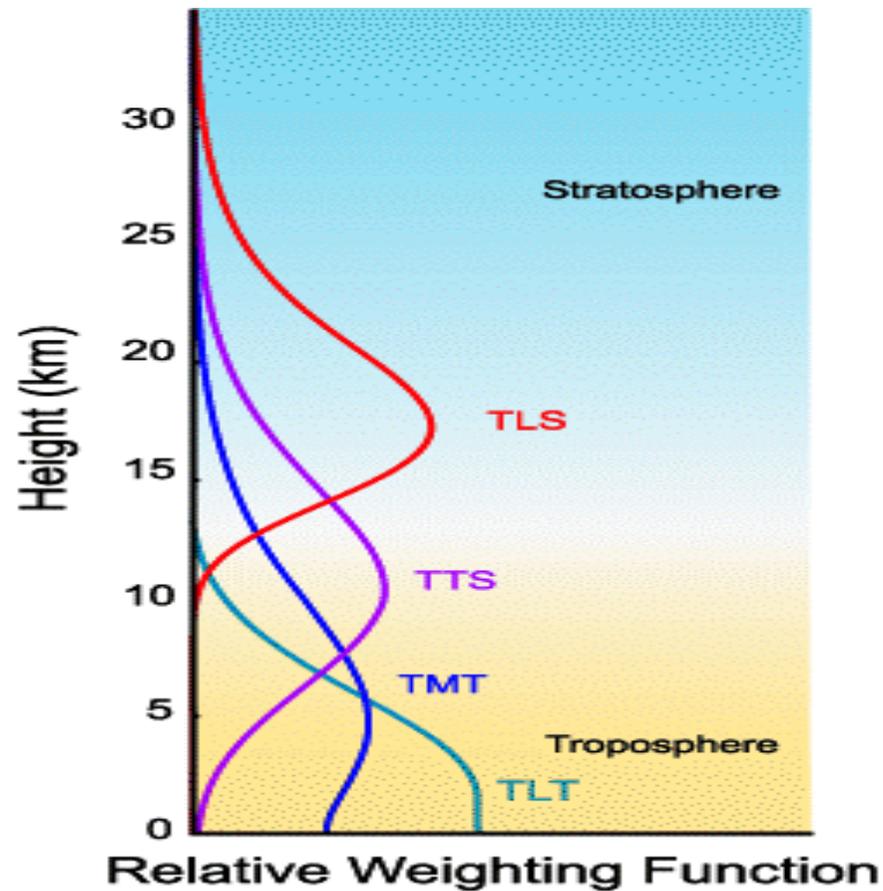
Temperature of the lower troposphere,TLT (RSS)
1979- 2009
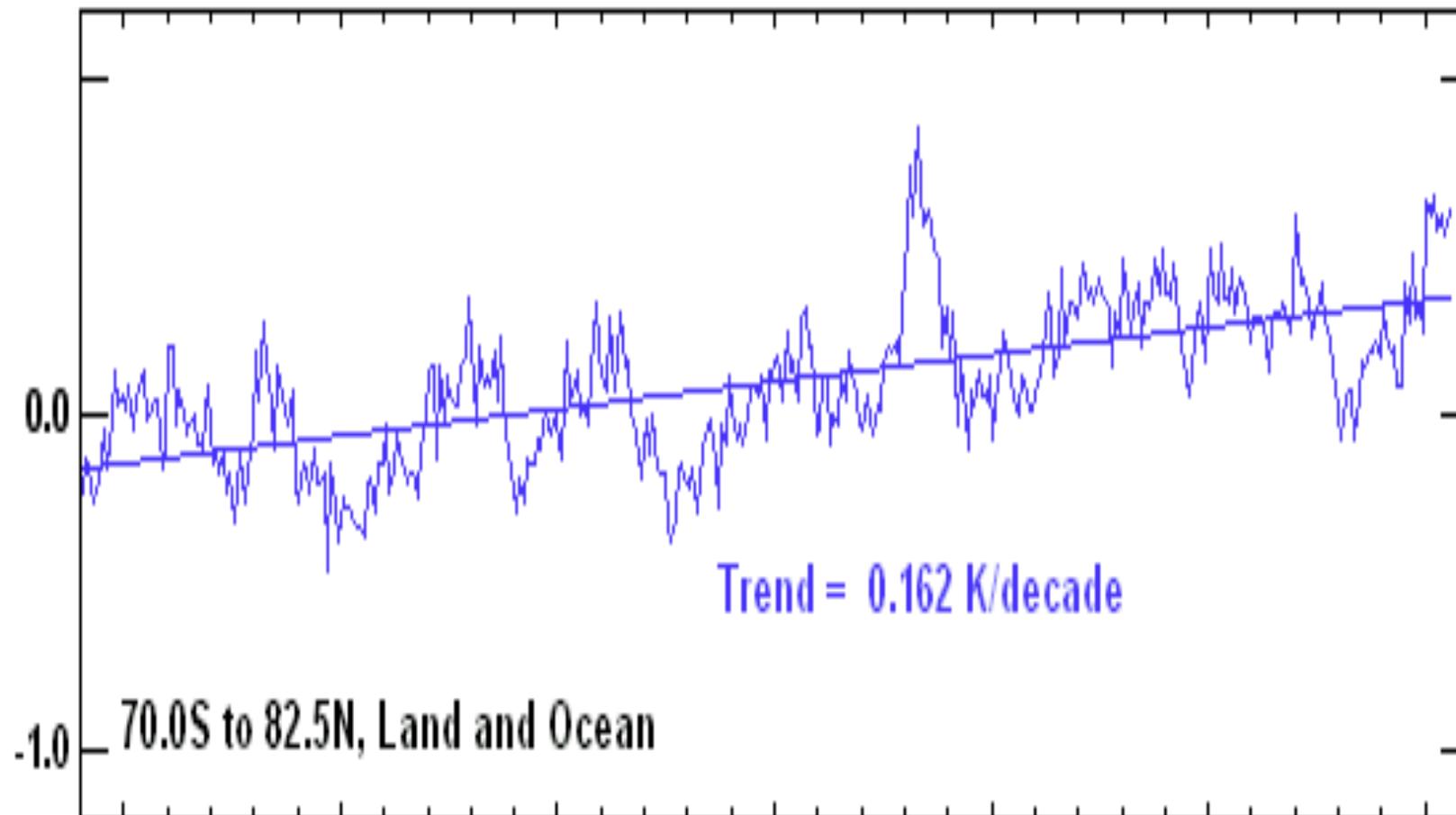
Trend = 0.162 K/decade

70.0S to 82.5N, Land and Ocean
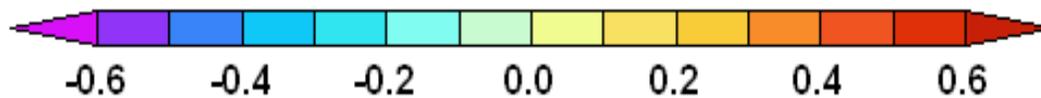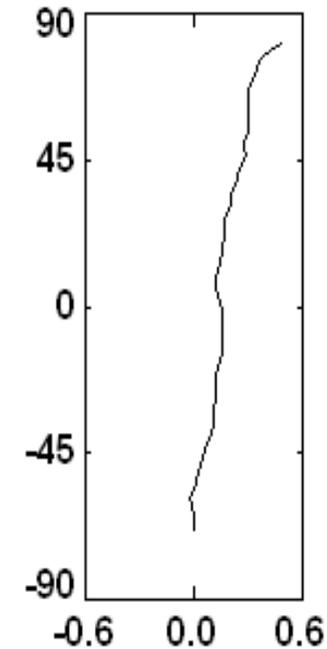
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Color coded map of decadal trends in MSU channel TLT (1979 - 2009). Data poleward of 82.5° North and 70° South, as well as areas with land or ice elevations above 3000 meters, are not available and are shown in white.
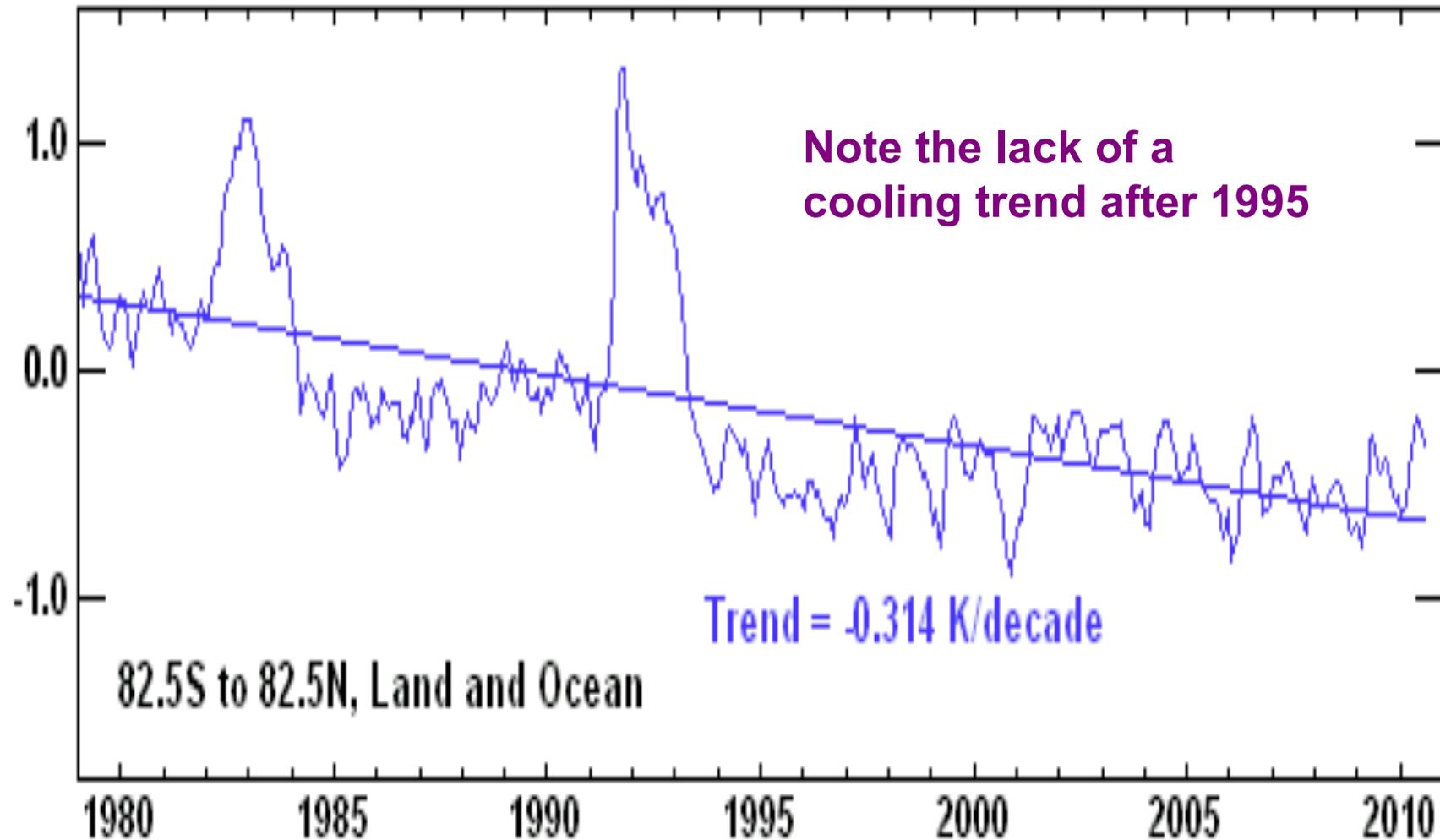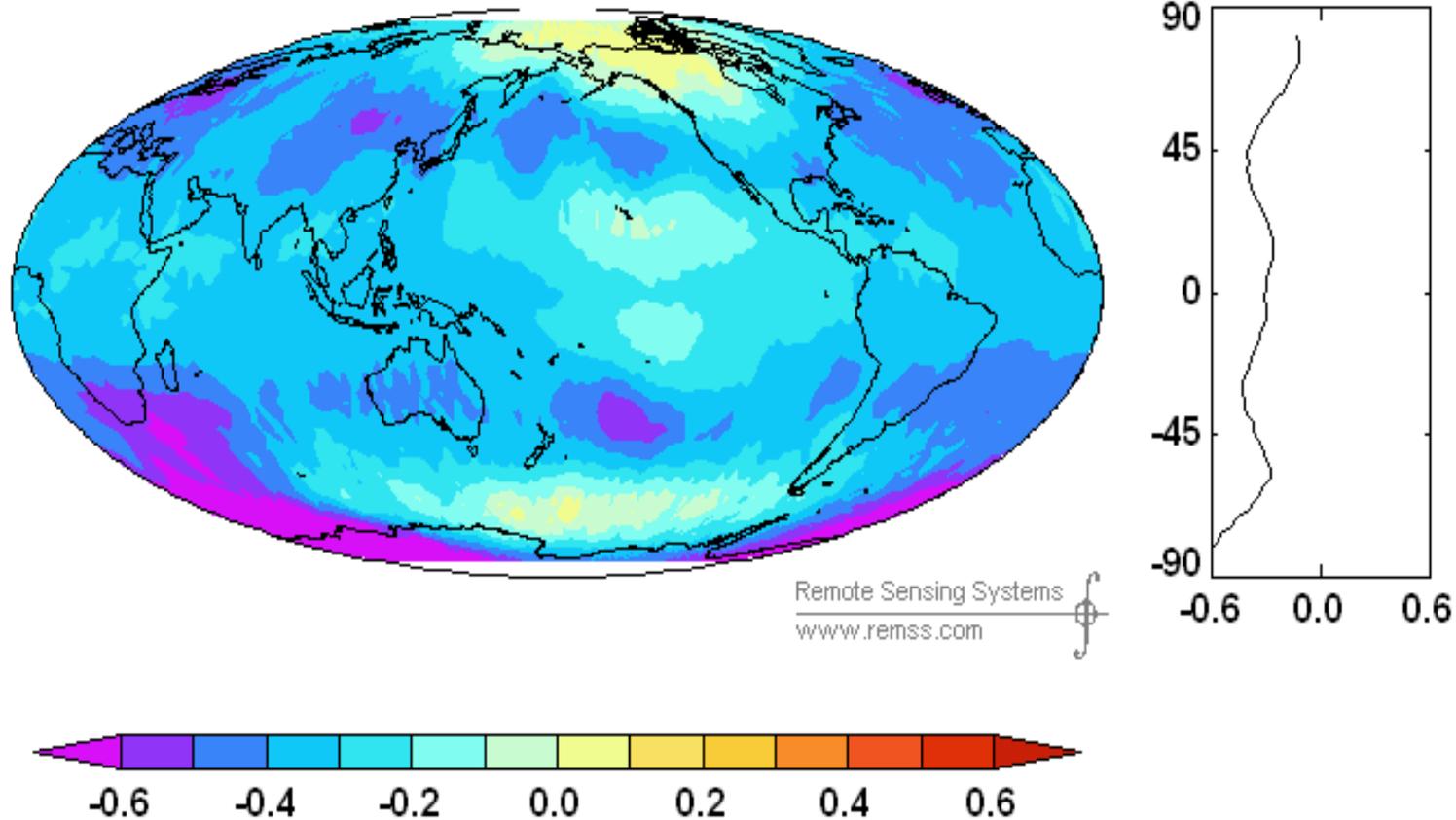

Remote Sensing Systems
www.remss.com

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Temperature of the lower stratosphere, TLS (RSS)
1979 - 2009

Note the lack of a cooling trend after 1995

Trend = -0.314 K/decade

82.5S to 82.5N, Land and Ocean

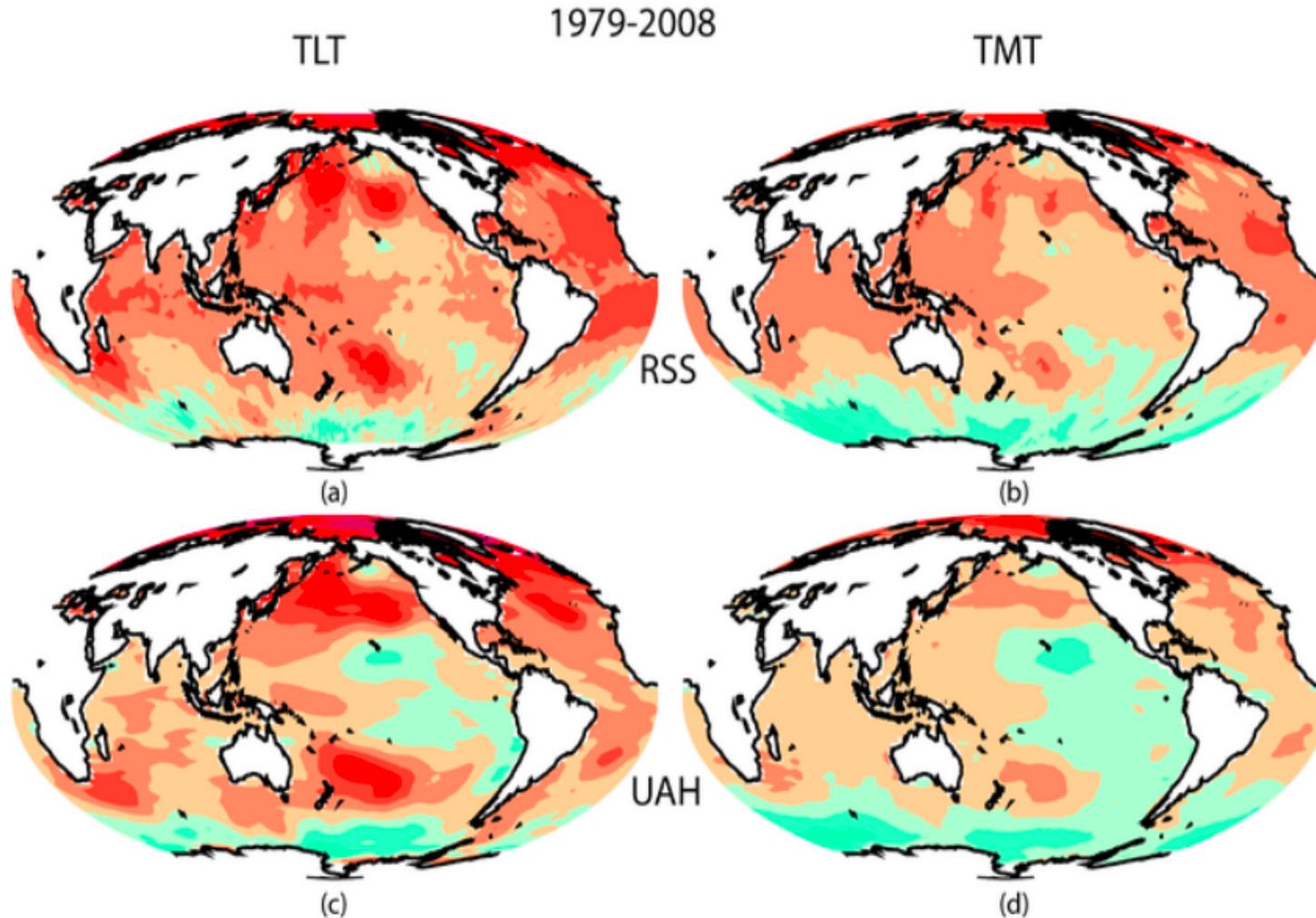**Graz, 8 September 2010**   **Climate monitoring**
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Color coded map of decadal trends in MSU/AMSU channel TLS (1979 - 2009). Data poleward of 82.5。 are not available and are shown in white. This channel is dominated by stratospheric cooling.

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30-year trends RSS and UAH
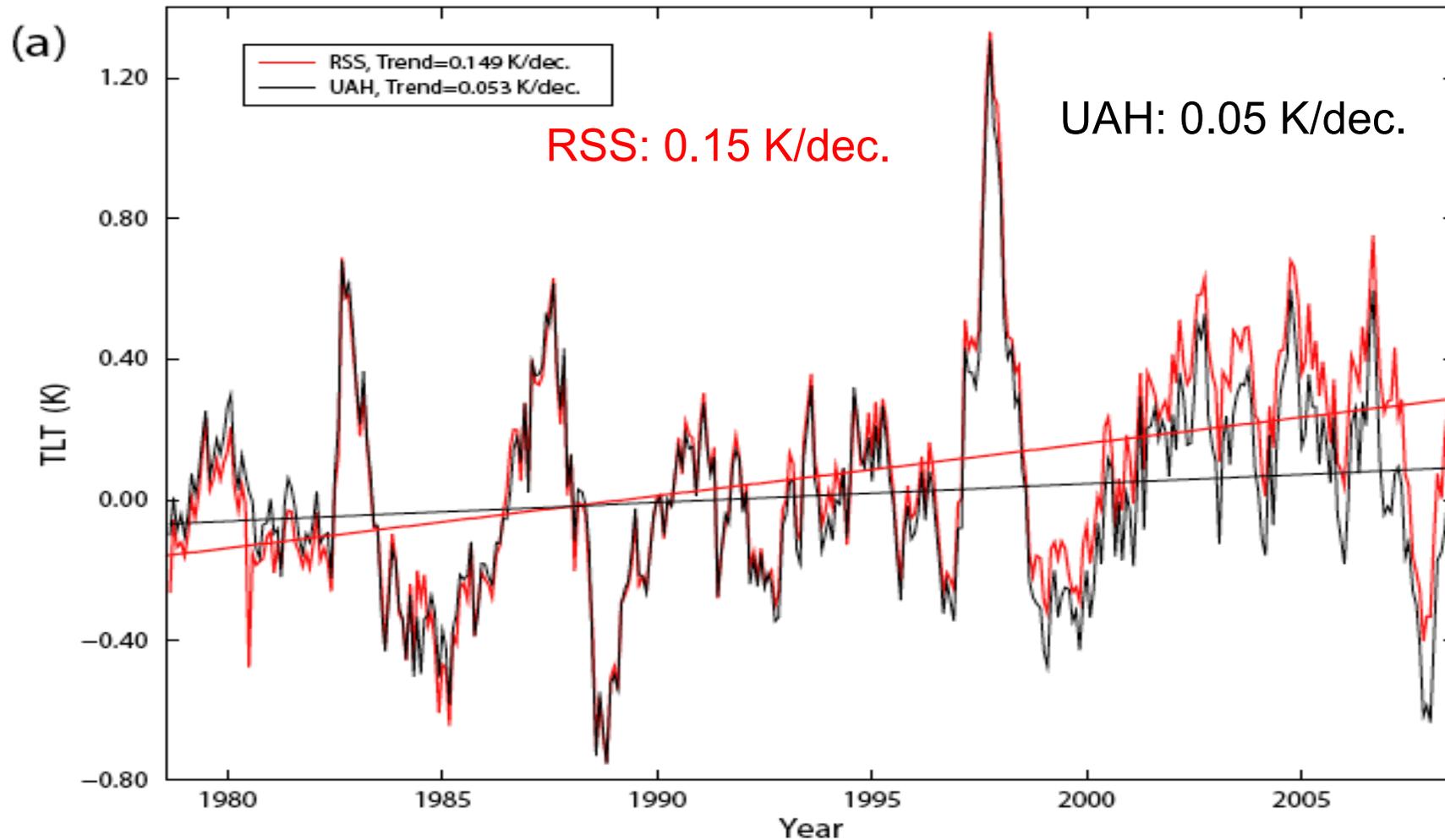## TLT and TMT

1979-2008

TLT

TMT

RSS

(a)

(b)

UAH

(c)

(d)

Gra

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Observed MSU trend for TLT (lower troposphere) 1979 - 2008.

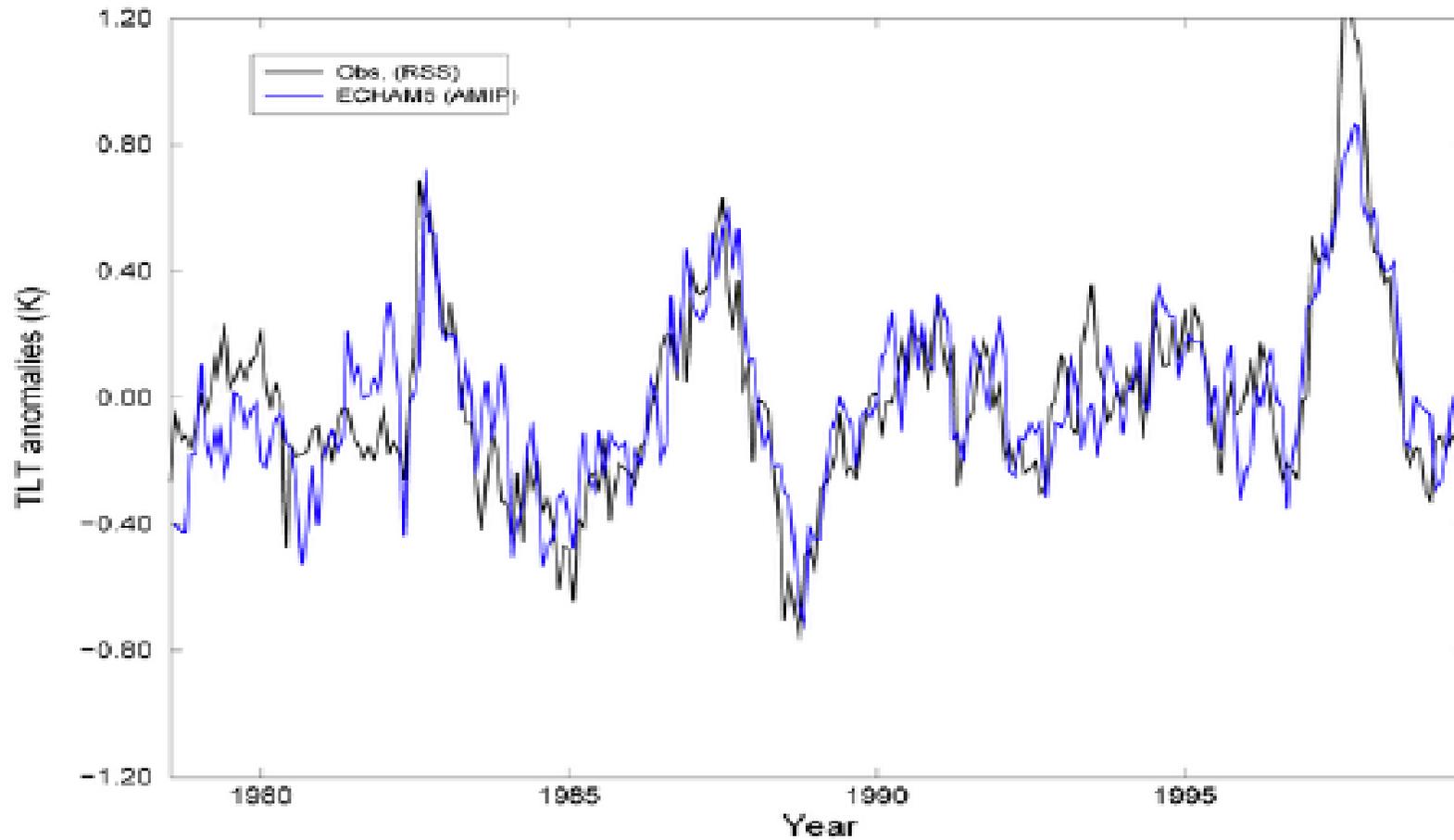## Remote Sensing Systems and University of Alabama

TLT (anomaly) - SST (anomaly) in the tropics 20S - 20N

	1979 - 1992	1993 - 2008
UAH	+ 0.01	+ 0.01
RSS	- 0.01	**+ 0.13**
JRA25 (UAH)	0.00	0.00
JRA25 (RSS)	0.00	0.00

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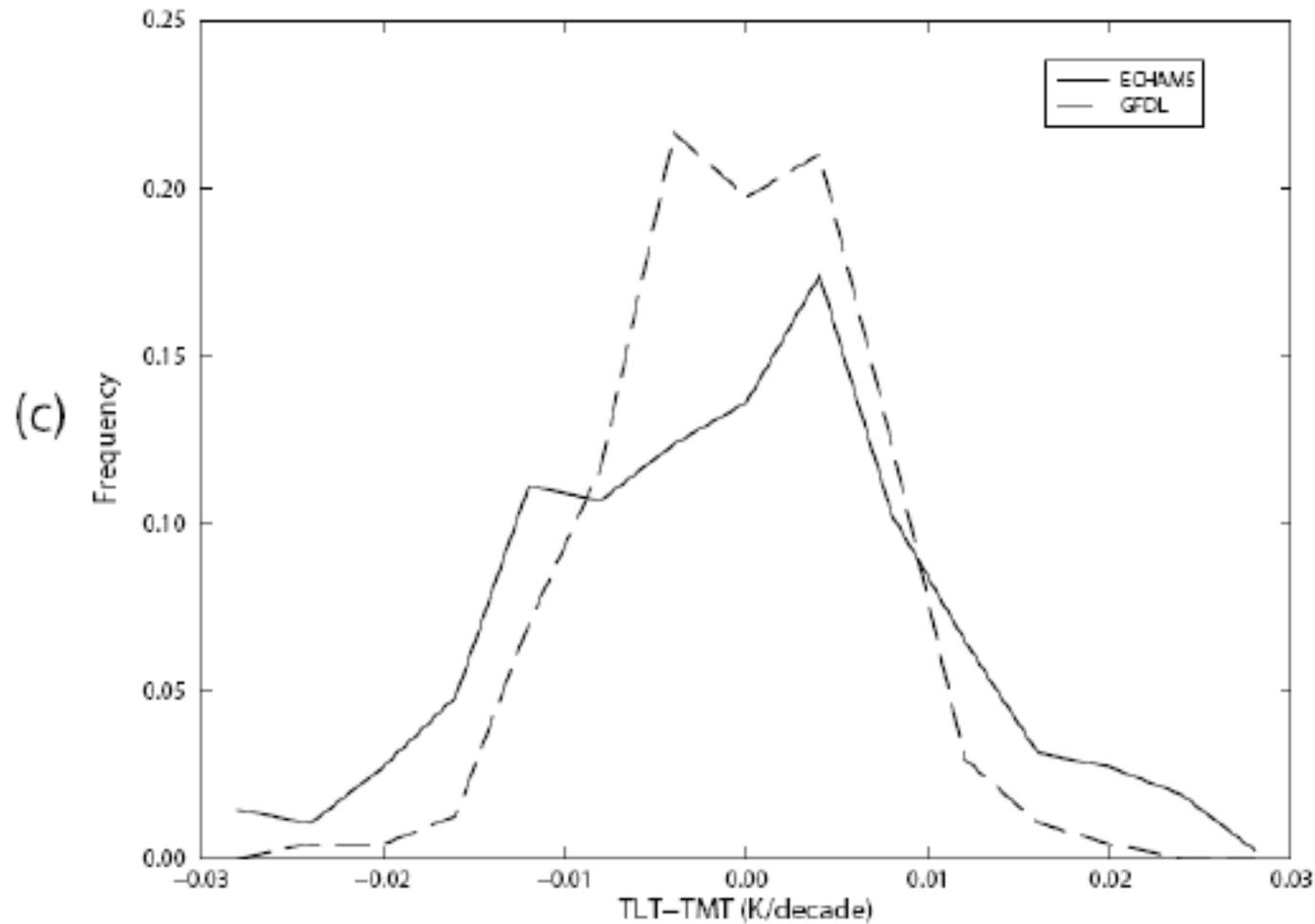# ECHAM5/T213 AMIP-run (blue) (using observed SST) compared to TLT (black) (RSS). 20N-20S, 1979-2007

Decadal tropical temperature trends 1979-2008 over ocean areas (20°S- 20°N)

Bengtsson and Hodges, Clim.Dyn. 2010.

Data set UAH	TLT	TMT	TLT-TMT
Observations	0.053 ° C	0.017 ° C	**+0.035 ° C**
JRA 25	0.074 ° C	0.018 ° C	**+0.056 ° C**
ECHAM 20C-1	0.225 ° C	0.227 ° C	**-0.002 ° C**
ECHAM 20C-2	0.163 ° C	0.181 ° C	**-0.018 ° C**
ECHAM 20C-3	0.107 ° C	0.114 ° C	**-0.007 ° C**

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Pdf-distribution for TLT - TMT from 500-year control integrations. ECHAM5(full), GFDL(dashed)

Obs and re.anal

0.35-0.56

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Summary of temperature validation

- Global surface temperature increase is rather modest and if caused by increasing greenhouse gases only suggest a long-term climate sensitivity of some $0.3°K/Wm^{-2}$

- Upper air temperature from MSU at least in the tropics appear to **warm slightly slower** than at the surface and opposite to models in general.

- It is suggested that the **MSU data from UAH are more consistent** and more in agreement with re-analyses from JMA and ECMWF.

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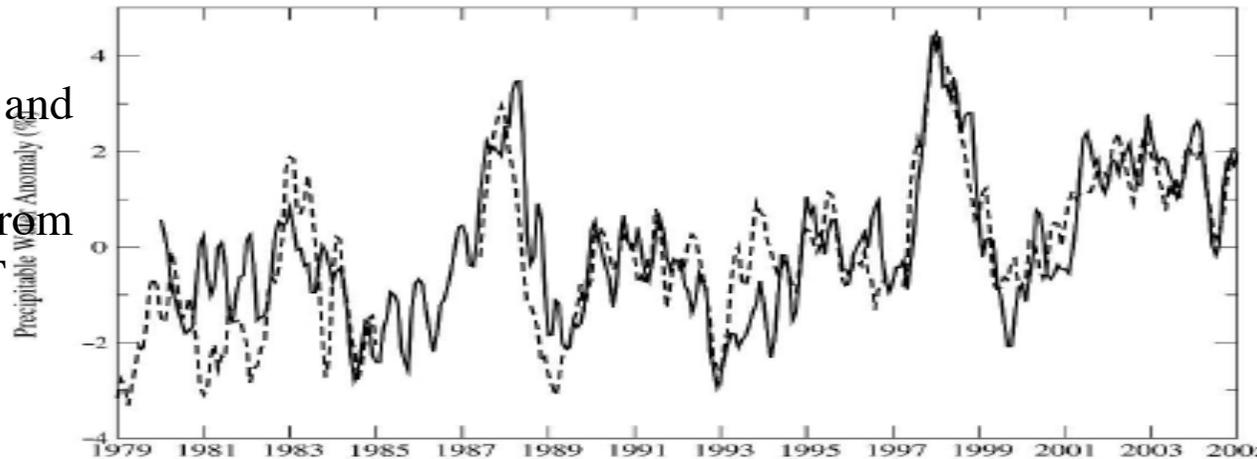# Assessment of water vapour changes from observations and models.

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Water vapour and temperature

For a temperature change, **dT**, the humidity change, **dq**, follows the
C-C relation seen as a conservation of relative humidity

Observations and
model
calculations from
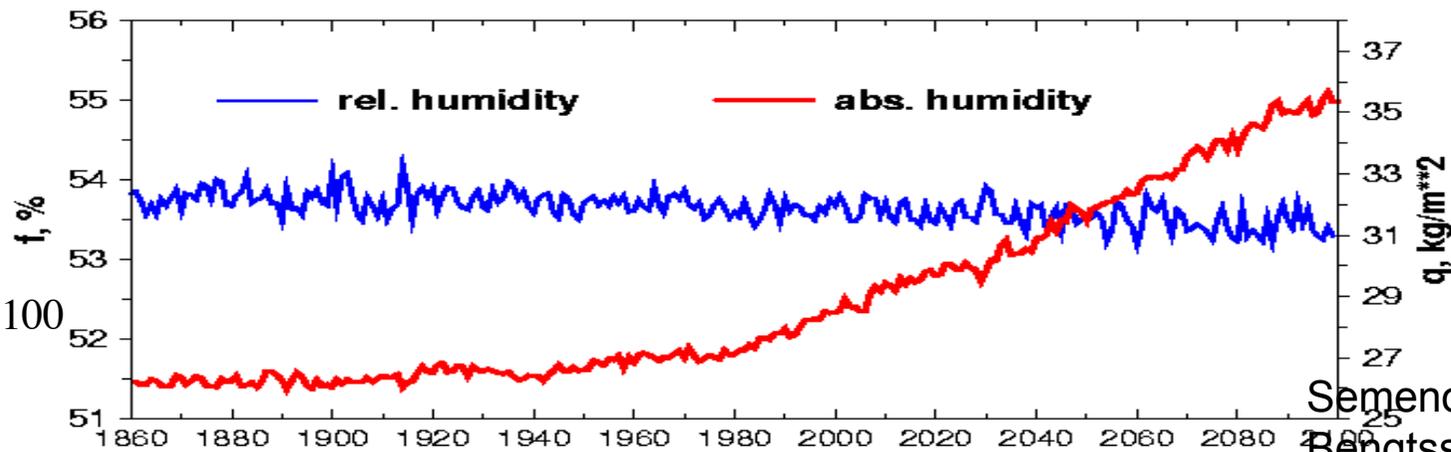observed SST
1979-2005

dT + **0.4°C**

dq + **3%**

Held and
Soden, 2006

dT+ **4°C**

dq + **35%**

Model 1860-2100

Semenov and
Bengtsson, 2002

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Climate change experiment using ECHAM5

- We have investigated two periods:

- **20 C: 1959-1990** using observed/estimated greenhouse gases and aerosols
- **21 C: 2069-2100** using scenario A1B

- A1B is a middle-of-the-line scenario

- Carbon emission peaking in the 2050s (16 Gt/year)
- CO_2 reaching 450 ppm. in 2030
- CO_2 reaching 700 ppm. in 2100

- SO_2 peaking in 2020 then coming done to 20% thereof in 2100

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Arctic atmospheric water cycle in km^3

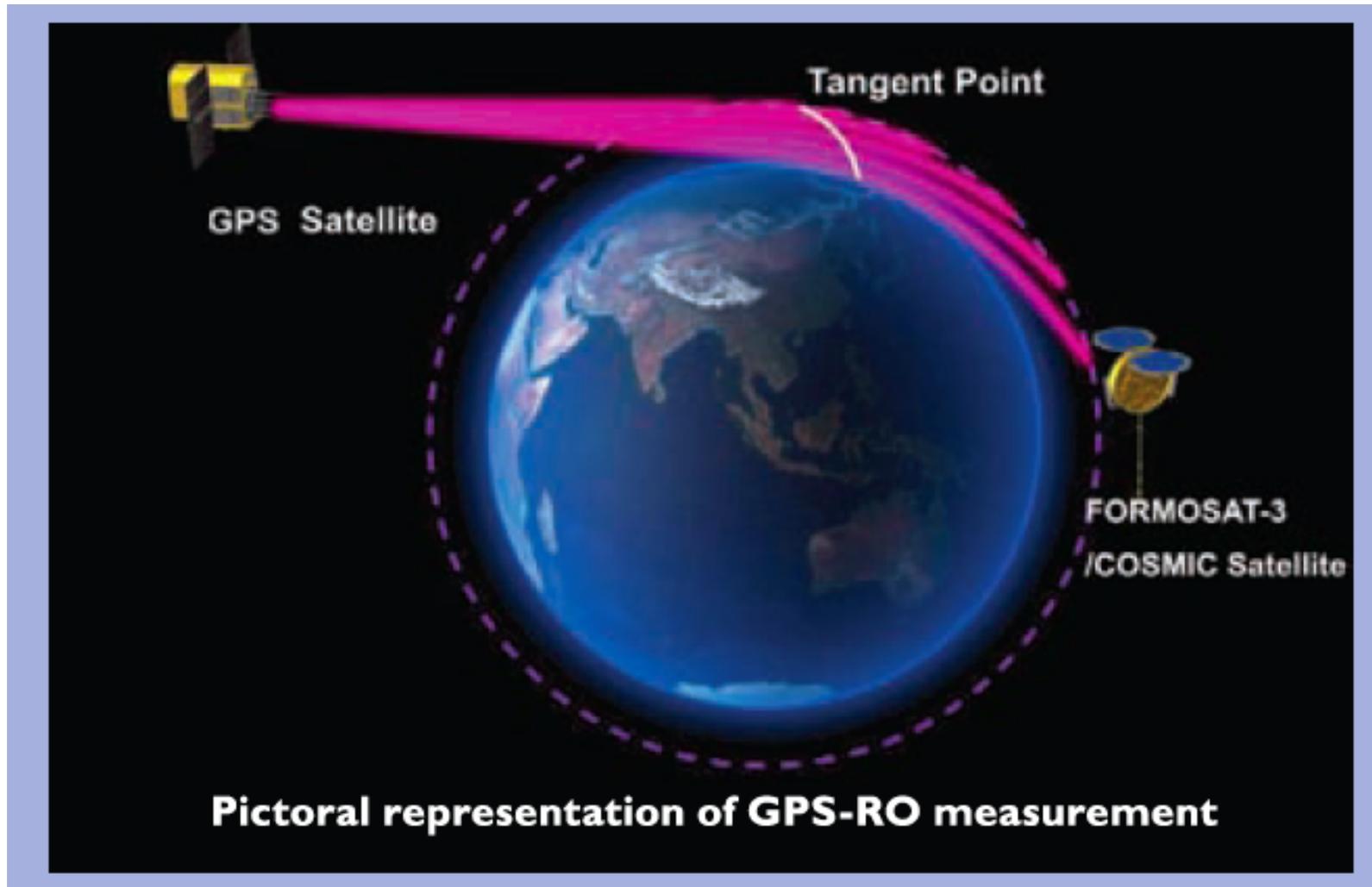| Parameter/Data	Precipitation	Evaporation	Net transport into the region across 60N
ERA-Interim re-analysis 1989-2009	**17408**	**8073**	**9335***
ECHAM5 T213 1959 - 1990, 20 C	**17263**	**7720**	**9543***
ECHAM5 T213 2069 - 2100, C 21 A1B scenario	**21584** (+25%)	**9301** (+ 20%)	**12283*** (+ 29%) *(ca. 5% has been added due to underestimation in transp. calculation)

The atmospheric water cycle

- The atmospheric water cycle follows closely Clausius-Clapeyrons (C-C) relation.

- That means that also transport of water vapour scales with the C-C relation.

- That means more precipitation in areas of convergence

- The global precipitation increases much slower than global water vapor.

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Why monitoring using GPS-RO occultation?

- No satellite to satellite bias (Haij et al. 2004)

- Great precision (Anthes et al. 2008)

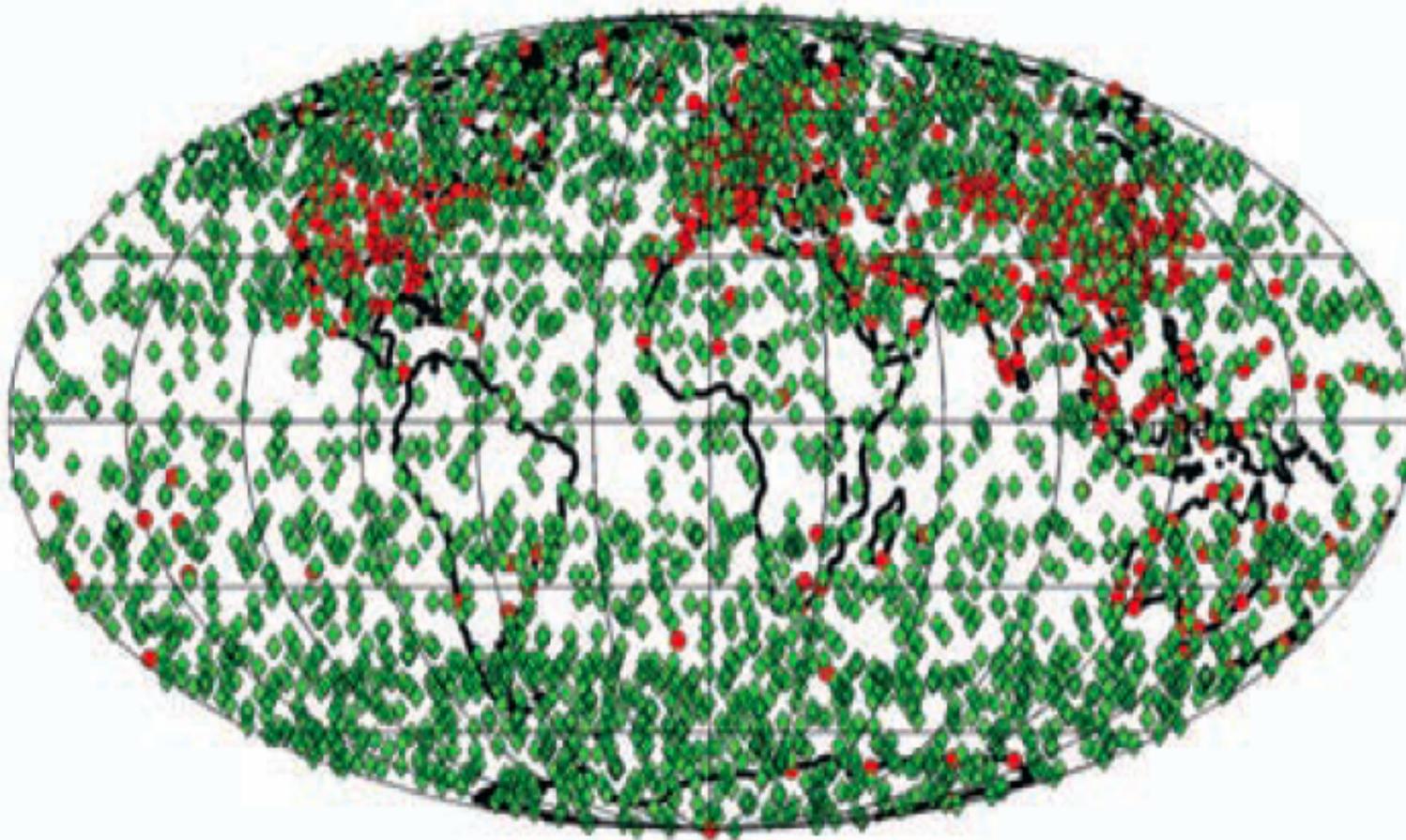- No synoptic sampling bias (no cloud effect)

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GPS-RO measurements

Pictoral representation of GPS-RO measurement

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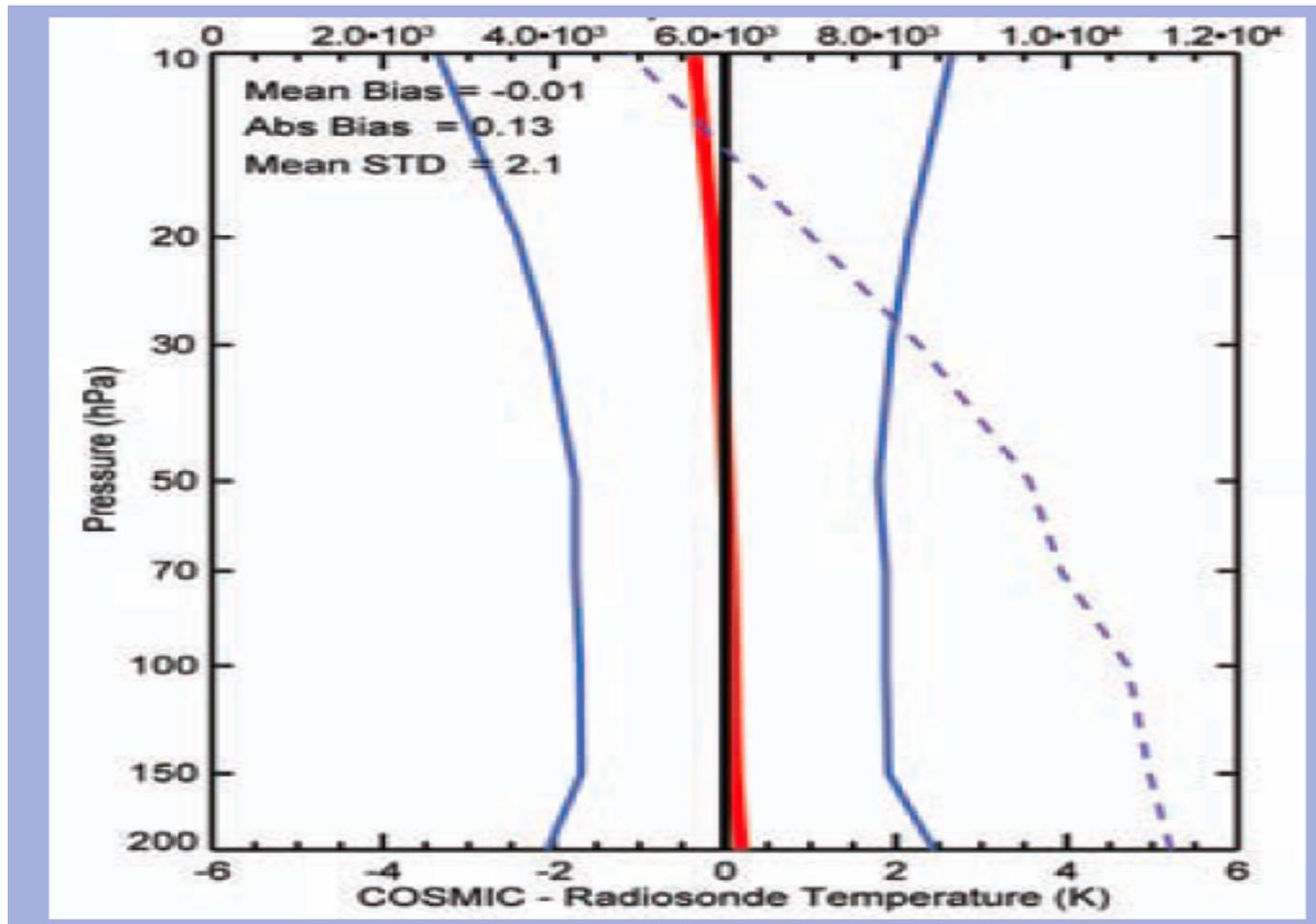# COSMIC Occultation over 24 hours (green dots). Operational radiosondes (red dots) (Ho et al. 2009)

Occulation Locations for COSMIC, 6 S/C, 6 Planes, 24 Hr

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COSMIC and Vaisala-RS92 radiosondes
mean difference (red), Standard deviation (blue)

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# On the determination of atmospheric water vapor from GPS measurement.

Hagemann, Bengtsson, Gendt: 2003, JGR

- We used **GPS** data from global IGS network

- Temperature from operational ECMWF analyses were used to determine the temperature profile (required accuracy ca 4C). Estimated accuracy ca 0.5 kg water for the vertical profile.

- Surface pressure, if not available, was interpolated from nearby meteorological stations.

- Calculations were done twice daily for Jan. and July 2000 and 2001

- Results were compared with operational analyses of water vapour.

Science questions

1. How well can we determine IWV from GCM forced by observed SST?

2. How well can we determine it from analyses with observations typical of the pre-satellite period?

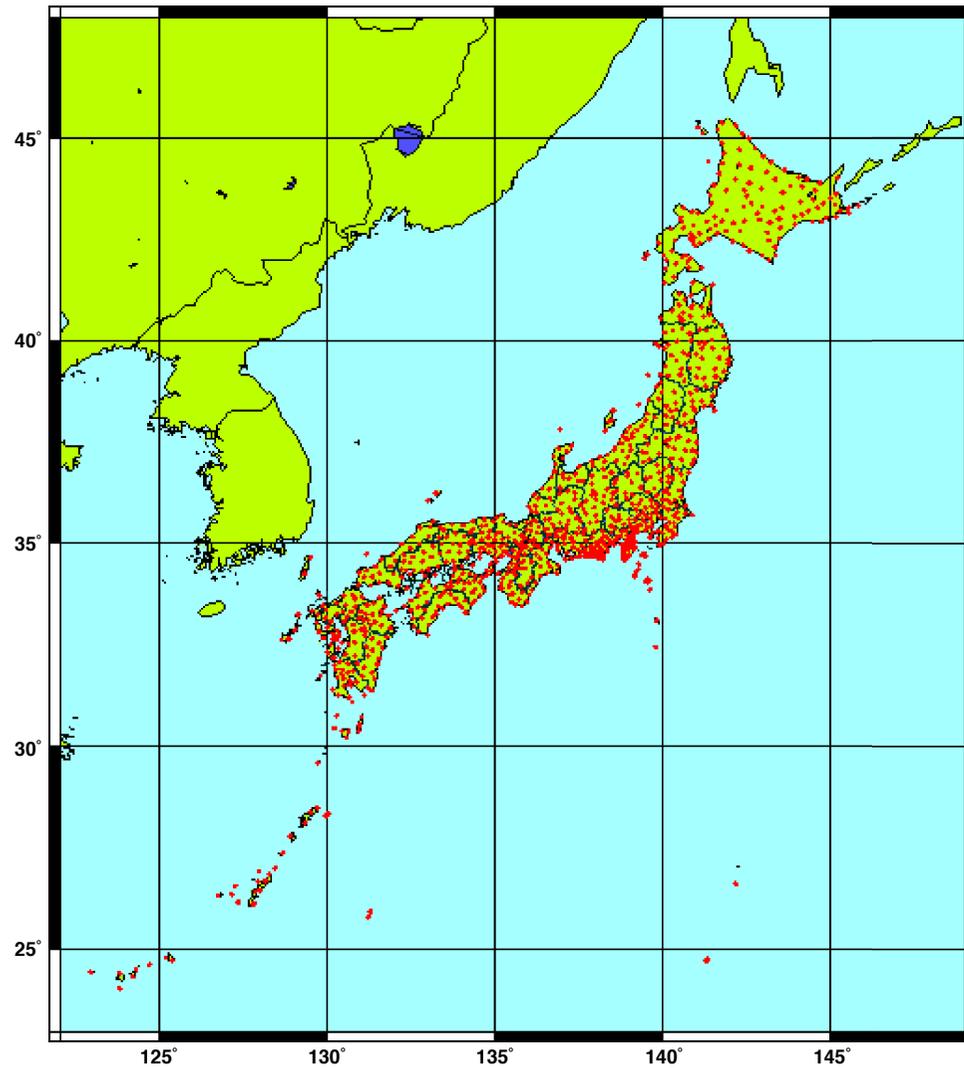3. How well can we determine it from the present observing and assimilation systems?

The IGS network of ground-based GPS stations 2005
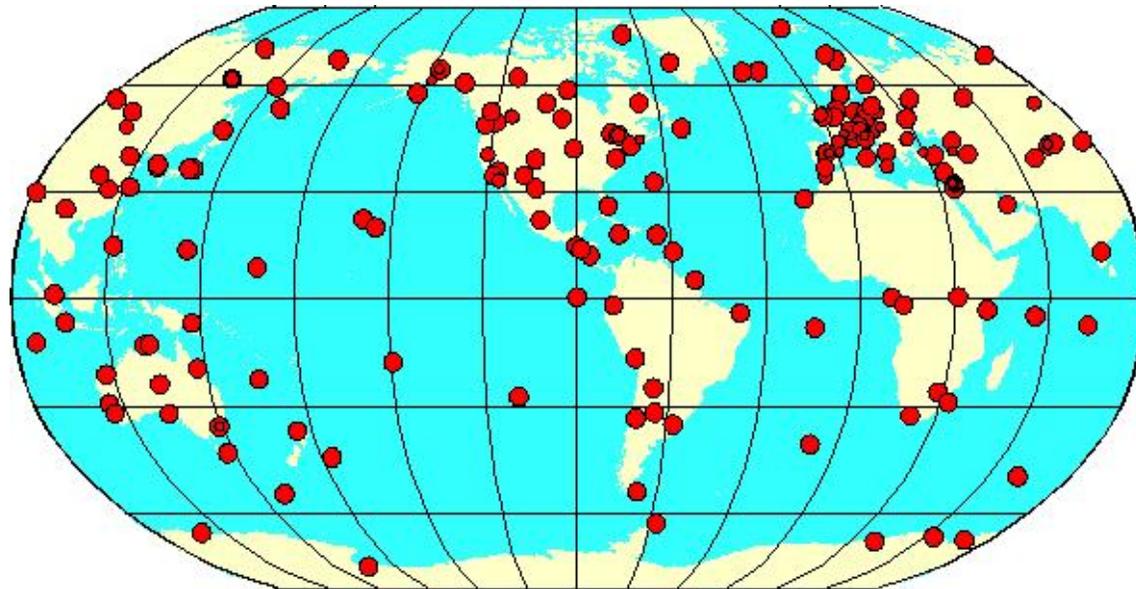
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GPS-Network in Japan (2005)

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Comparing operationally analysed IWV and IWV calculated from surface based GPS measurements

1. Calculate IWV from GPS signal delay (temperatures from ECMWF operational analyses and pressure from the GPS station or if not available interpolate from met stations)

(Care must be taken in the vertical interpolation of moisture due to the fact that the model height differs from station height)

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Error estimates

Measurement error: co-located GPS stations (mid-latitudes) indicate very small errors (<0.7 mm IWV)

Horizontal interpolation error: (<100 km) and small vertical interpolation (<200 m) also indicate small errors (<0.6mm)

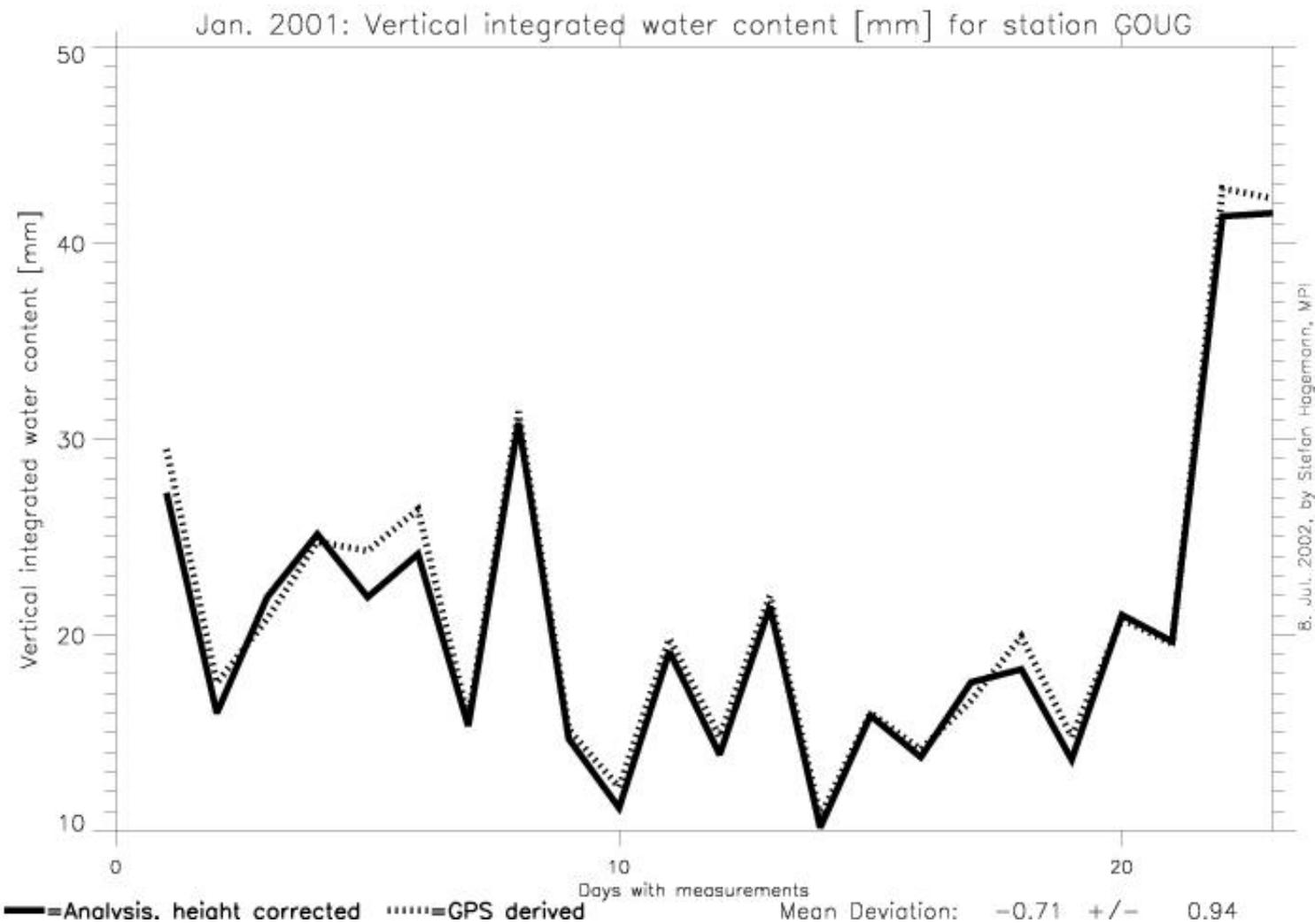# July 2000: IWV [mm] for station LPGS (Argentina)

Juli 2000: Vertical integrated water content [mm] for station LPGS
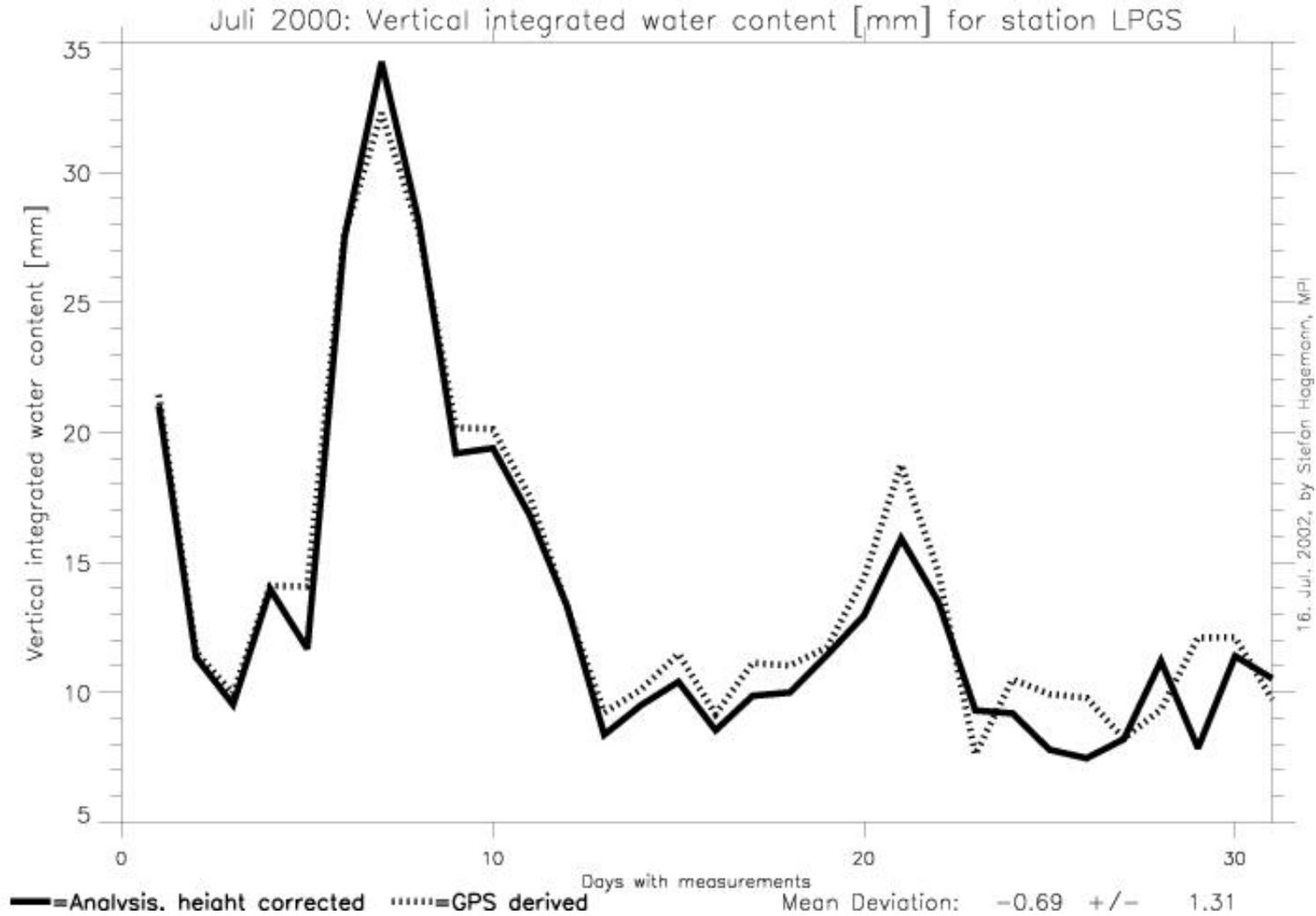
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January 2001: IWV [mm] for station Gough Island (South Atlantic)

Jan. 2001: Vertical integrated water content [mm] for station GOUG

Days with measurements

=Analysis. height corrected   =GPS derived   Mean Deviation: −0.71 +/−   0.94

8. Jul. 2002, by Stefan Hagemann, MPI

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GPS-measurements compared with operational analyses from ECMWF

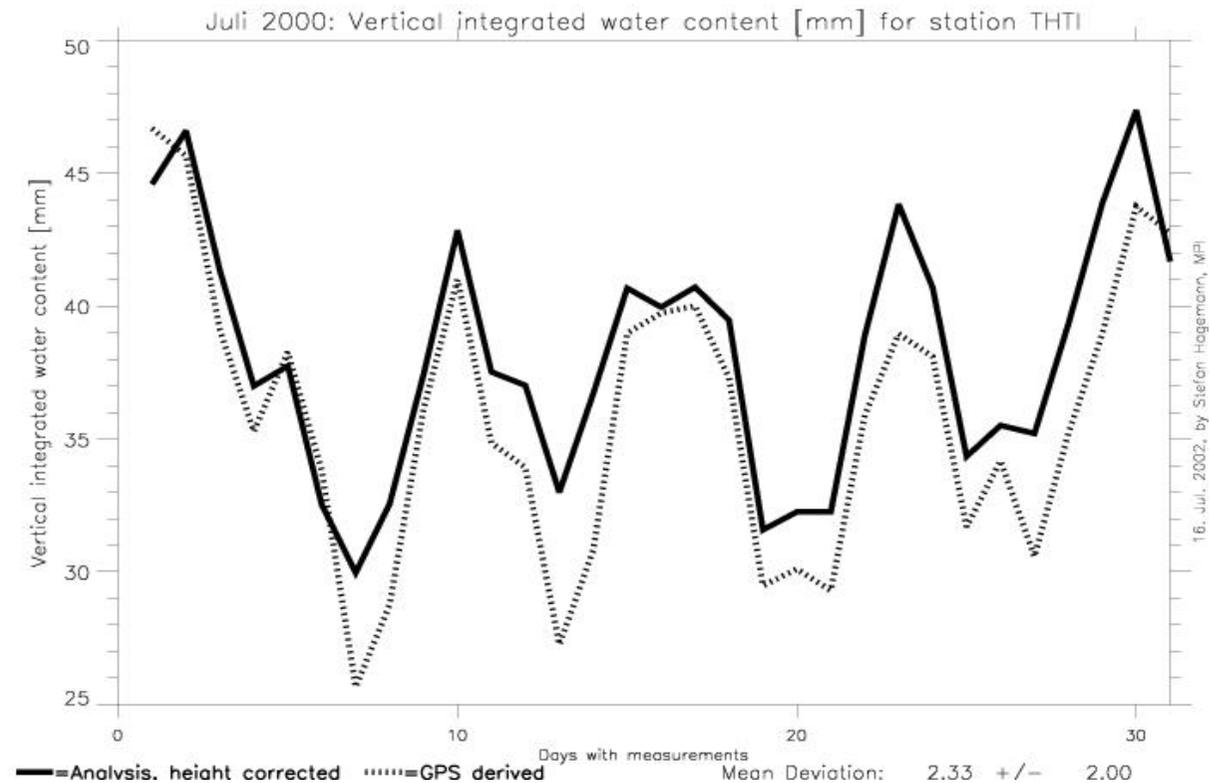## July 2000: IWV [mm] for station Tahiti (Polynesia)

$dF = a \times \ln \mathbf{q}$

Water vapour forcing

We represent temporal and areal mean by red.

We now have the approx. relation:

$\ln q - \ln q = -1/2(q'/q)^2$

Juli 2000: Vertical integrated water content [mm] for station THTI

Vertical integrated water content [mm]

Days with measurements

Analysis, height corrected   ......=GPS derived   Mean Deviation: 2.33   +/-   2.00

16. Jul. 2002, by Stefan Hagemann, MPI

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Very positive experience of using GPS occultation in weather prediction. Promises for climate monitoring of temperature and water vapour.

Proposals for the future

- an integrative approach-

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Total water vapor from IGS and COSMIC
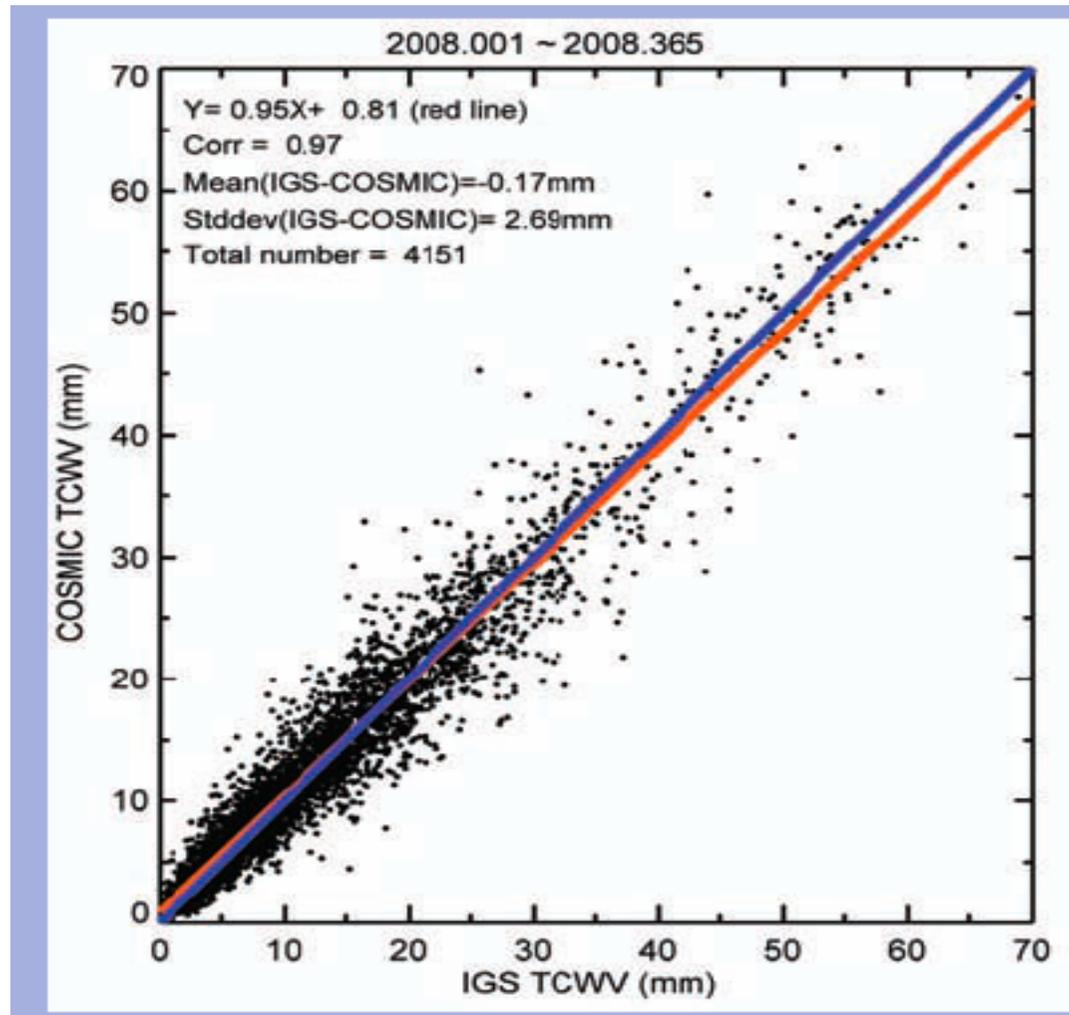
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Monitoring is required at high space and time resolution for multi-decadal periods.

- **The global energy balance**
- Monitoring external (e.g. solar irradiation) and internal forcing (atmospheric composition such as greenhouse gases and aerosols)
- **Large scale variables**
- State of the surface (such as SST)
- Atmospheric variables (T, V and Q)
- Accurate and bias-free
- **Internal energy fluxes**
- To be determined indirectly from data-assimilation (re-analysis) This will include precipitation.

END

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