



# **Investigating the Water Vapor and Lapse Rate Feedback to Surface Temperature Change from the Atmospheric InfraRed Sounder**

**Antonia Gambacorta, NOAA/PSGS, Camp Springs, MD**

**Chris Barnet, NOAA, Camp Springs, MD**

**Lynn Sparling, UMBC, MD**

**NASA Sounder Science Team Meeting, October 13th 2009**

Contact: [antonia.gambacorta@noaa.gov](mailto:antonia.gambacorta@noaa.gov)



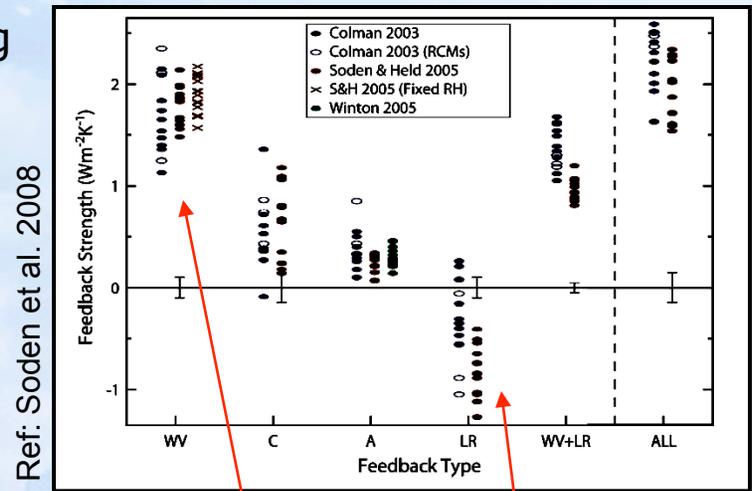
# Outline

- Follow up to results shown during previous meeting (Fall 2007):
  - temperature and water vapor correlations in the tropical troposphere
- We investigate the water vapor and temperature sensitivity to surface temperature change with a focus on the tropical troposphere
- The sensitivity analysis shows a large spatial and vertical gradient in the water vapor and temperature feedback to surface temperature change
- Implications for climate
- Ref.: A. Gambacorta et al., *Geophys. Research Letters*, in submission

# Motivation

- Large disagreement among present GCMs concerning the estimate of climate feedbacks
  - **Largest uncertainties from the water vapor, clouds and temperature components**

- Traditional assumptions of model simulations:
  - 1) Constant relative humidity:**  
 $RH = q/q_s = \text{const}$ ;  $dq/dSST = dq_s/dSST \sim 7-10\% / K$   
 (Clausius-Clapeyron eq. of thermodynamic equilibrium)
  - 2) Constant or decreasing lapse rate:**  
 $\Delta T_{\text{trop}} = \Delta SST$  (zero lapse rate feedback)  
 or  $\Delta T_{\text{trop}} > \Delta SST$ ; (negative lapse rate feedback)



$$\frac{dOLR}{dT_{surf}} \approx \sum_i \frac{\partial OLR}{\partial q_i} \frac{\partial q_i}{\partial T_{surf}} + \sum_i \frac{\partial OLR}{\partial T_i} \frac{\partial T_i}{\partial T_{surf}} + \dots$$

- Drying hypothesis: increased SST, increased precipitation efficiency, decreased moistening of the UT region;  $dq/dSST \neq dq_s/dSST$  ("Iris hypothesis", Lindzen, 1990)
- Large disagreement among observational studies of water vapor and temperature correlations and their sensitivities to SST changes
- Lack in the past of a comprehensive and reliable observational data set



# AIRS Temperature and Water Vapor characteristics

- Whole TOA – surface retrievals of temperature and water vapor
  - The full vertical extent of the retrieval profiles allows for a complete study of the atmospheric variable correlations in the upper, middle and lower troposphere.
- Cloud-clearing algorithm allows uniformity in the spatial coverage
  - no clear-sky bias is a key element for the science applications performed in this study.
- Vertical resolution
  - High vertical resolution is fundamental to capture the vertical structure in the atmospheric variable correlation analysis performed in this study.
  - AIRS v5 tropospheric temperature (moisture) retrieval resolution, as determined by the full-width-half-maximum of the averaging kernels, ranges between  $\sim 2.5\text{km}$  ( $3\text{km}$ ) near the surface and  $6\text{km}$  ( $4\text{km}$ ) near the tropopause (*Ref.: Maddy and Barnett, 2007*)
- Retrieval accuracy
  - Temperature rms  $\sim 1\text{K}$ ;
  - Water vapor rms  $\sim 10\%$  (lower and middle trop) –  $20\%$  (upper trop)
  - Extensively validated retrieval algorithm

(*Ref: Fetzer et al., 2003; Divakarla et al., 2006; Tobin et al., 2006; Fetzer et al., 2008;*)

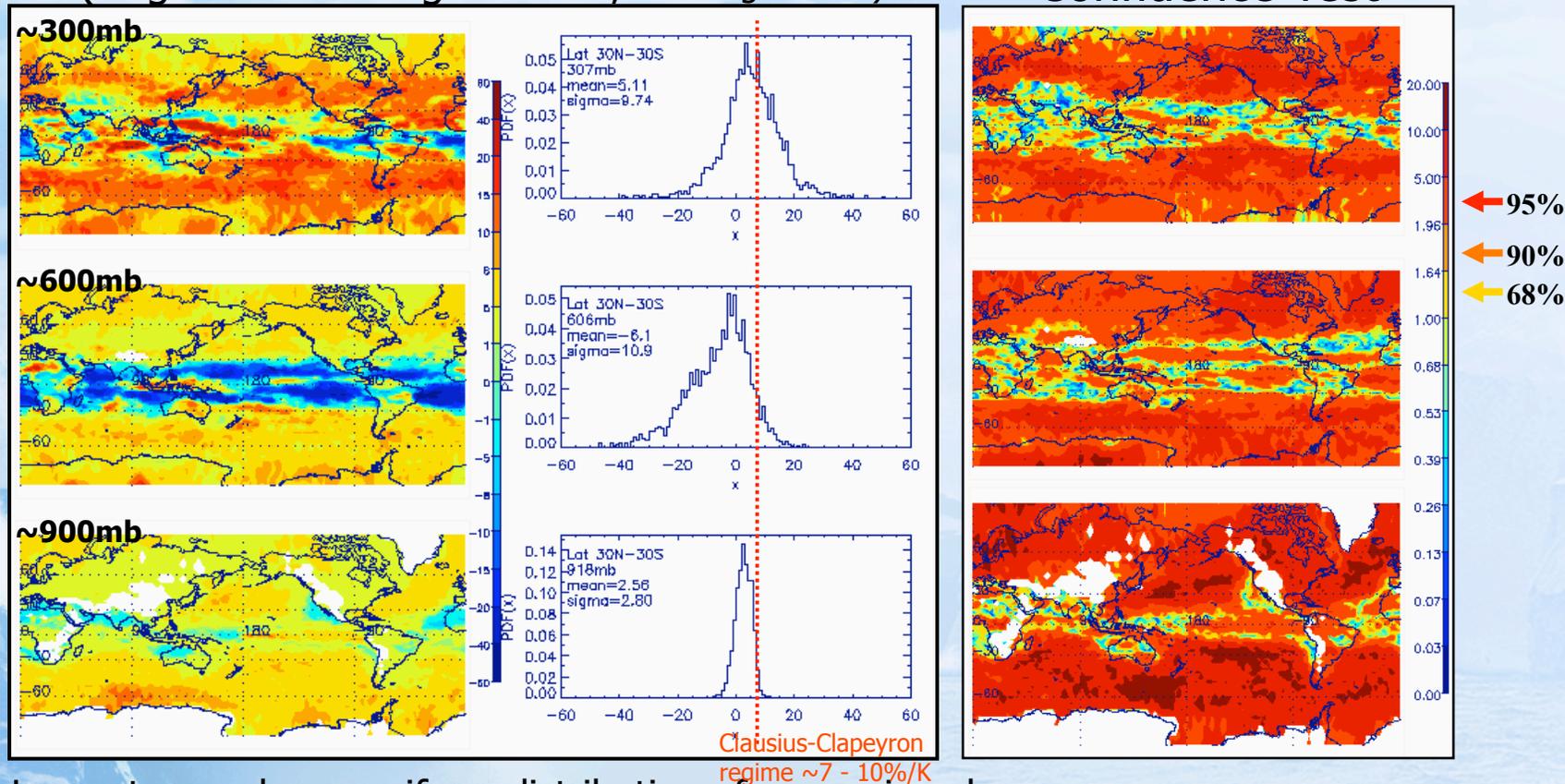


# ...From Fall 2007 AIRS Science Meeting:

Water vs temperature *at the same pressure level*  $i$ :  $dq_i/dT_i$  (%/K)  
 (monthly anomalies,  $q$  normalized by its long term average)

(August 2003- August 2007, 3x3 degree res.)

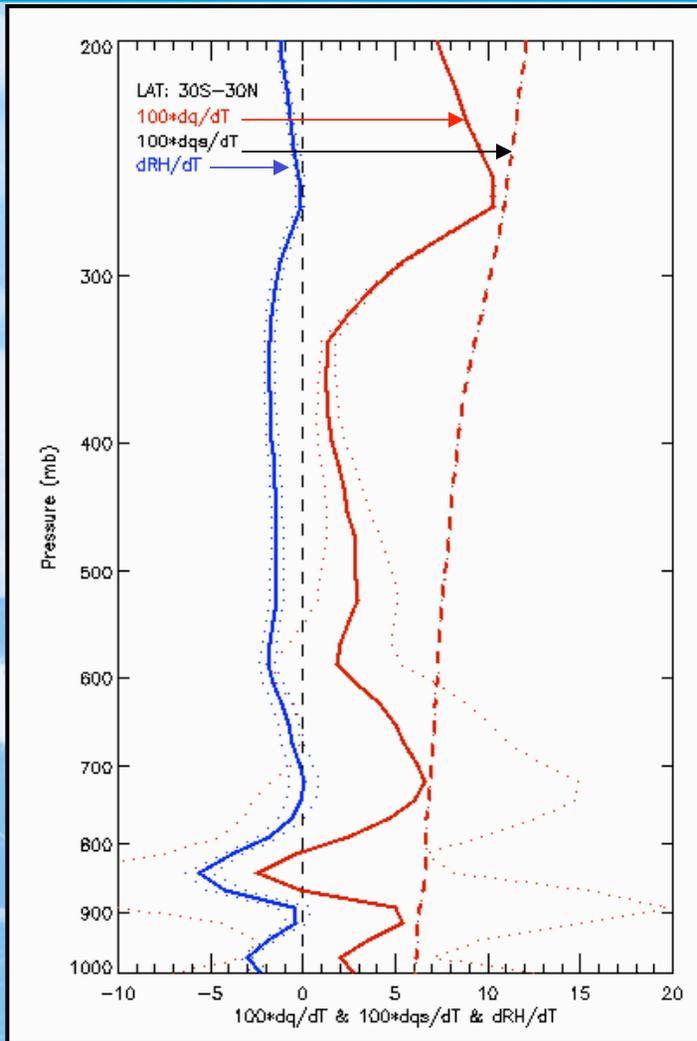
## Confidence Test



- Lower troposphere: uniform distribution of regression slopes
- Free troposphere: strongly longitude-altitude regression gradient
- Extended regions of high positive and negative regression values of high statistical significance

• REF.: A. Gambacorta, C. Barnet, B. Soden, L. Strow, *Geophys. Research Letters*, doi:10.1029/2008GL033805.

# Drawing a conclusion on the tropical water vapor – temperature relation



- Large gradient in the q-T correlations of the tropical free troposphere:

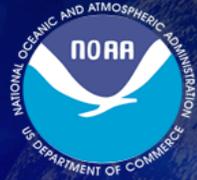
$$dq/dSST \neq dq_s/dSST$$

- Overall Upper Troposphere Tropical Correlations:

- In the upper troposphere, water vapor and temperature converge towards thermodynamic equilibrium

- Upper troposphere temperature increase accompanied by water vapor increase:

⇒ no overall UT drying effect observed



# ...Questions

- Large gradient of the  $q$ - $T$  correlations in the tropical free tropospheric :
  - **Slopes show values up to one order of magnitude higher than the Clausius-Clapeyron regime;**
  - **And of opposite sign;**



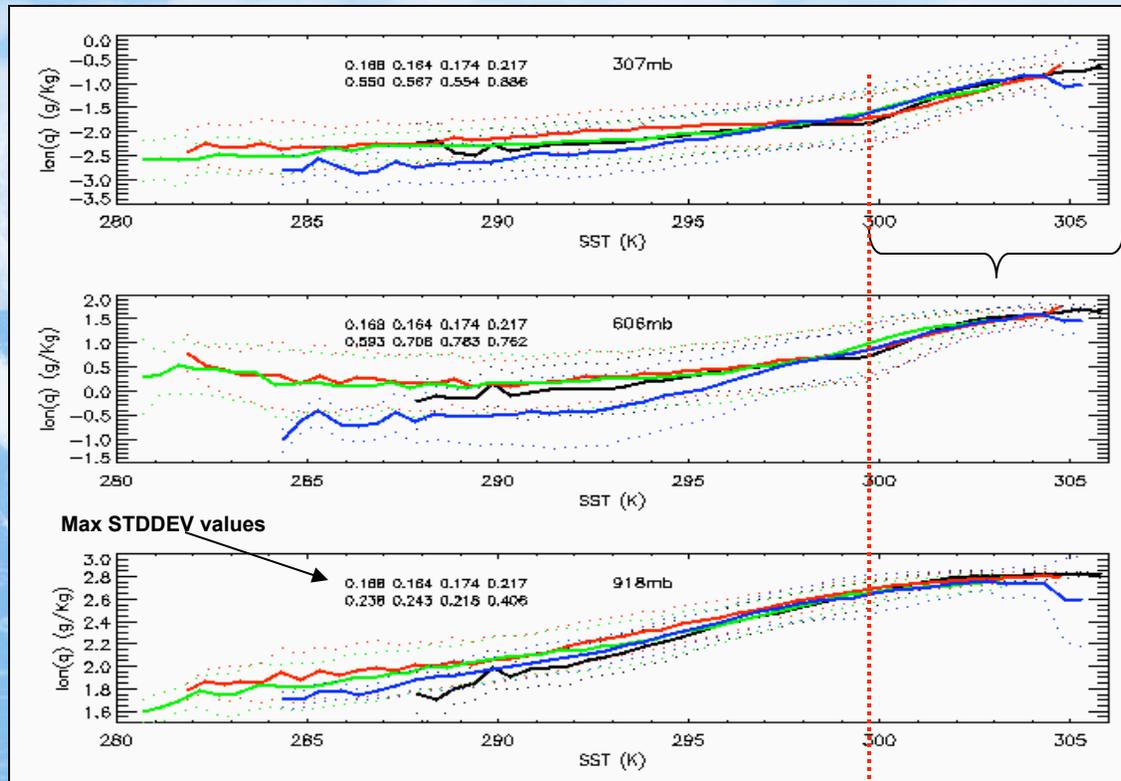
**Other mechanisms are regulating water vapor in these regions besides local temperature. What are they?**

- Spatial distribution of regression slopes resembles the patterns of the large scale circulation:
  - **1) High Positive correlations resembling areas surrounding convective activity:** convection and re-evaporation of cirrus anvils as main moistening sources
  - **2) High Negative correlations resembling areas of subsidence activity:** dry subsiding air anticorrelates with increased local temperature
  - **Can we find evidences in support of these arguments? Have these features ever been observed before? Are the GCMs able to reproduce them?**



# Conditional mean of water vapor versus surface temperature

- Inamdar & Ramanathan (1994): SST threshold  $\sim 300\text{K}$  for the onset of the convective regime (“Super Greenhouse Effect”)
- Hallberg & Inamdar (1996): additional decrease in upper tropospheric temperature under the convective regime



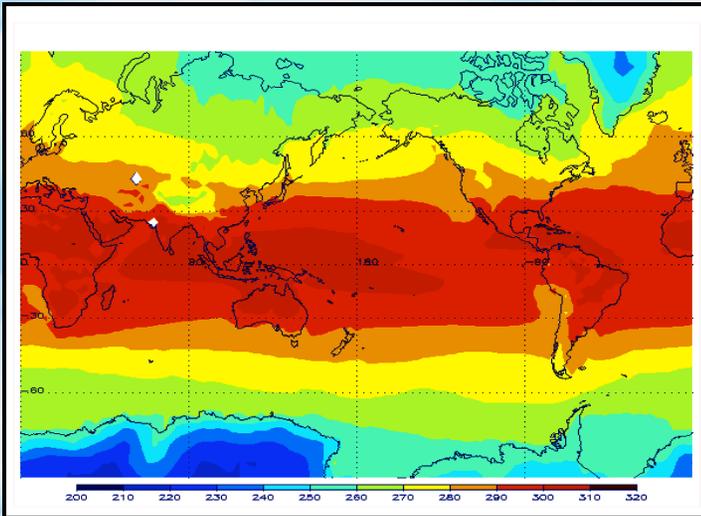
T > 300K  
Western Pacific  $\sim 17\%/K$   
Eastern Pacific  $\sim 21\%/K$   
Atlantic Ocean  $\sim 15\%/K$   
Indian Ocean  $\sim 10\%/K$

Convective threshold (“super greenhouse effect”)

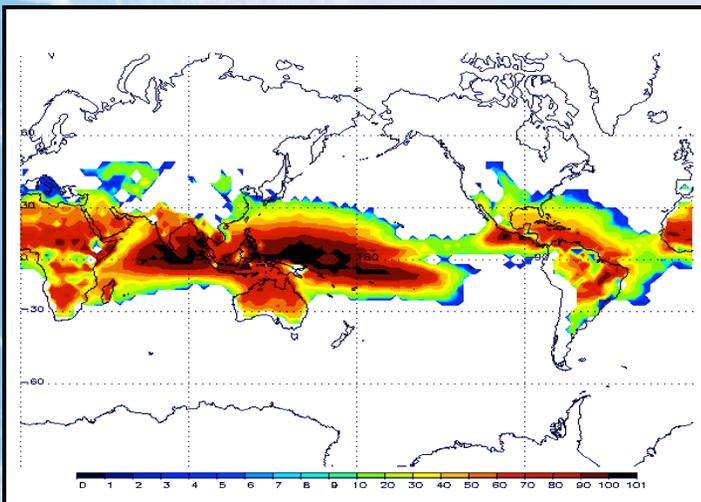


# AIRS 4-year surface temperature average and 300K threshold occurrence

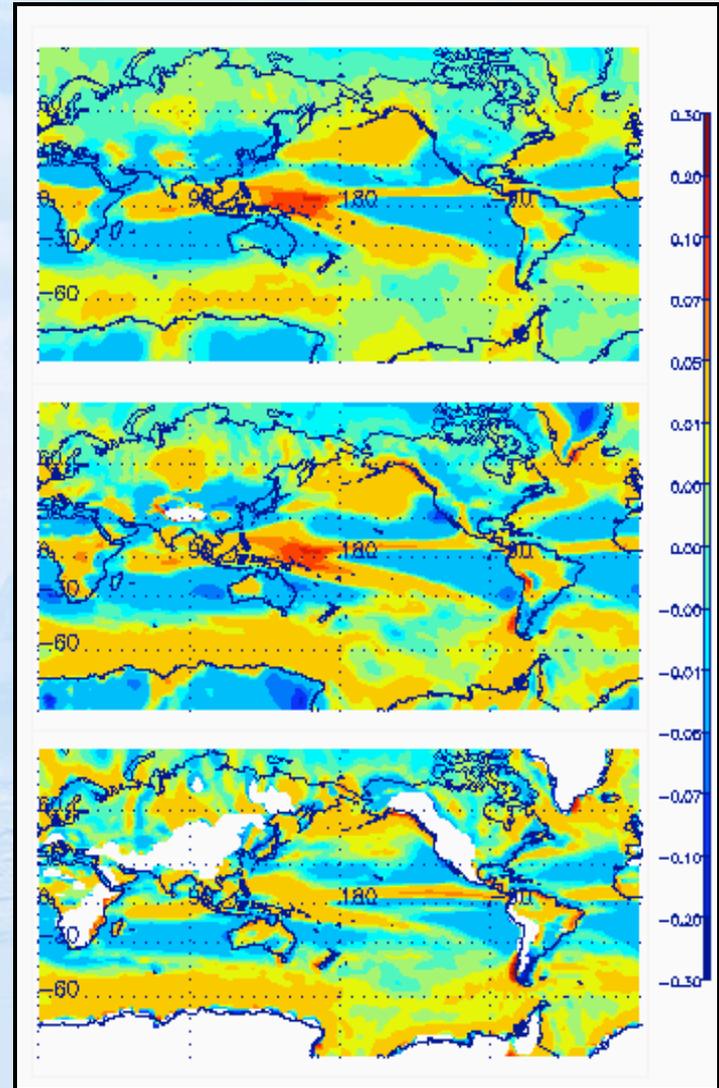
# NCEP vertical velocity (opposite sign) Red: upper motion Blue: downward motion



**Average Surface Temperature (K)**



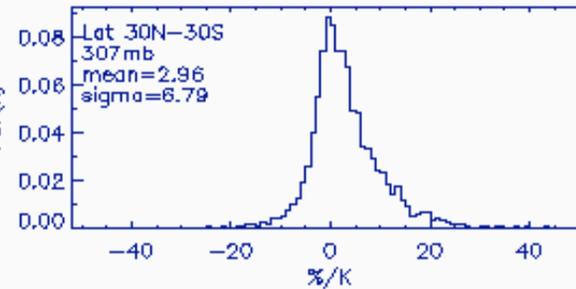
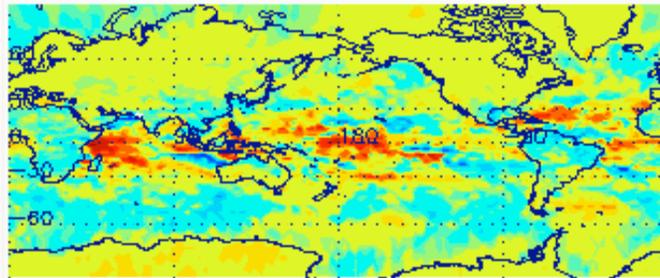
**T > 300K Occurrence (%)**



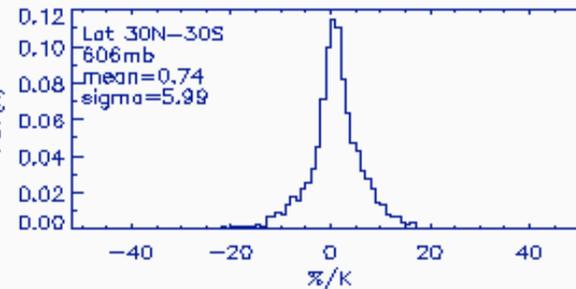
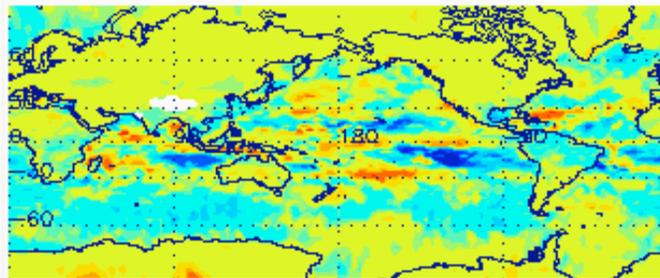
**(Pa/sec)**

# Slopes of Water Vapor vs Surface Temperature (%/K)

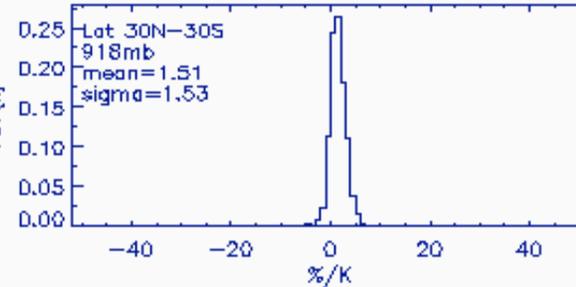
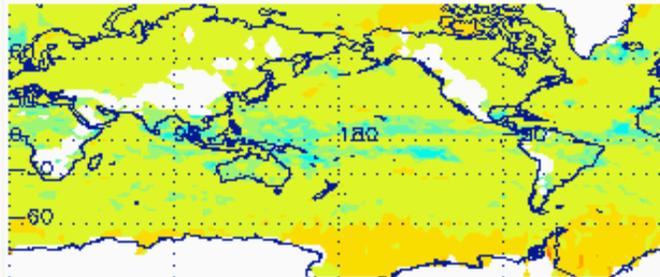
~300mb



~600mb



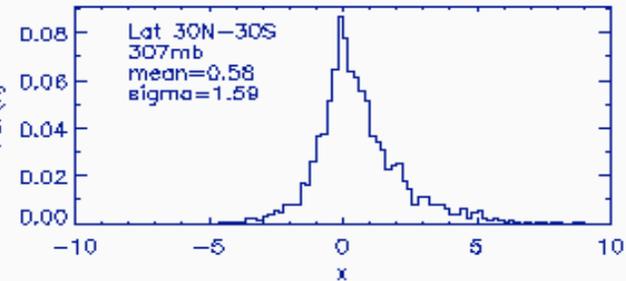
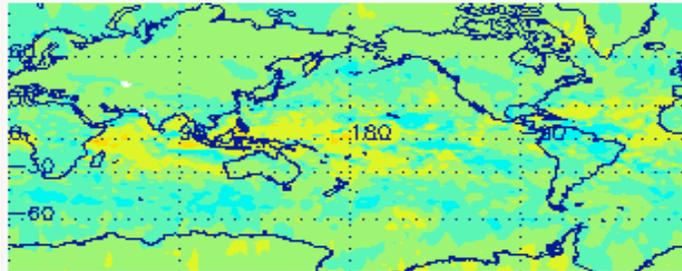
~900mb



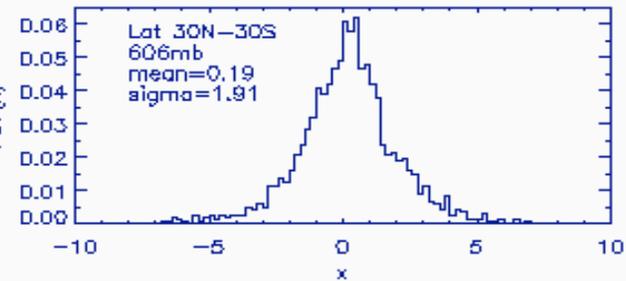
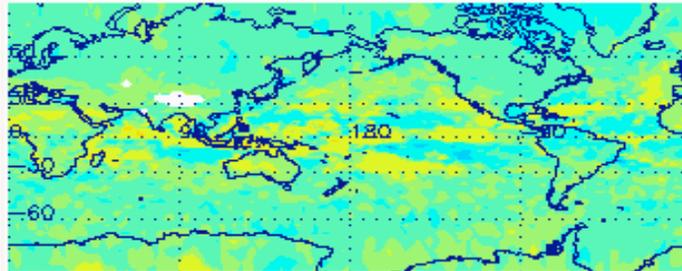
- Similar characteristics as for layer to layer correlations
- Highest positive regressions found over convective areas
- Highest negative regressions found over subsidence areas

# Slopes of Relative Humidity vs Surface Temperature (%/K)

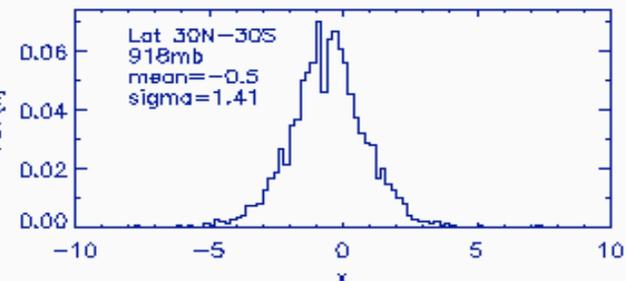
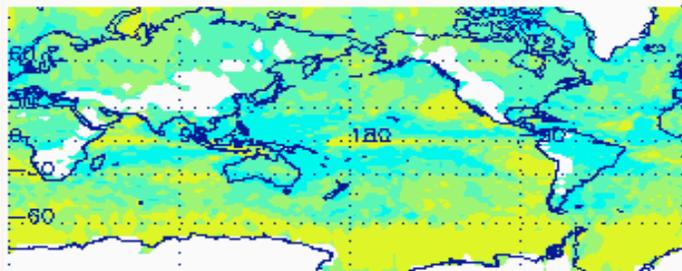
~300mb



~600mb



~900mb



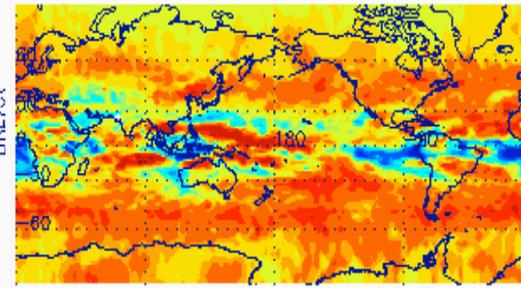
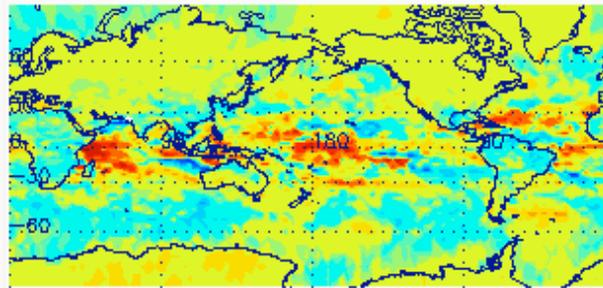
- Similar spatial patterns as in the water vapor – temperature regressions
- RH varies up to 10%/K in the tropical free troposphere



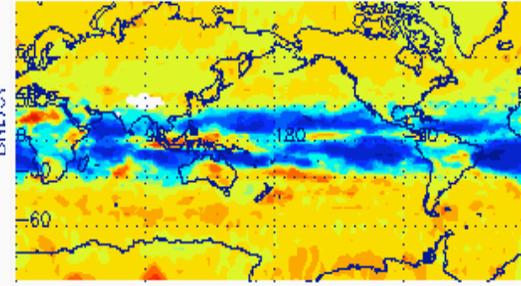
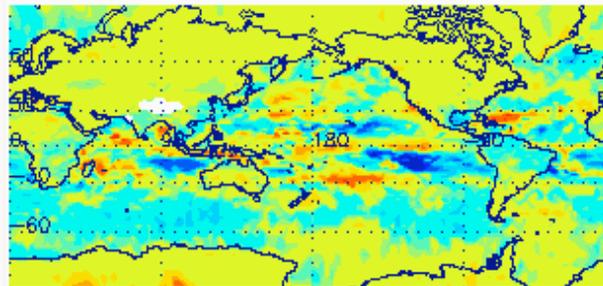
### Slopes of Water Vapor vs Surface Temperature (%/K)

### Slopes of Water Vapor vs Local Temperature (%/K)

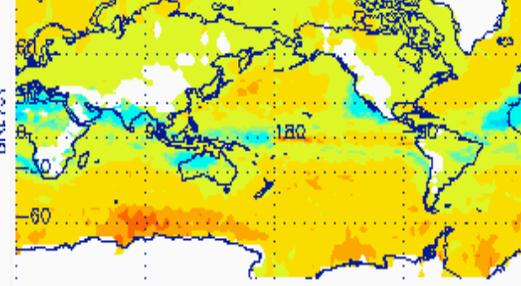
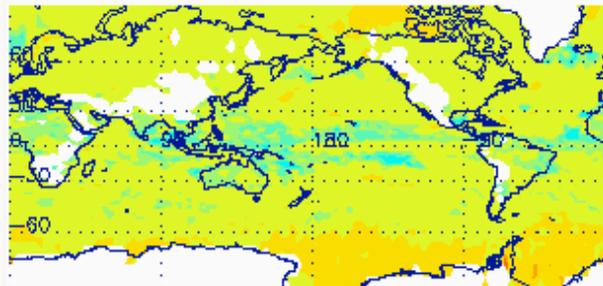
~300mb



~600mb

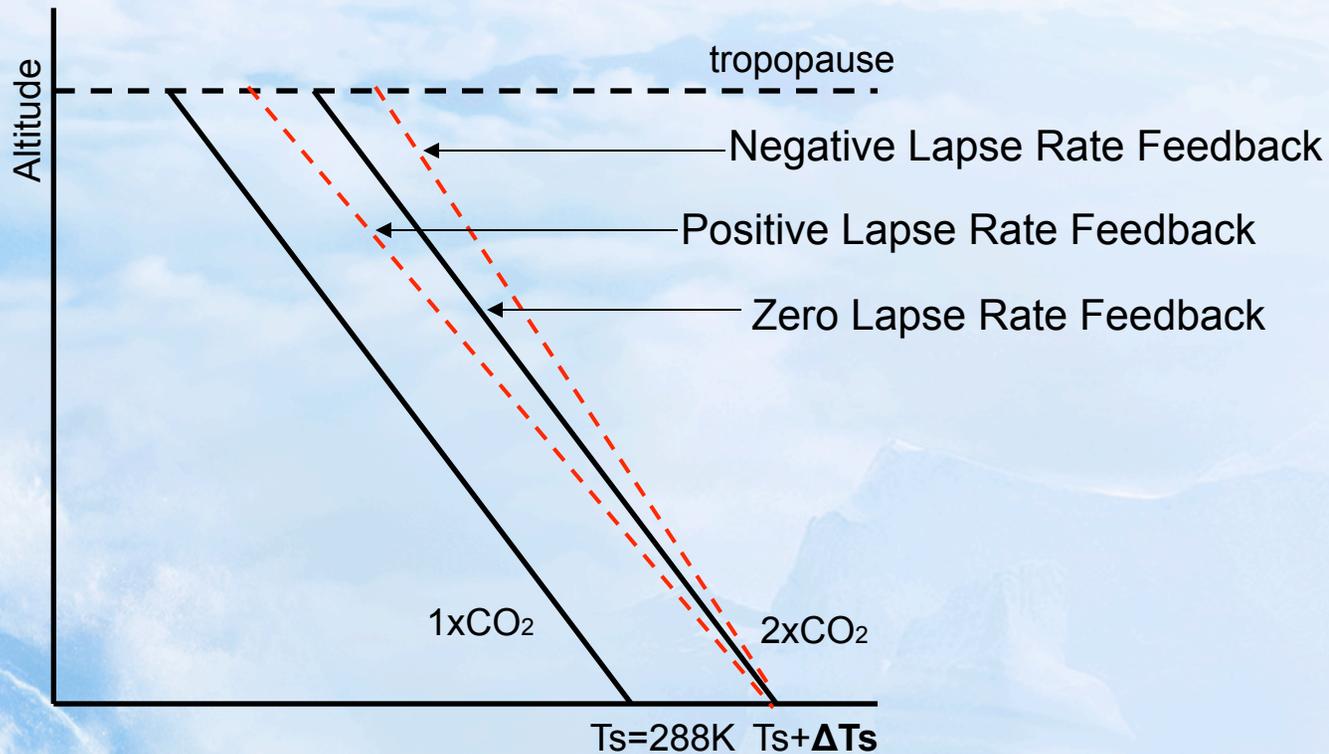


~900mb

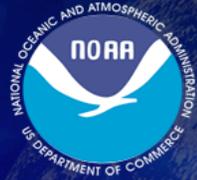


- Side by side comparison shows large and non-uniform differences between the layer-to-surface and layer-to-layer correlations indicating a non-zero and non-uniform lapse rate feedback to SST changes

# Temperature Lapse Rate Feedback



- **What is the sign of the lapse rate feedback?**
- **Is the lapse rate feedback uniform across the tropical region?**

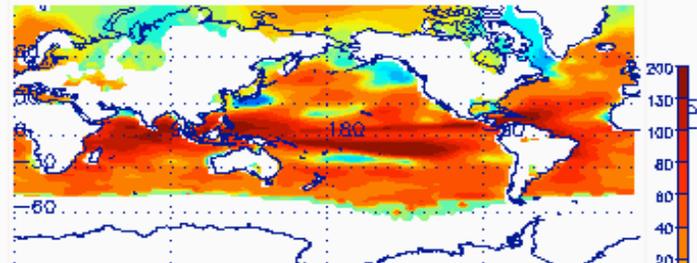
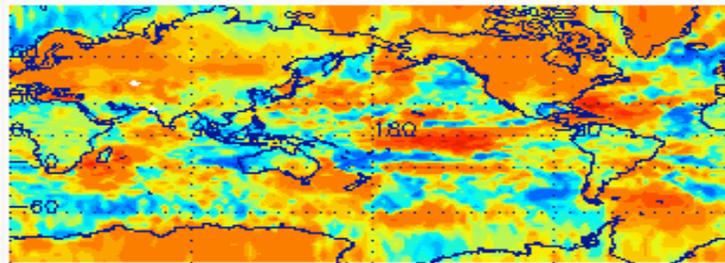


# Slopes of Temperature vs Surface Temperature $dT/dSST$ (%)

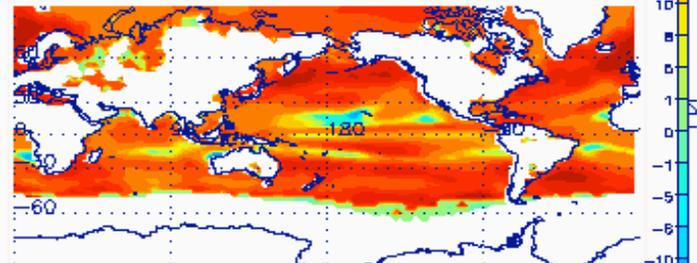
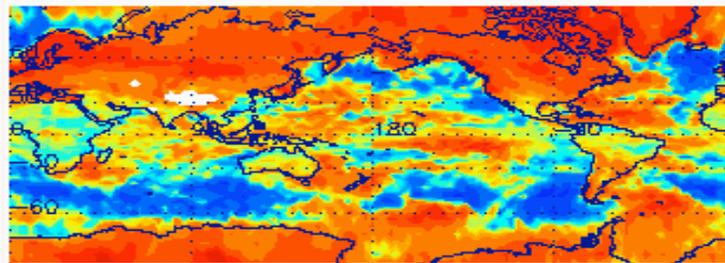
AIRS data: August 2003 – August 2007

GFDL Model data: Jan 1989 – Jan 2004

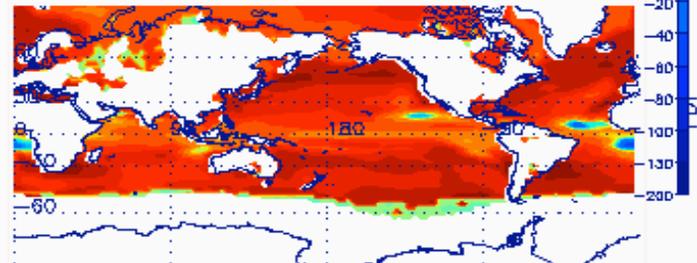
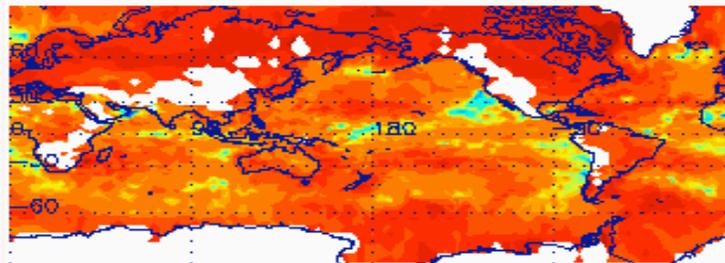
~300mb



~600mb



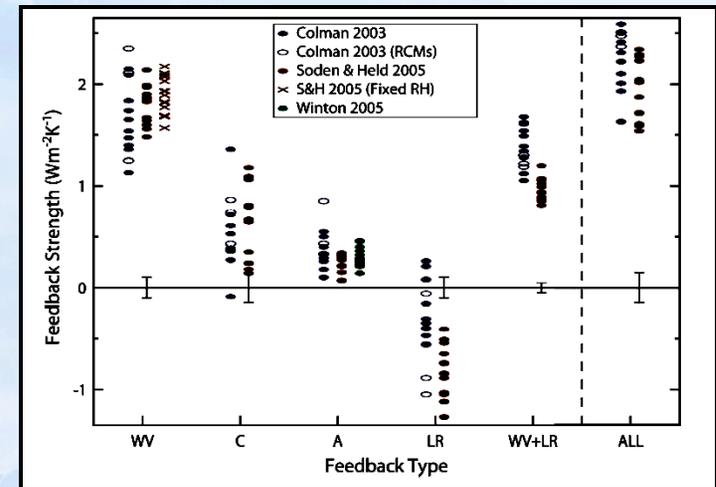
~900mb



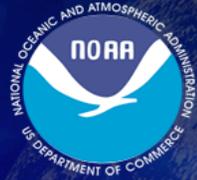
- **Strongly longitude – altitude dependent temperature lapse rate feedback**
- Low latitude West Pacific: UT temperature decrease (positive feedback). **Caveat:** confidence test of 50% - 68%
- Low latitude East Pacific: UT temperature decrease (negative feedback). Confidence test of 90% - 95%
- More uniform and mainly negative lapse rate feedback as seen by the GFDL model (preliminary results)

# Conclusions

- The sensitivity analysis conducted in this study shows a large spatial and vertical gradient in the water vapor and lapse rate feedback to surface temperature change
- Dynamic arguments identify the sources of high positive correlations in the convective activity and the sources of high negative correlations in the downward motion of the large scale circulation.
- Two contrasting lapse rate feedbacks appear to take place over the Pacific region: positive feedbacks over the West side induced by a decrease in temperature, negative feedbacks over the East side induced by a temperature increase to surface changes (note: see significance caveats on slide 14). Results appear to be in disagreement with the typical global circulation model assumption of a more uniformly negative lapse rate feedback across the whole tropics (work in progress).
- A close comparison between model outputs and observational data is necessary to reduce the uncertainties on climate change predictions.



$$\frac{dOLR}{dT_{surf}} \approx \sum_i \frac{\partial OLR}{\partial q_i} \frac{\partial q_i}{\partial T_{surf}} + \sum_i \frac{\partial OLR}{\partial T_i} \frac{\partial T_i}{\partial T_{surf}} + \dots$$

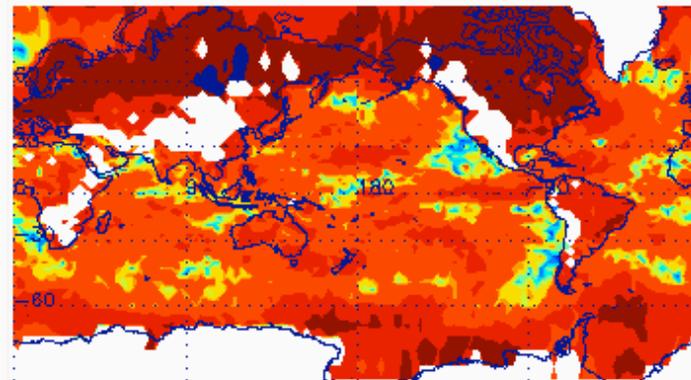
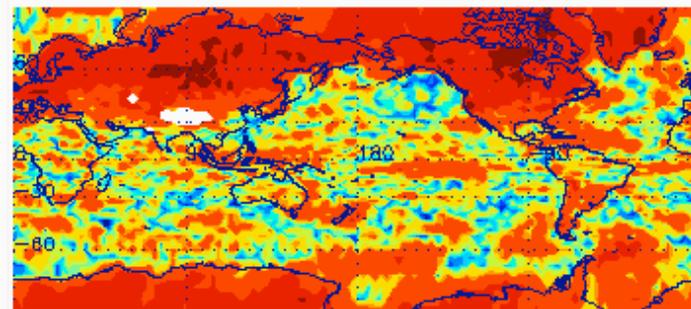
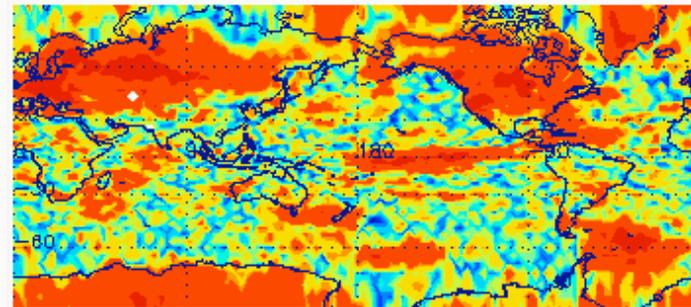


# Back up slides



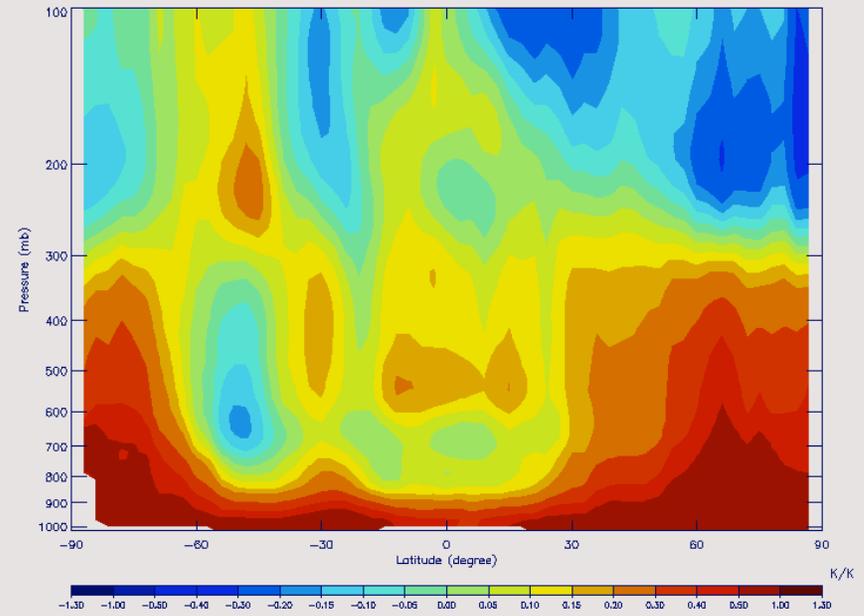
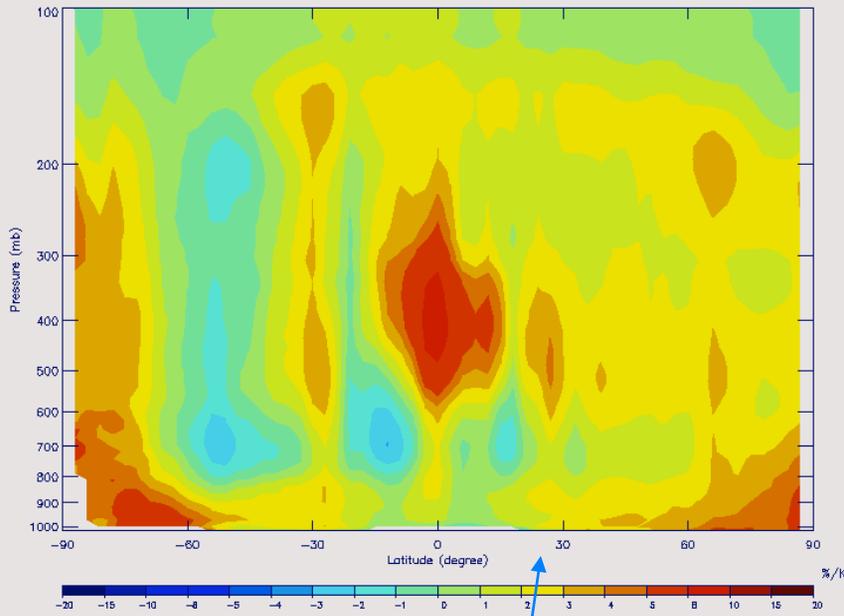


# T vs SST confidence test



← 95%  
← 90%  
← 68%

# Conclusions



$$\frac{dOLR}{dT_{surf}} \approx \sum_i \frac{\partial OLR}{\partial q_i} \frac{\partial q_i}{\partial T_{surf}} + \sum_i \frac{\partial OLR}{\partial T_i} \frac{\partial T_i}{\partial T_{surf}} + \dots$$

- The sensitivity analysis conducted in this study shows a large spatial and vertical gradient in the water vapor and lapse rate feedback to surface temperature change



# AIRS version 5 validation results

- **AIRS version 5:**
  - Enhanced temperature and water vapor products
  - New retrieval rejection criteria
- **AIRS version 5 validation:** [Ref.: *Gambacorta et al. , JGR, in submission*]
- Radiosonde data set from a site in the tropical Western Pacific (166E-0.5S)

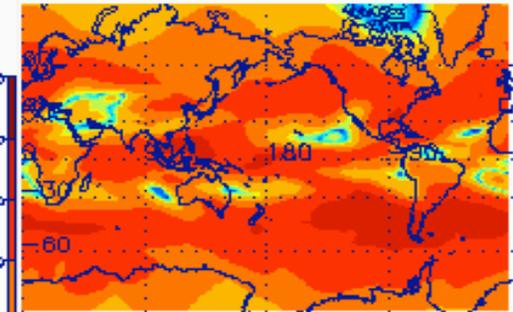
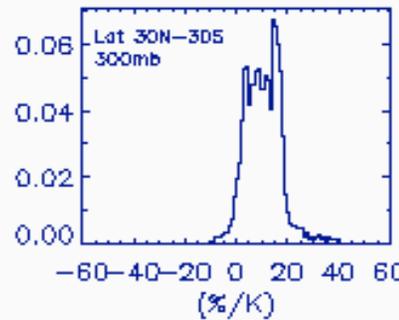
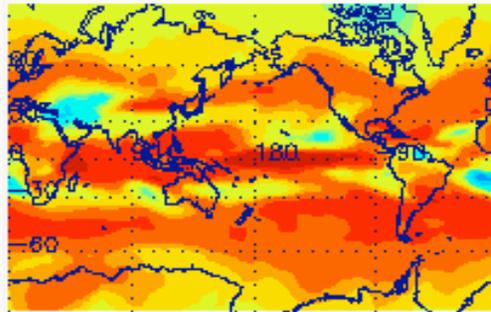
	RMS	GRMS	BIAS	IBIAS	RMS	GRMS	BIAS	IBIAS
LT	~1.2k	~0.1k	~-0.3k	~0.2k	~10/15%	~2%	~5%	~3%
MT	~0.6/0.8k	~0.1k	~-0.3k	~0.2k	~15/20%	~5%	~-2/5%	~10%
UT	~1/-2k	–	~-1/0.5k	~0.2k	~25%	~10%	~-2/5%	~10%

- Both RMS and bias statistics show good performance
- Compare well with other mission data sets (*i.e.* MLS on AURA satellite, Ref: Fetzer et al., 2008)
- Bias uncertainties do not affect our science study, which is based on perturbation correlations (Ref: John and Soden, 2007)

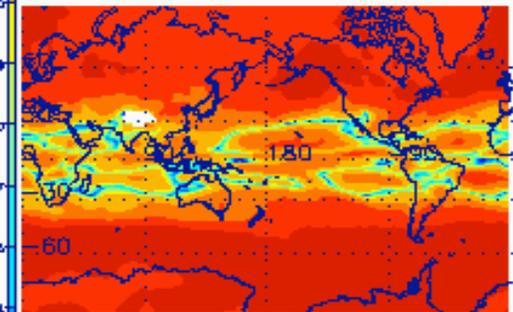
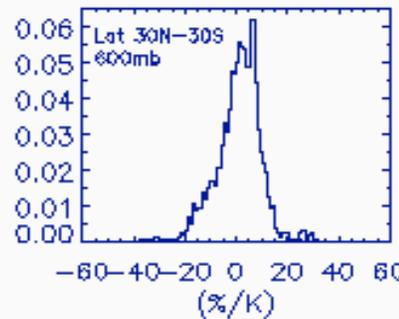
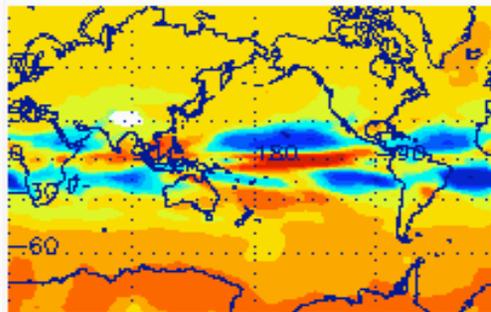


# $d(q_m / \langle q \rangle) / dT_m$ from the NOAA GFDL model & significance test

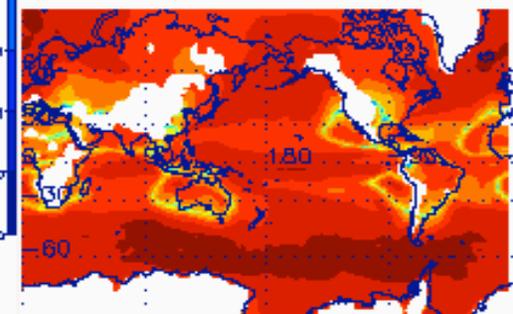
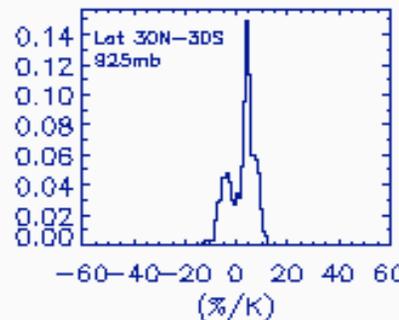
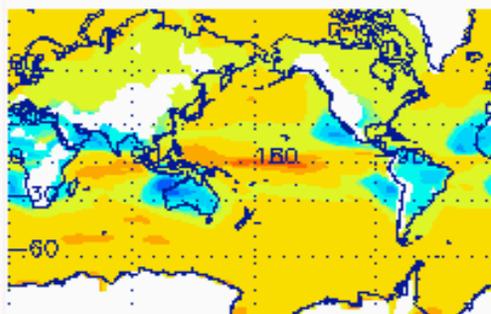
~300mb



~600mb



~900mb

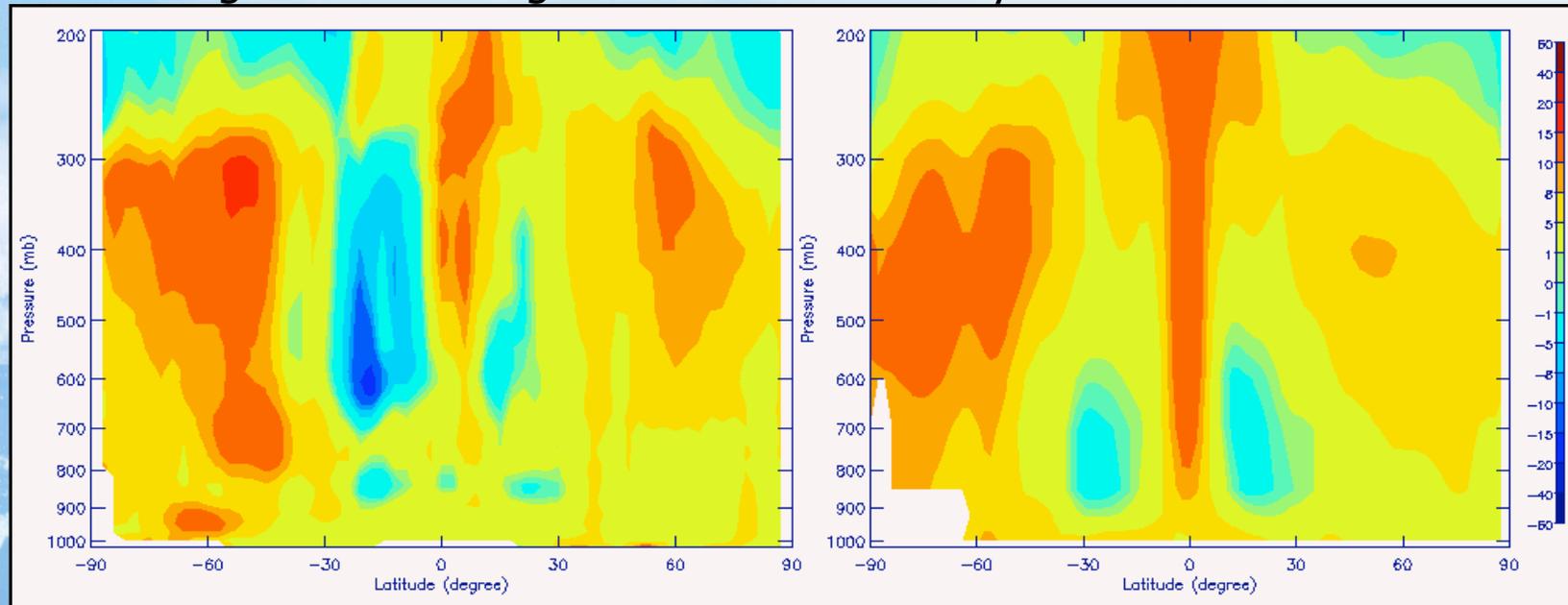




# Altitude - Latitude cross section of temperature and water vapor correlations (%/K)

August 2003 – August 2007

January 1998 – December 2004



**AIRS**

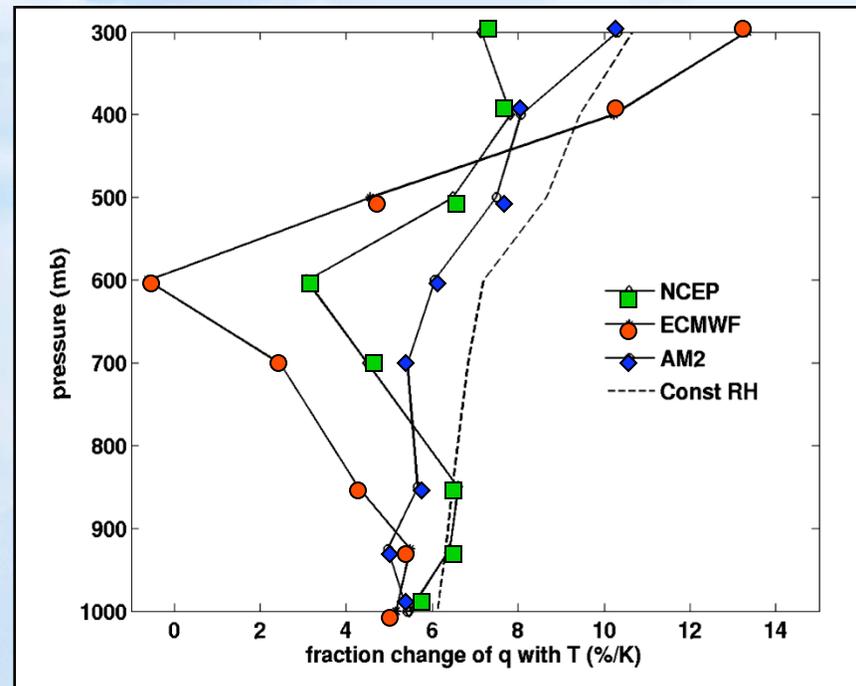
**GFDL**



# Observational studies of the water vapor greenhouse effect

$$dOLR \propto -d \ln q$$

$$\frac{d \ln q}{dT} \sim \frac{1}{\langle q \rangle} \frac{dq_m}{dT_m}$$



(Ref.: Huang, Soden and Jackson, GRL, 2005)

- $\langle q \rangle$  = Annual mean specific humidity
- $q_m, T_m$  = monthly mean specific humidity and temperature anomalies
- **A large discrepancy among observational studies of the water vapor greenhouse effect component**

# Statistical Significance of the fit

- Is the linear fit  $b$  indicative of a real underlying cause or is a chance fluctuation?
- "standard error",  $SE$ :

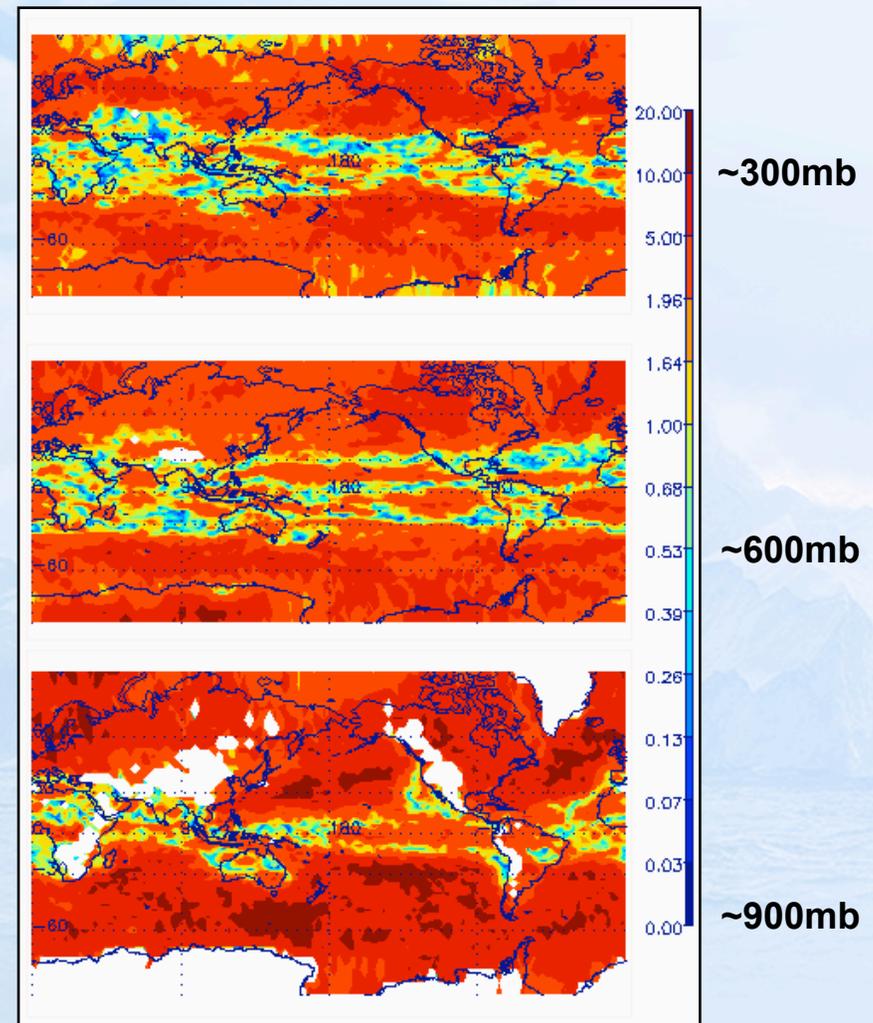
$$SE = \sqrt{\frac{\chi^2}{\sum_{n=1}^N (T_n - \langle T \rangle)^2}}$$

- $P([b-SE, b+SE]) =$  (confidence test)
- "statistical significance",  $SIG$ :

$$SIG = b / SE > 1 \Leftrightarrow 68\% \text{ confidence}$$

$$SIG = b / SE > 1.64 \Leftrightarrow 90\% \text{ confidence}$$

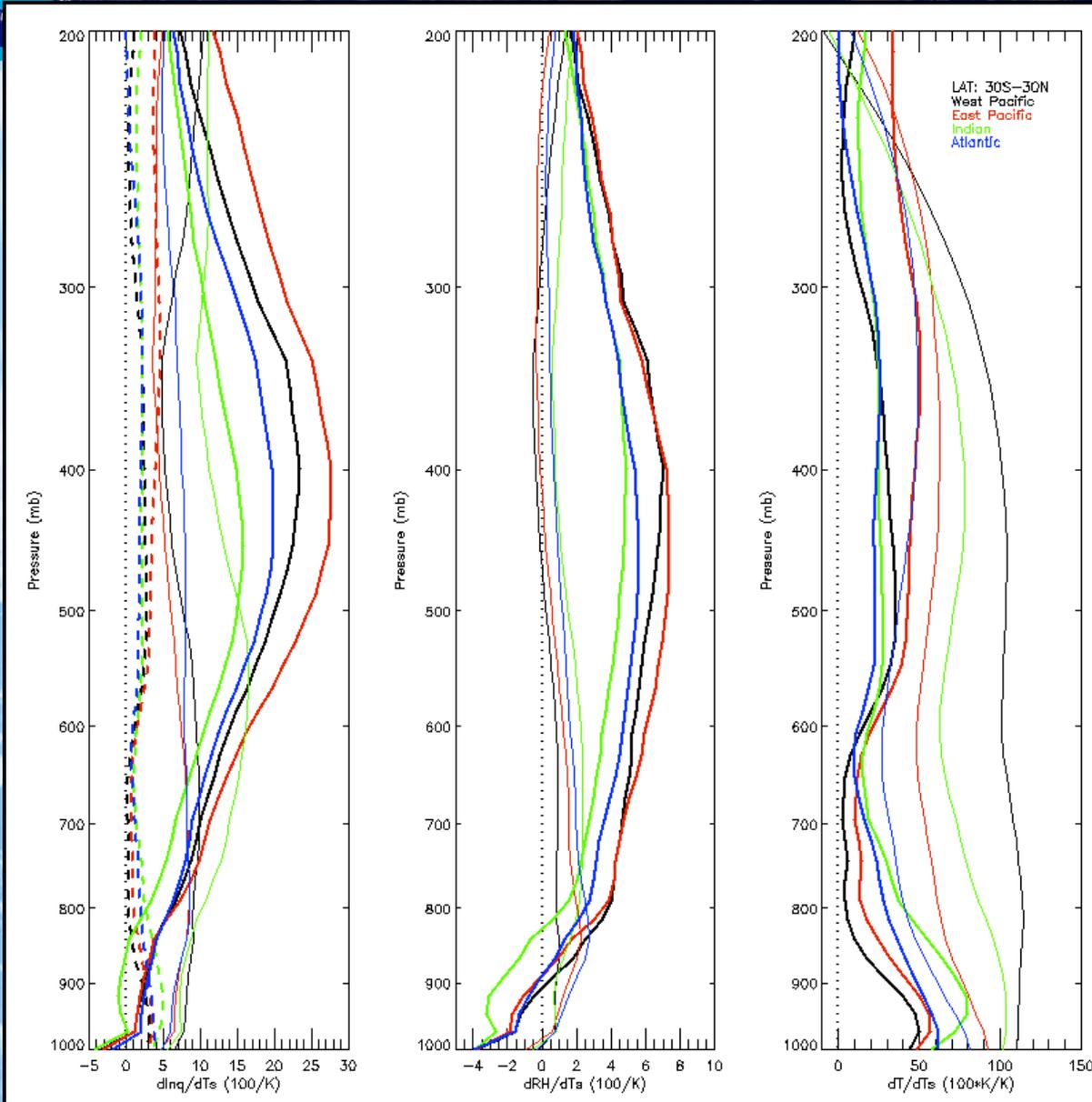
$$SIG = b / SE > 2 \Leftrightarrow 95\% \text{ confidence}$$





# Conditional mean slopes – vertical profiles, 30S-30N

(thick lines: convective regime; thin lines: non convective; dashed lines: convective const. rel. hum.)

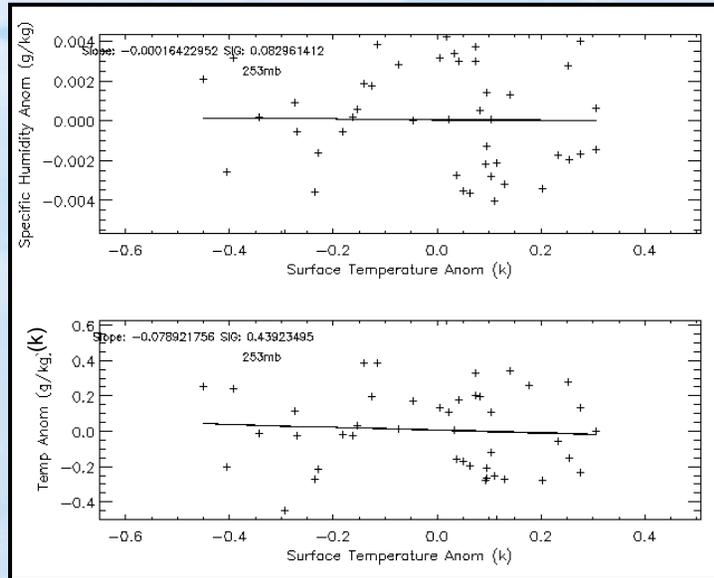


- Very non uniform response in wat vap, RH and temperature to surface variations

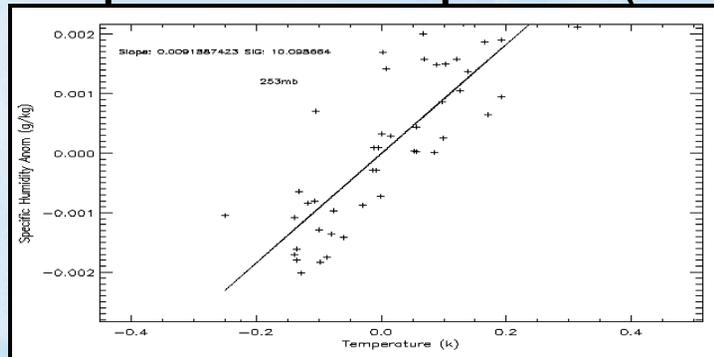


# Statistical Significance of tropical regressions (case study at 250mb)

## Wat vapor vs Surface temperature (30S-30N)



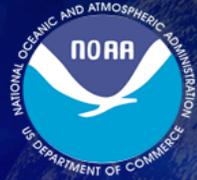
## Wat vapor vs Local temperature (30S-30N)





# Conclusions

- A large gradient existing in the horizontal and vertical structure of the water vapor and temperature correlations
  - *Convective activity is found to moisten the UT region at rates up to one order of magnitude higher than the thermodynamic regime. RH is seen to vary with a rate up to 10%/K.*
  - *Subsiding motion is responsible of negative correlations at a rate of one order of magnitude higher than the thermodynamic regime. Large lapse rate feedbacks are seen in this region up to  $\sim 1\text{K/K}$ .*
- Linear regression of tropically averaged humidity
  - Versus surface temperature: statistically insignificant.
  - Versus same level temperature: highly significant, highly positive in the UT region, converging towards thermodynamic equilibrium. As temperature increases, water vapor increases: *No drying effect as suggested by Lindzen.*
- A sensitivity study over convective and non-convective regime to assess the water vapor dependence on surface variations:
  - *occurrence and strength of the "water vapor super greenhouse effect".*
- A preliminary study to directly relate greenhouse effect to surface temperature, through its sensitivity to water vapor feedback from multiple layers in the troposphere.
  - *Observational Radiative Kernel approach*
- **We value the results of this research as a useful reference to identify the mechanisms regulating water vapor in the tropics and its radiative feedback. This analysis provides useful insights in helping discriminate among model results and improve our capability to make predictions about the future of our climate.**



# Future Work

- **Long term data record is fundamental to accurately assess the present trend in climate**
- **Multi-instrument strategy:** AIRS, IASI (InfraRed Atmospheric Sounder Instrument), CrIS (Cross-track InfraRed Sounder)
  - Mission overlap, employment of the same retrieval algorithm with the same underlying spectroscopy
  - A long-term uniform and un-biased climate data record useful for climate trends studies.