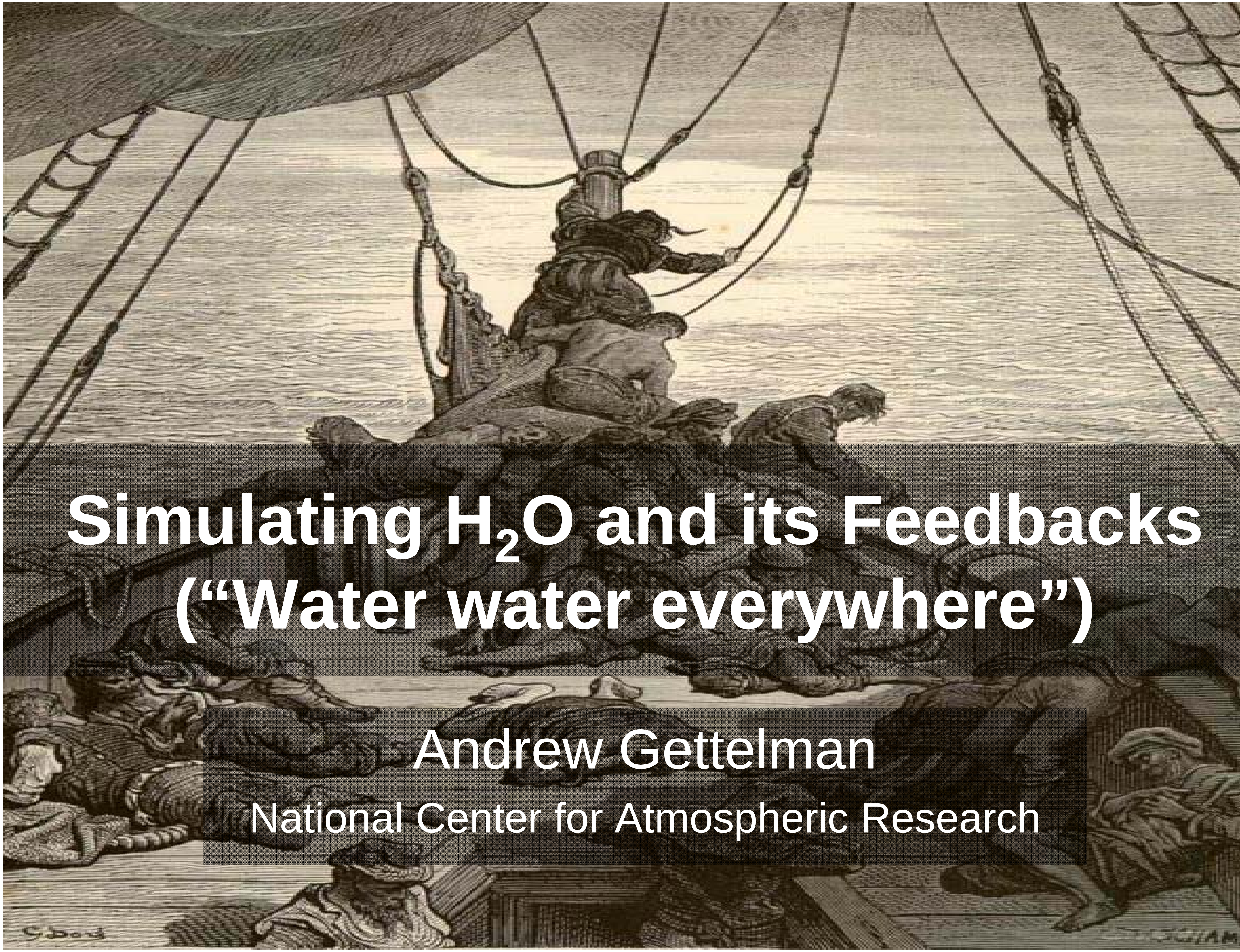


Simulating H_2O and its Feedbacks (“Water water everywhere”)

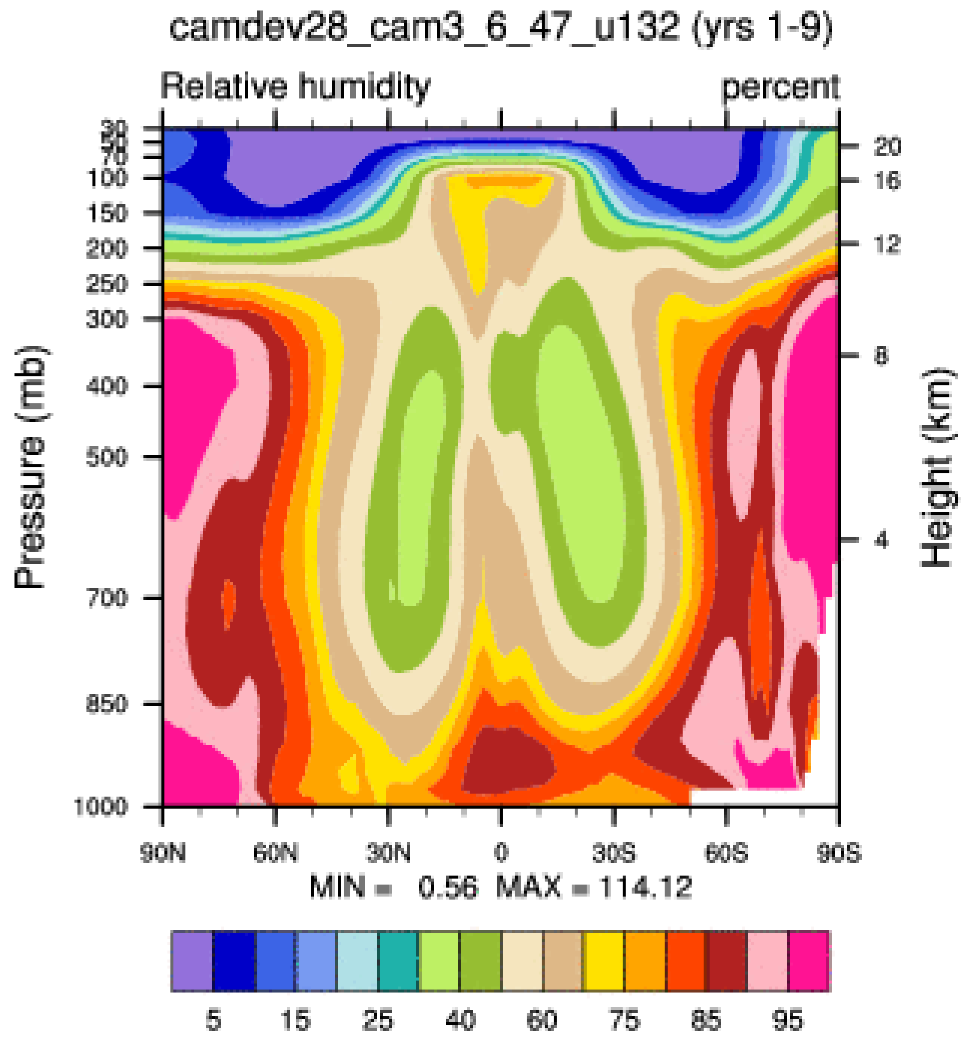
Andrew Gettelman

National Center for Atmospheric Research

Outline

- Water vapor transport & modeling
- Humidity in a GCM
- Observed & Simulated Distributions of H_2O
- Basic concepts of water vapor feedback
- Observed and Simulated H_2O feedbacks

Basic Humidity Structure

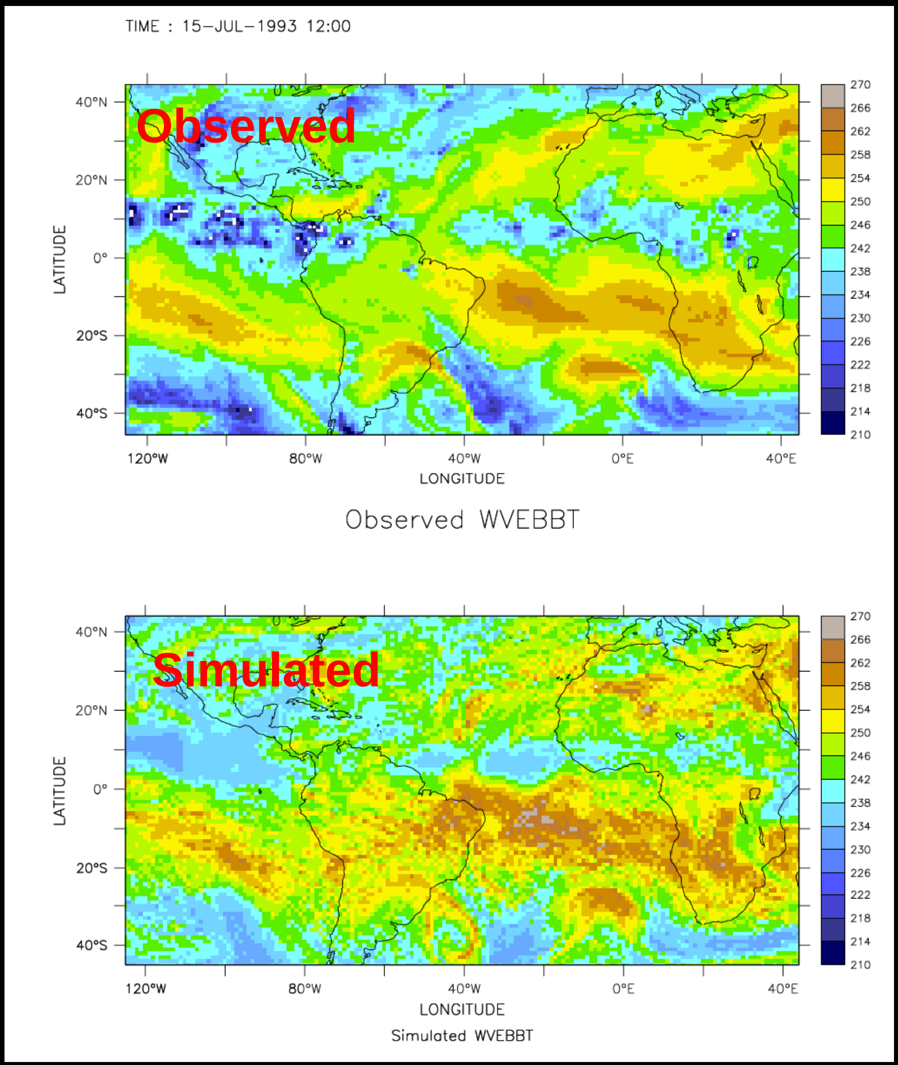


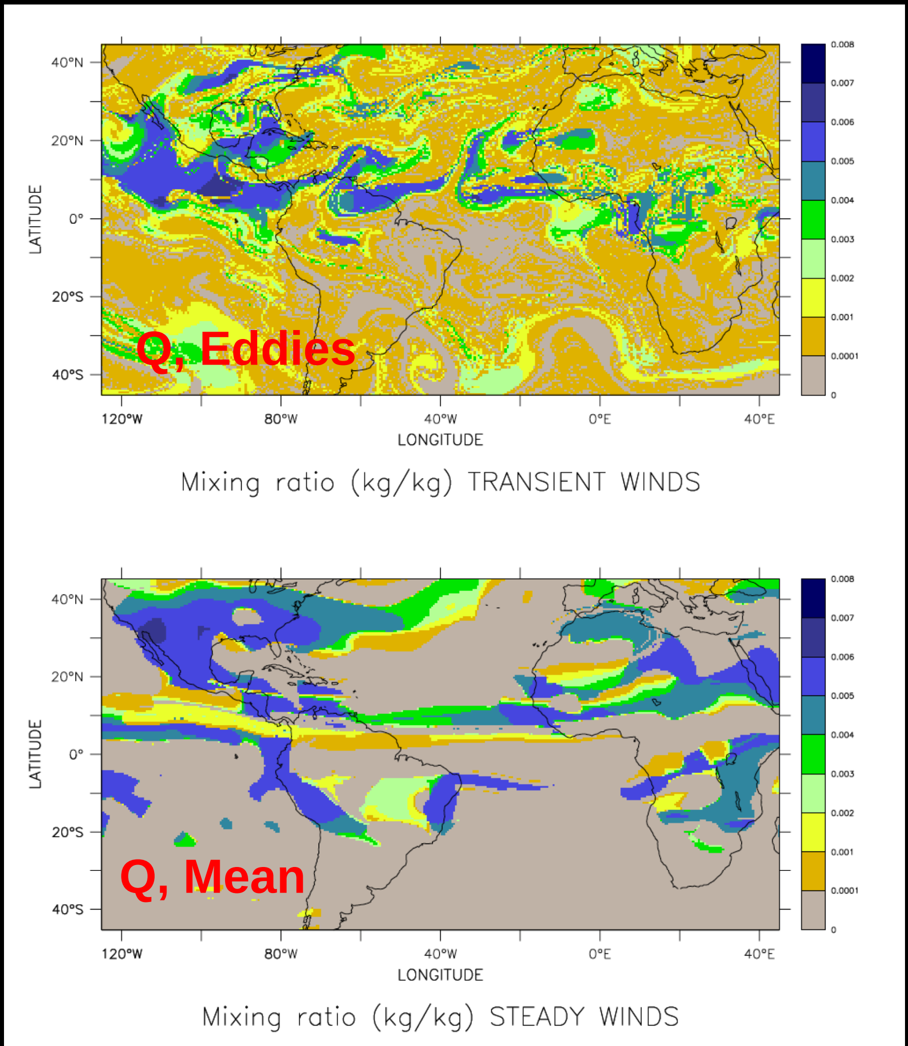
Key features:

- High Humidity
  - Polar regions
  - Boundary Layer
  - Tropical Upper Trop
- Low Humidity
  - Stratosphere
  - Subtropics

How does it get that way?

Advection ...by eddies





Pierrehumbert & Roca 1998, GRL

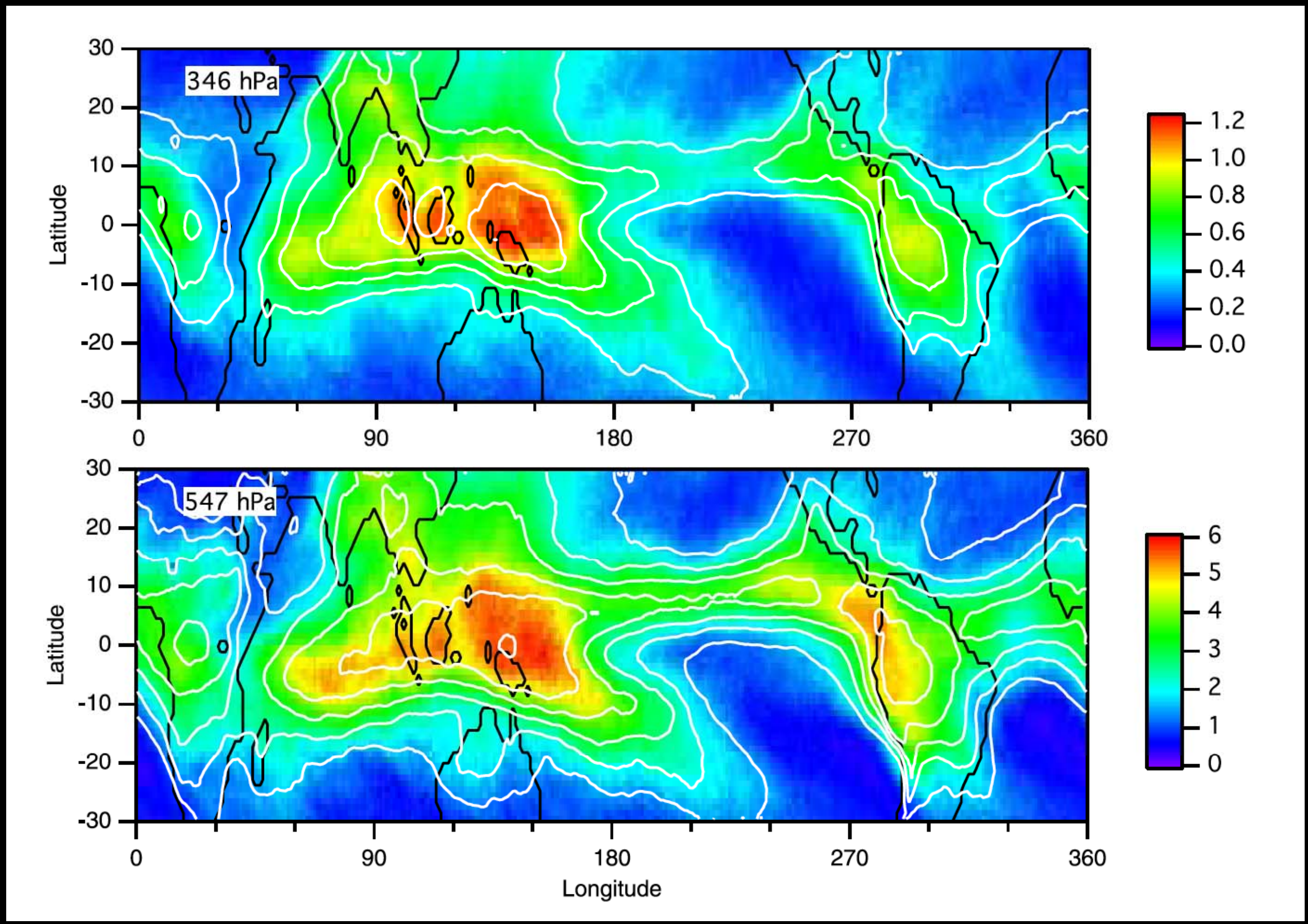
Basic Concept

- Run trajectories and constrain the humidity by RH < 100%
  - "Last Saturation" type models
- Does a pretty good job of reproducing the basic pattern
- This is one reason why GCM's do a decent job.

‘Last Saturation’ Models

AIRS v. Simulations

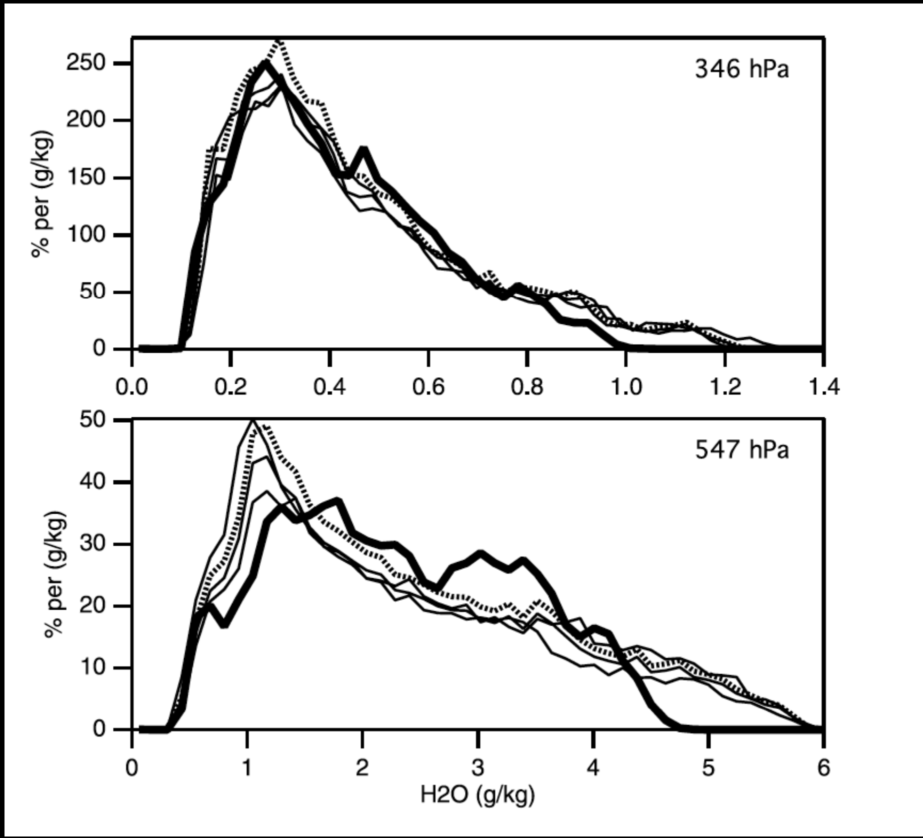
Dessler & Minschwaner, 2007, JGR



‘Last Saturation’ Models

AIRS v. Simulations

Dessler & Minschwaner, 2007, JGR

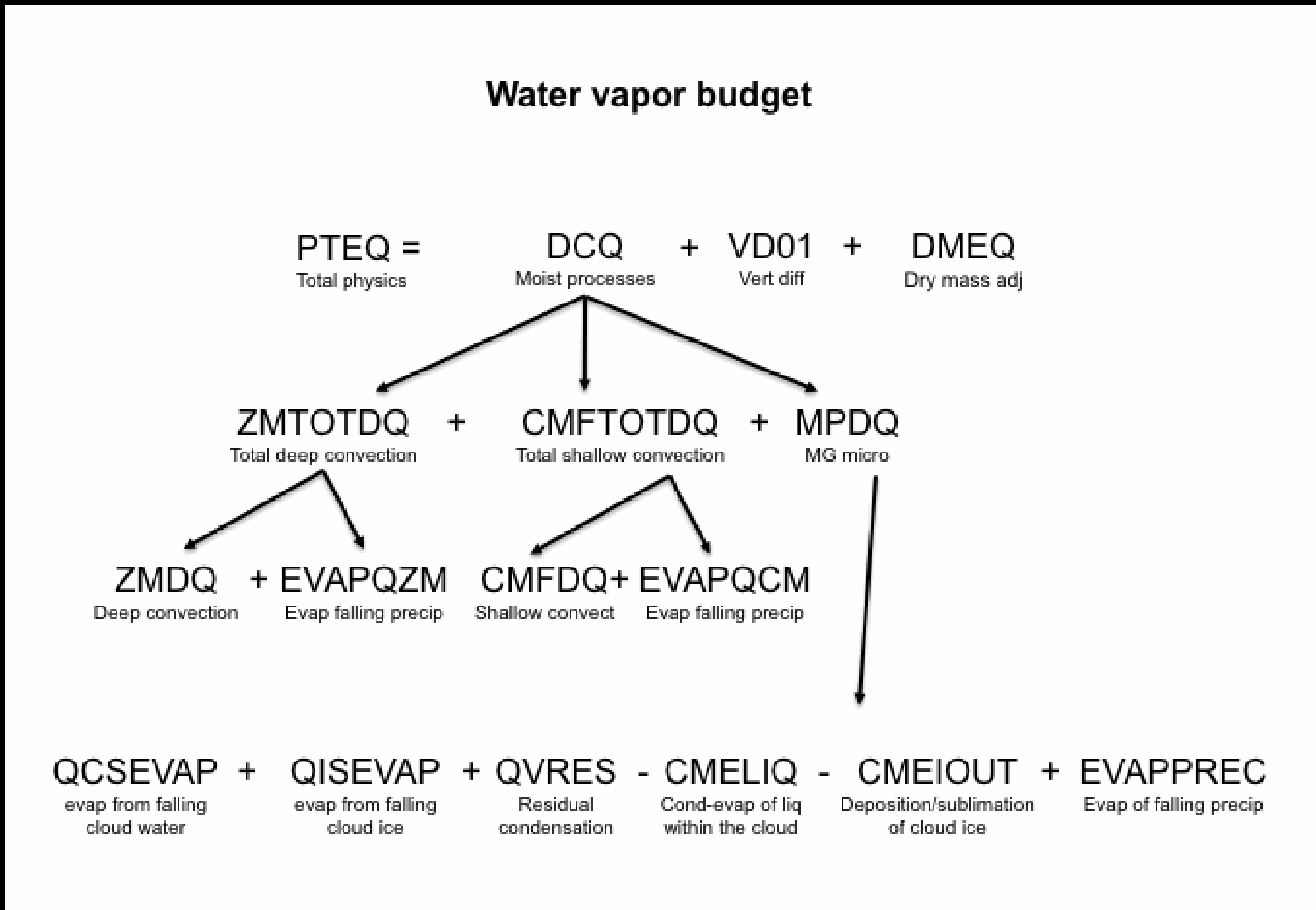


Humidity in a GCM

- Water is a predicted & advected species
  - Special case: also affects heat budget whenever it changes phase
- Make sure it is:
  - Positive Definite
  - Conserved (total mass)
- Basic Concept is ‘Saturation Adjustment’
- Plus a lot of other stuff!
  - Microphysics
  - Convection

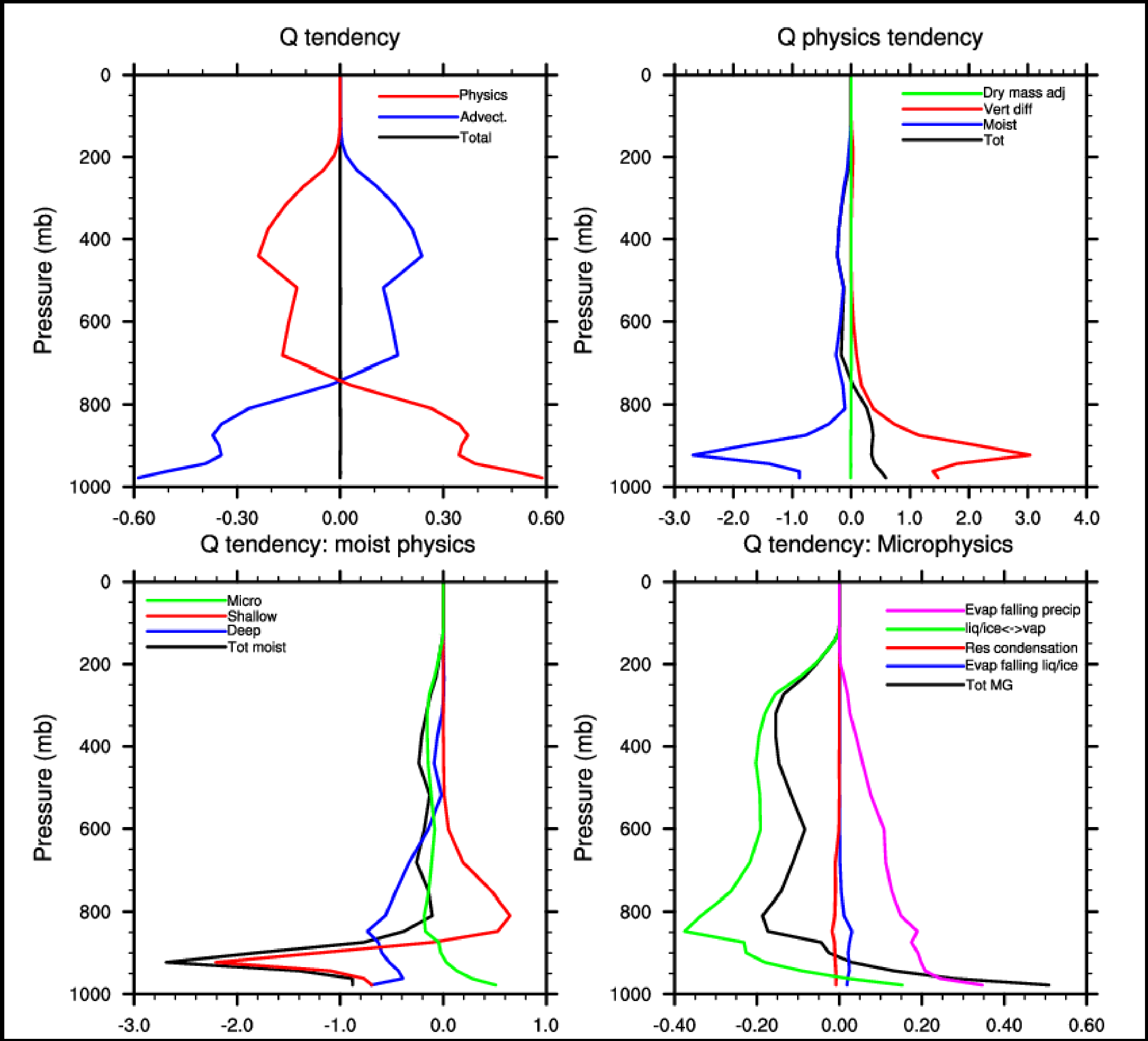
GCM Water Vapor Budget

NCAR CAM4: “Moist Physics”

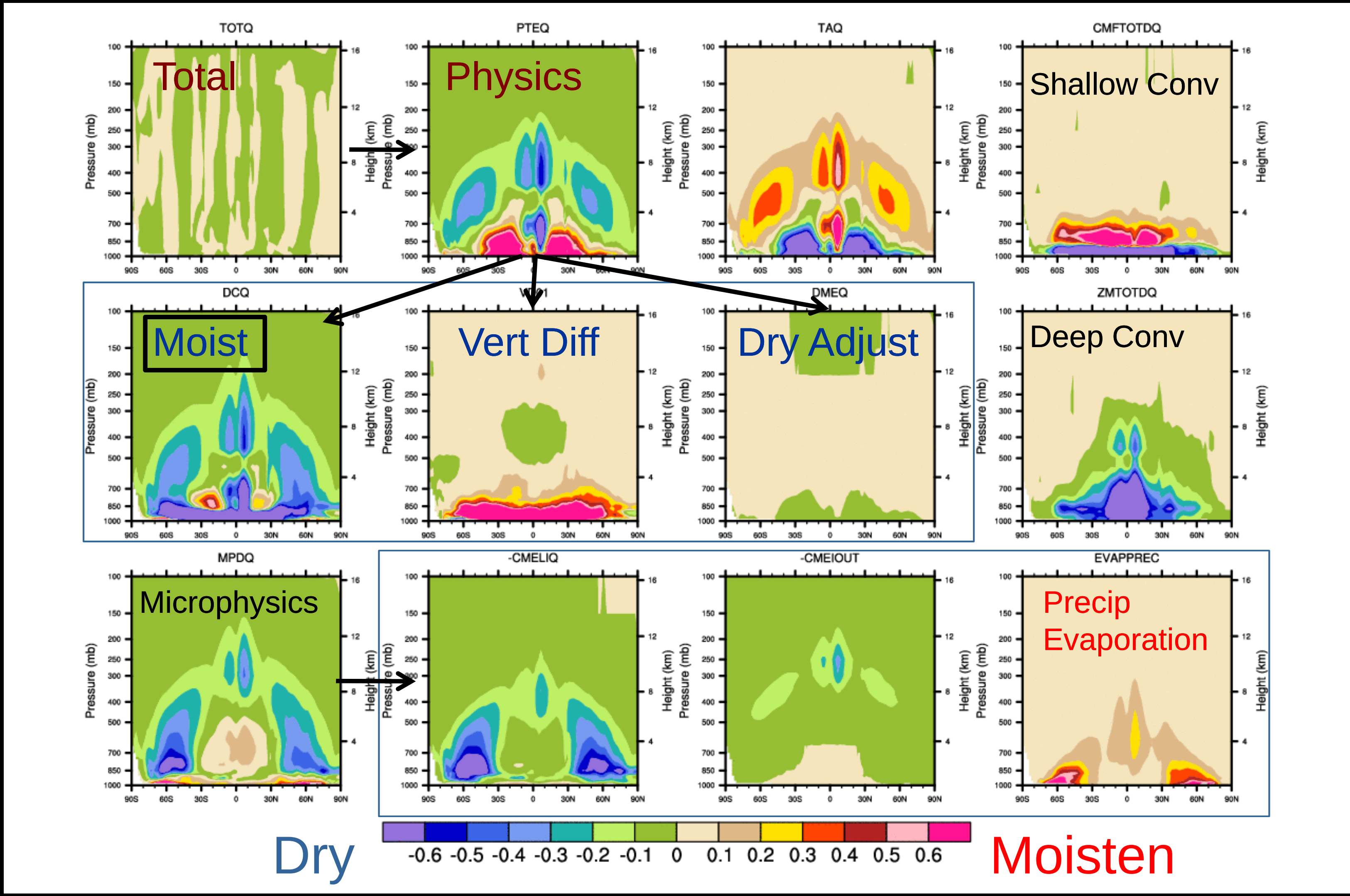


Phil Rasch will discuss in more detail this week

GCM Processes: H_2O (Q) Tendencies



GCM Q Tendency (2)



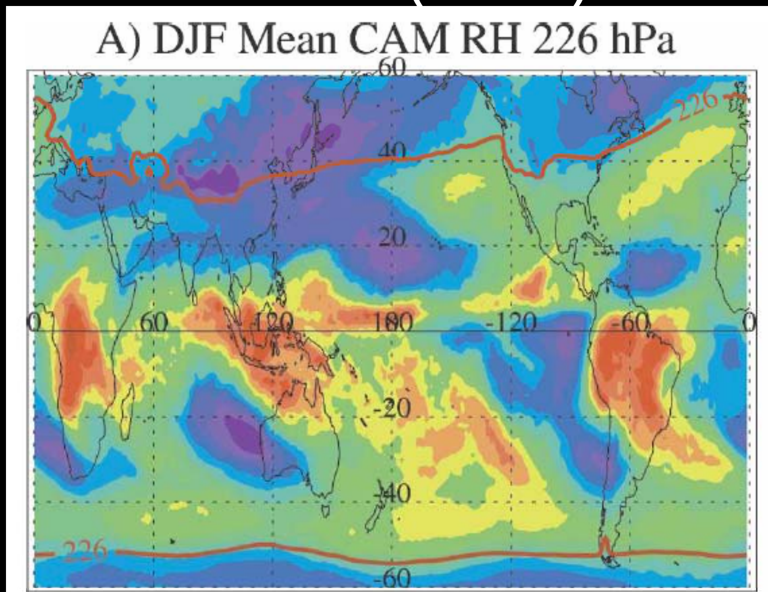
Observed & Simulated Humidity

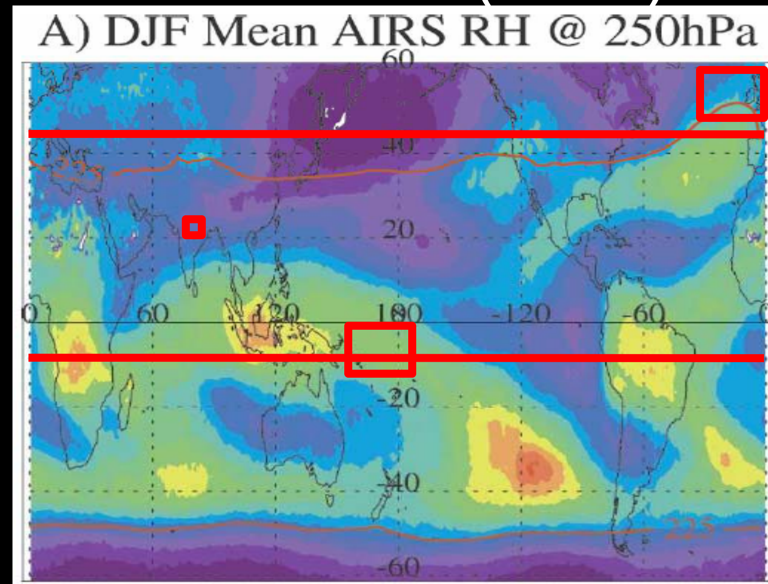
- AIRS observations
  - Nadir IR sounder
  - 50kmx50km footprint, 2x daily
  - ±20% humidity in 1-3km layers for $q > 20ppm$
- CAM3 Climate Model
  - 200km resolution
  - Bulk Microphysics and Cloud Fraction

Water Vapor (RH)

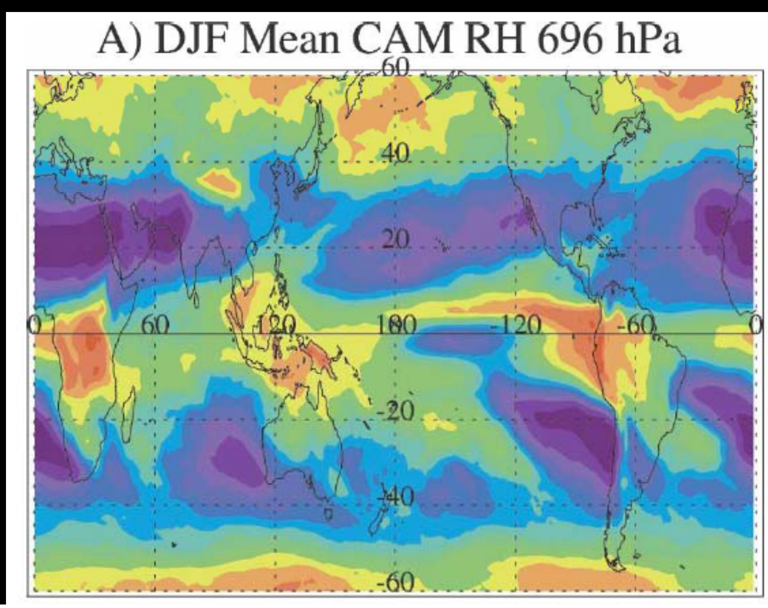
Simulation (CAM) | Observations (AIRS)

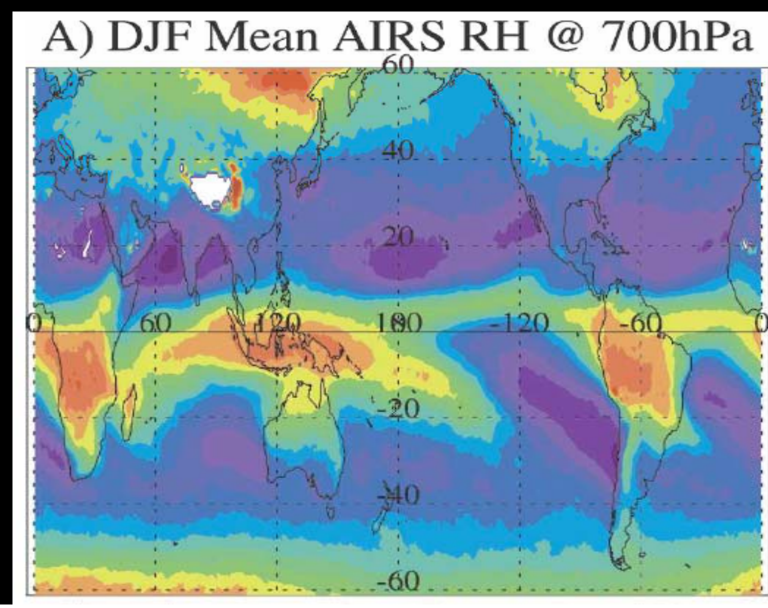
250 hPa



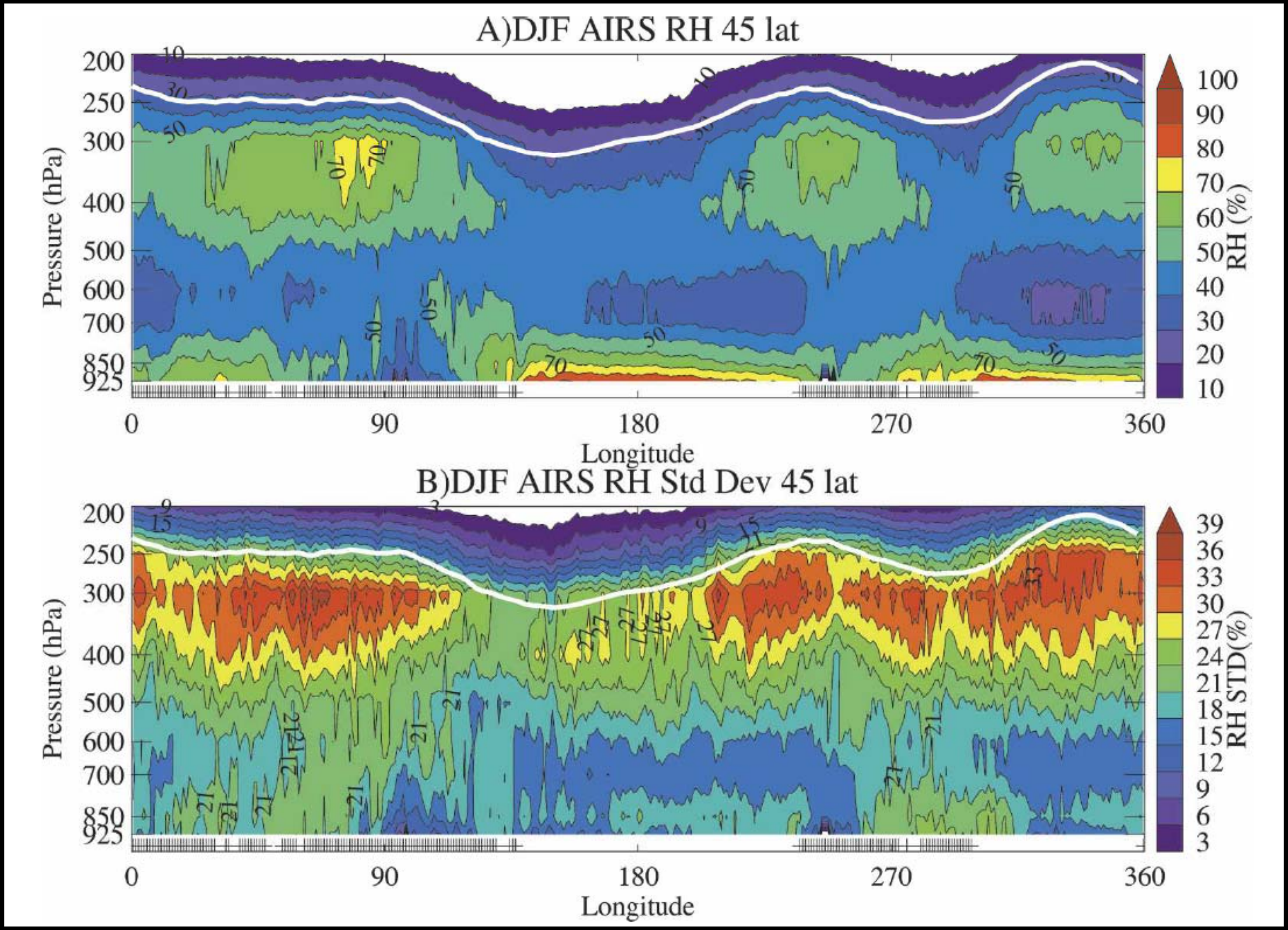


700 hPa

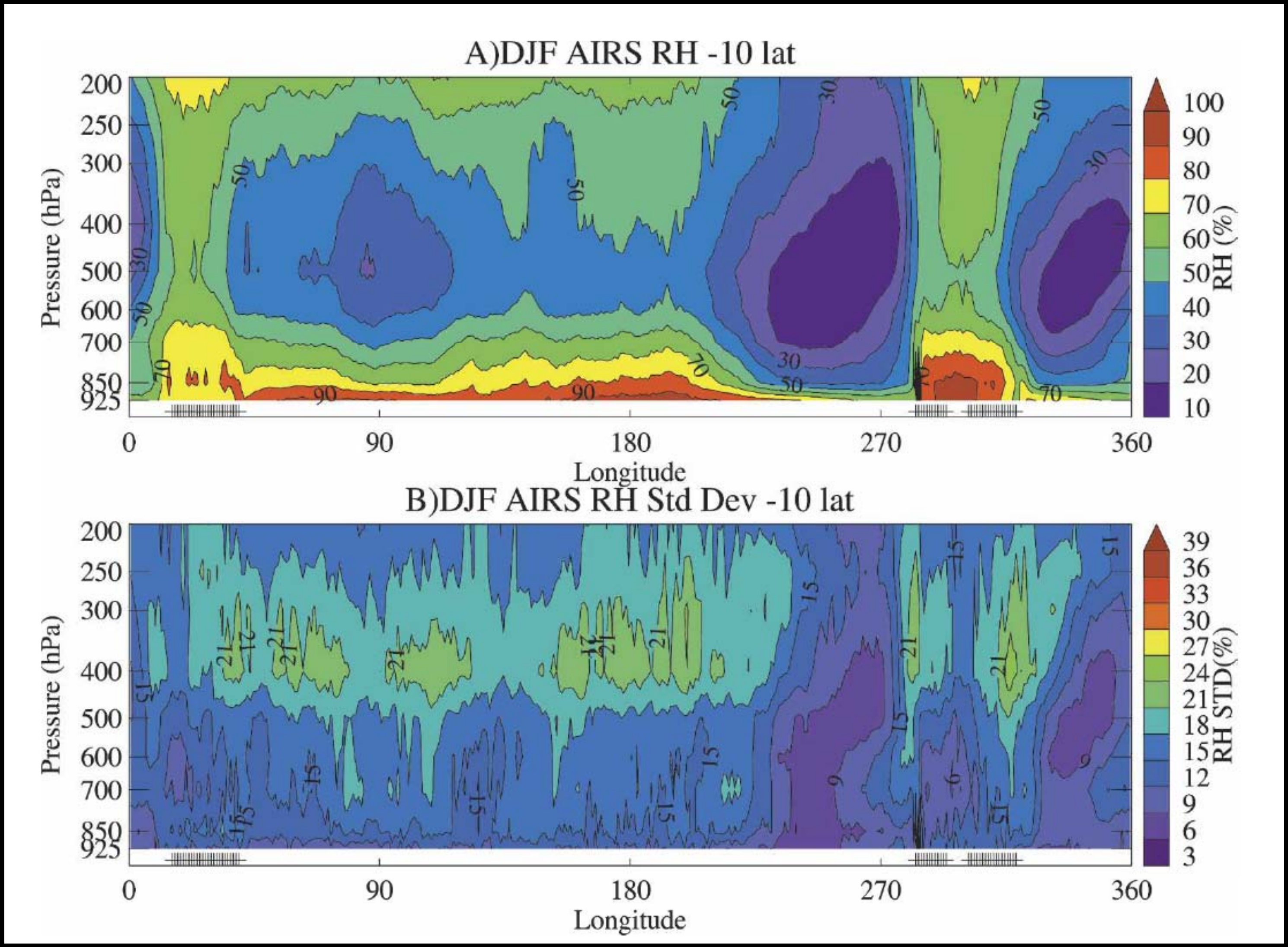




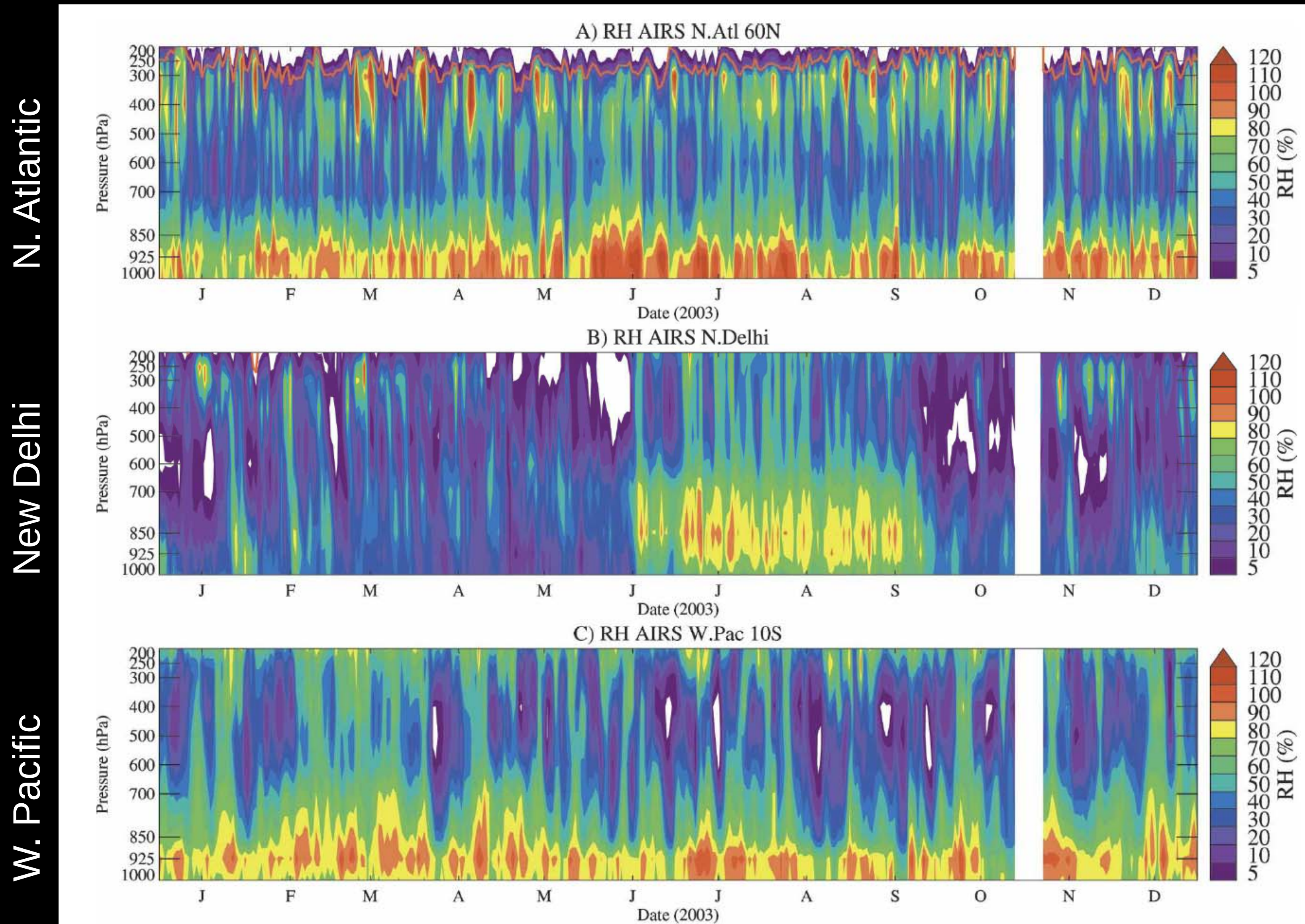
Vertical Structure: Mid Lats



Vertical Structure: Tropics



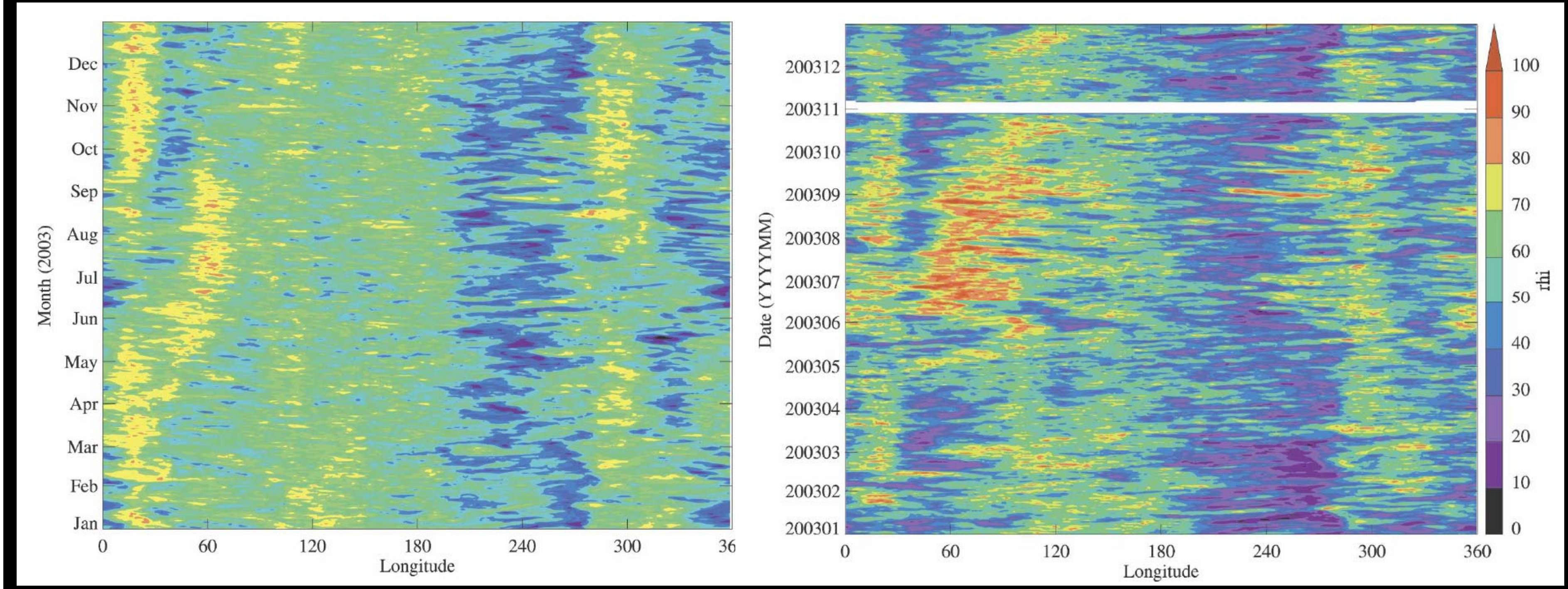
Vertical Timeseries



Convective Clouds: Organization

225hPa Relative Humidity (10S-10N)

Model AIRS



Not enough simulated RH variability: wrong Cloud organization

Water Vapor Feedback

- H_2O is the primary greenhouse gas
  - Absorbs a lot in the infrared
- H_2O is a function of Temperature
- Distribution due to advective transport
- What happens to H_2O if the temperature changes?
- Why?

“[W]ater vapor, confessedly the greatest thermal absorbent in the atmosphere, is dependent on temperature for its amount, and if another agent, as CO_2, not so dependent, raises the temperature of the surface, it calls into function a certain amount of water vapor which further absorbs heat, raises the temperature and calls forth more vapor”

TC Chamberlin, 1905

Quoted in Held and Soden, 2000

Water vapor Feedback

- +T → +H2O → +Absorption → +T
- How much does it matter?
  - Quite a bit…
- Where is water vapor important?
  - Where it is dry
  - Where there is lots of emission to space (subtropics and the upper troposphere)

Feedback: Definition

Feedback for a process *i* defined as:

$$F_i = dR_i/dT_s$$

R= top of atmos radiative change due to i

T_s=surface temperature

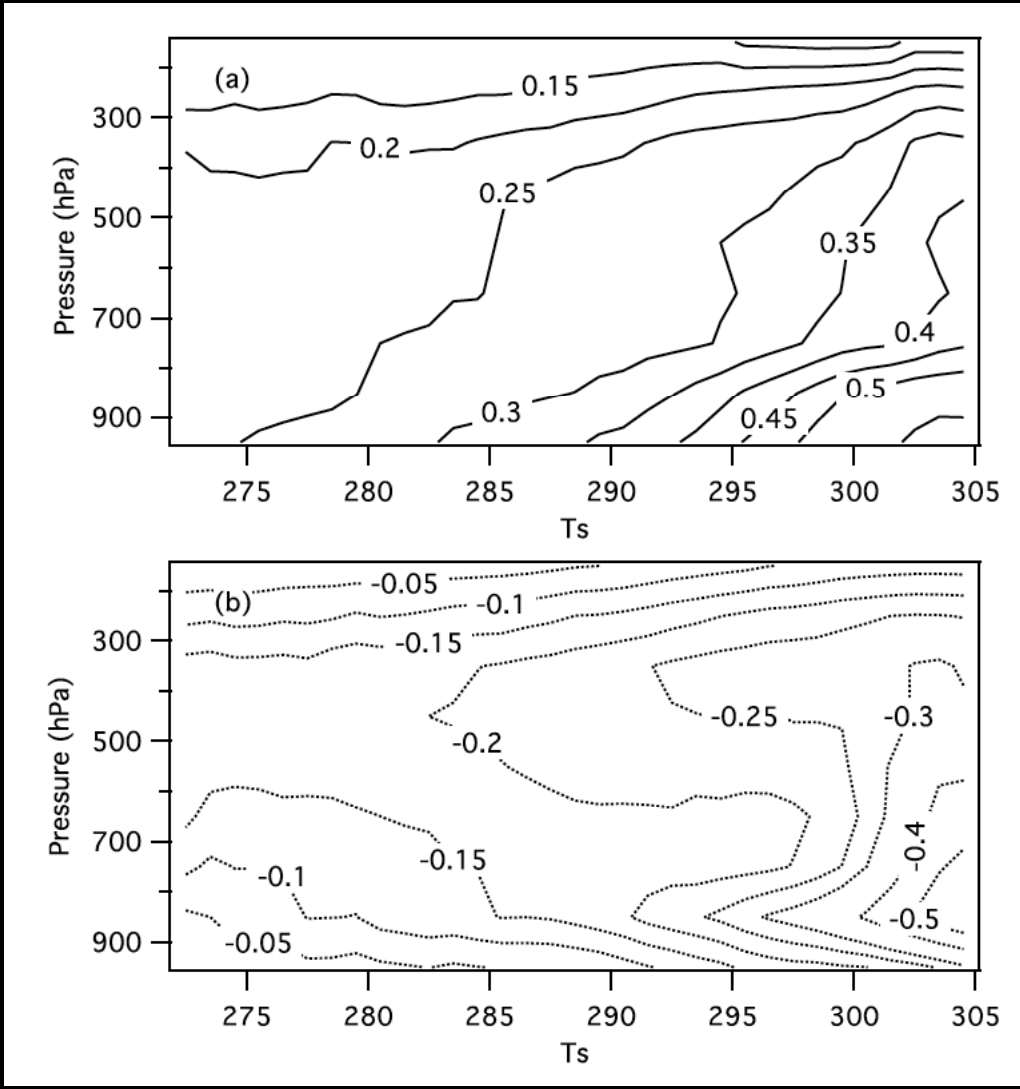
F has units of $Wm^{-2}\ K^{-1}$

Feedbacks can be summed

(may not be linear)

Where does H_2O Matter?

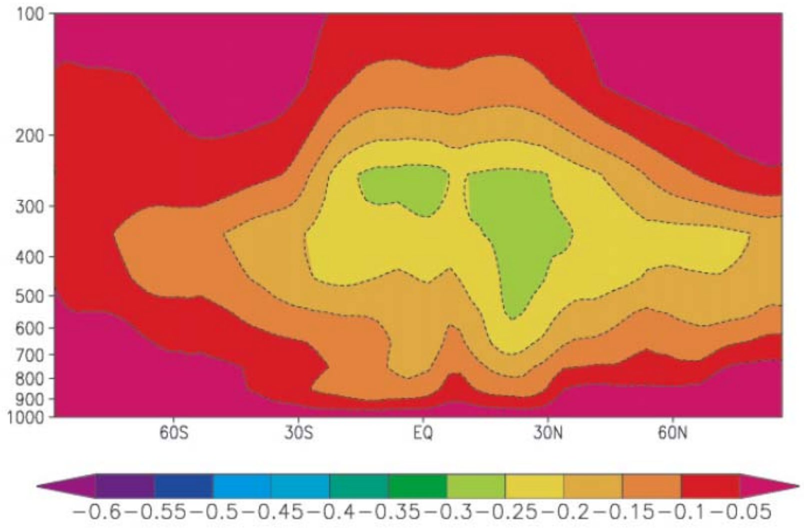
- Change in OLR for
- Top: T+1K
- Bottom: H_2O+10%



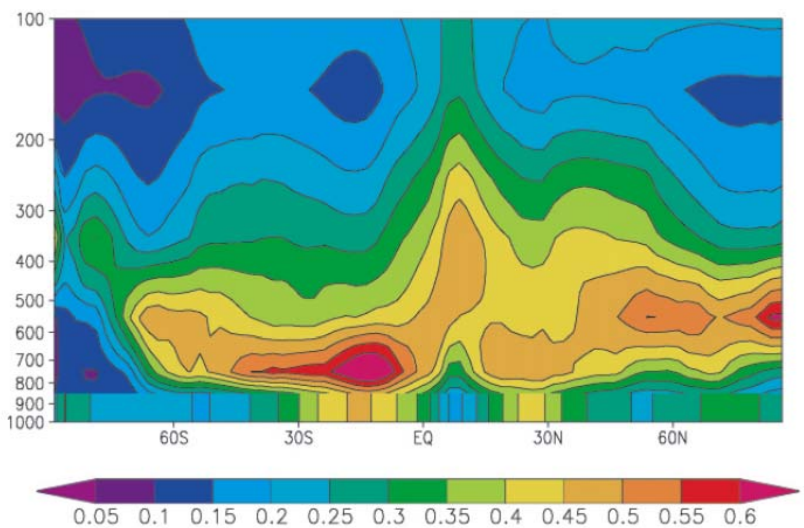
Dessler et al 2008

Where does H_2O Matter (2)?

- Change in OLR for T+1K
- Top: Q_{sat}(T+1K)



- Bottom: T+1K



Soden & Held 2000

Water Vapor ‘Amplification’

- Moller 1963
- Manabe & Wetherald 1967
  - Radiative convective model

H_2O increases warming by 77%

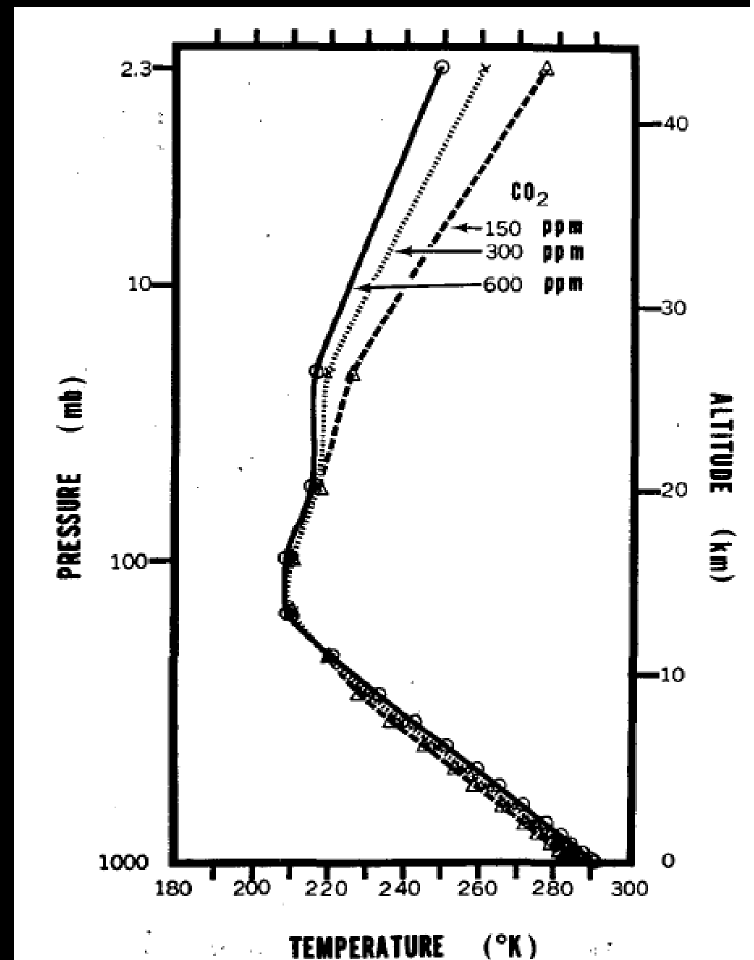


TABLE 5. Change of equilibrium temperature of the earth's surface corresponding to various changes of CO_2 content of the atmosphere.

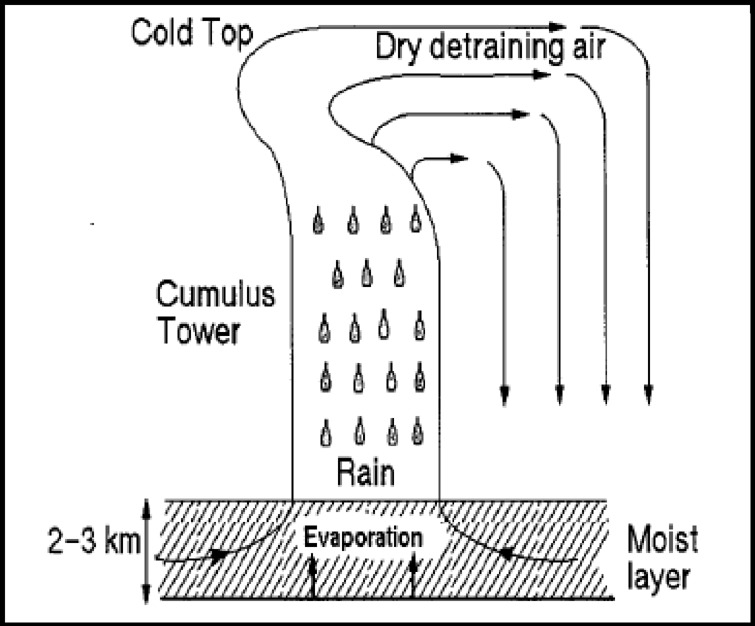
Change of CO_2 content (ppm)	Fixed absolute humidity: Average cloudiness	Fixed absolute humidity: Clear	Fixed relative humidity: Average cloudiness	Fixed relative humidity: Clear
300 → 150	−1.25	−1.30	−2.28	−2.80
300 → 600	+1.33	+1.36	+2.36	2.92

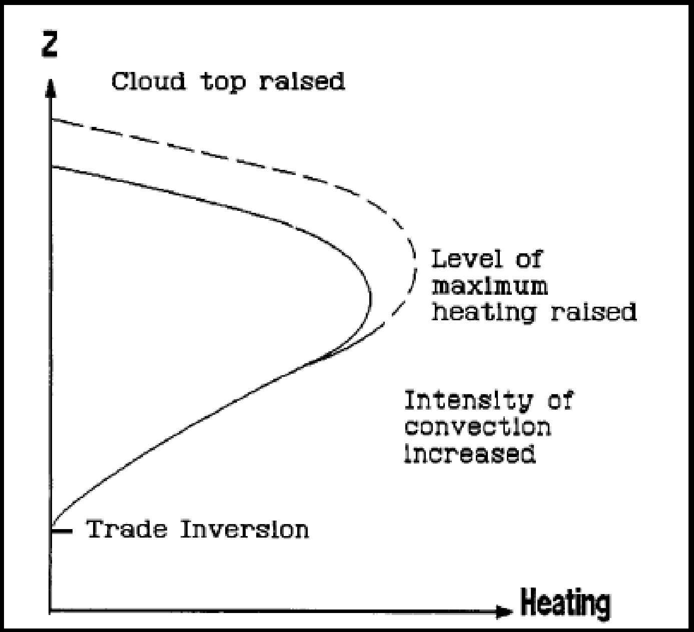
The Catch

- Most early studies assume fixed RH
- But H_2O is determined by dynamics
  (“Last Saturation” results)
- So how do we know that RH stays constant?
- Especially in the upper troposphere?

Negative H_2O Feedbacks

- What if convection goes deeper?
  - Dries Upper Troposphere
  - Increases T above emission level





Lindzen 1990, BAMS

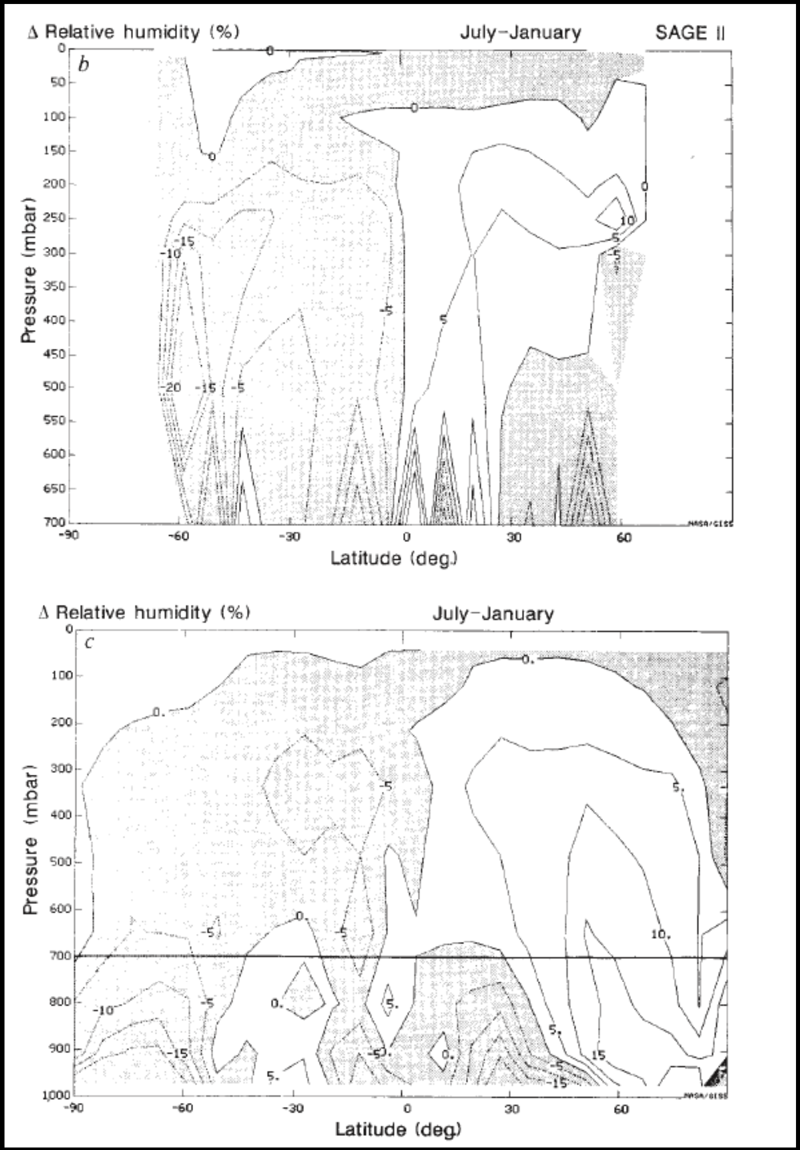
Model Simulations: Annual Cycle

In the annual cycle, warming in the summer moistens the upper troposphere

Top: SAGEII H_2O (annual cycle)

Bottom: GISS Climate Model

Rind et al, 1991, Nature



Which is correct?

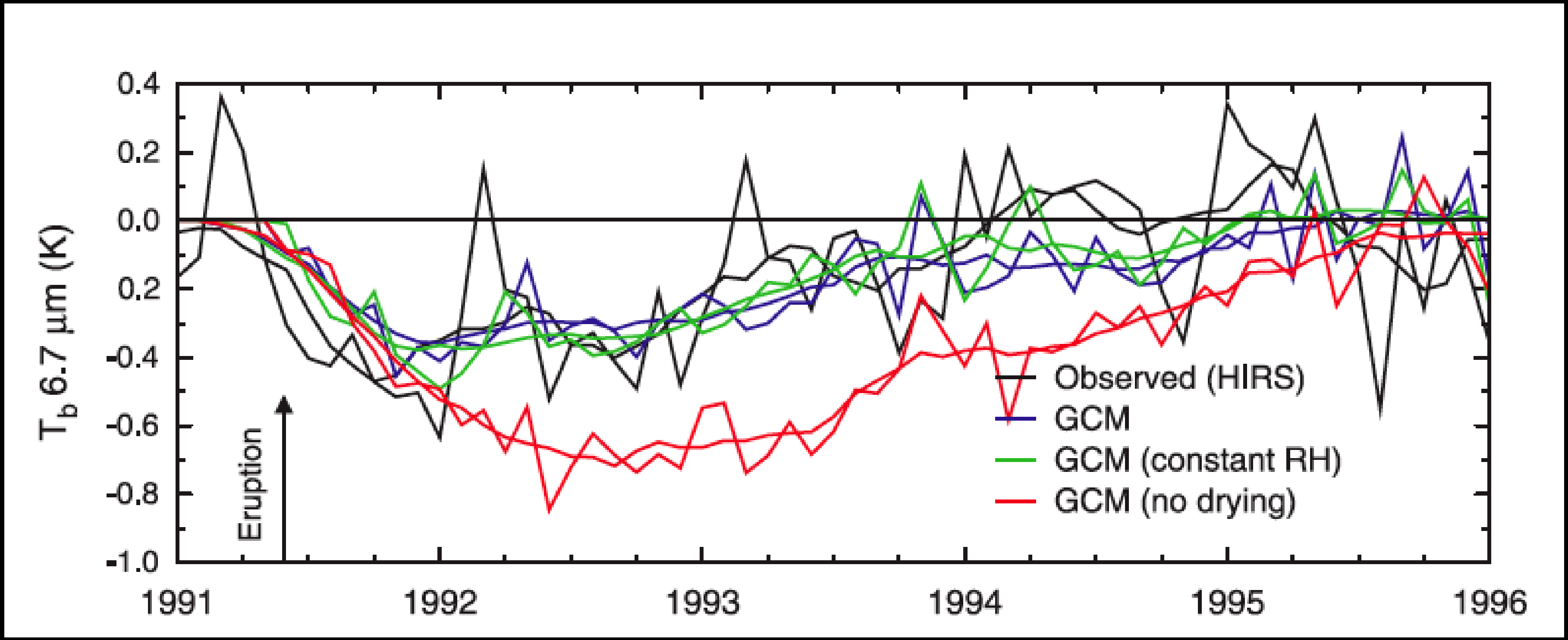
- “Last Saturation” Presumes Efficient RH condensation, but prescribes advection
  - Should work with deeper convection?

What do we observe?

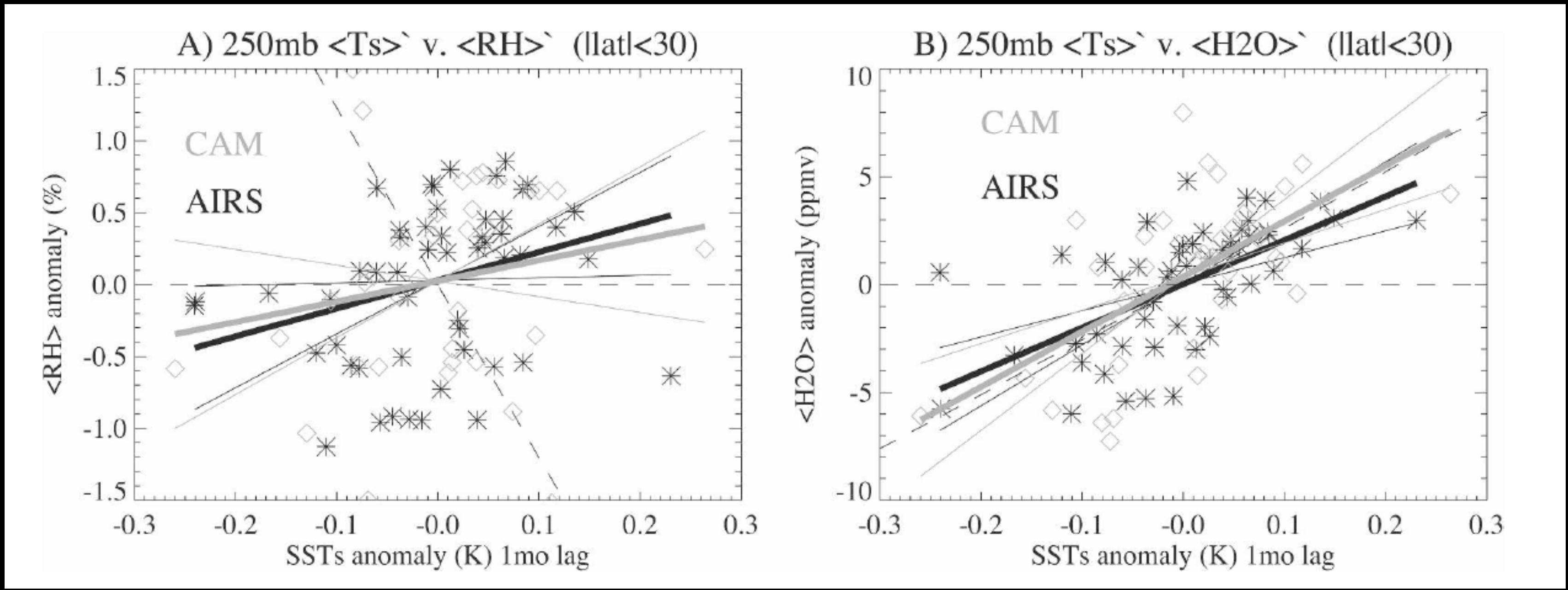
- Can’t observe climate change
- Look for analogues:
  - Annual cycle
  - Inter-annual variability:
    - Volcanic Eruptions, ENSO, Unforced variations

Effects of Mt. Pinatubo

Mt. Pinatubo cooled the planet. Also reduced H2O. Only with $F_{H2O} > 0$ can it be simulated (Soden, 2002)



Inter-annual Variability



Response of upper troposphere RH and H_2O to surface T
Model (CAM) and observations (AIRS) are similar
Both are ‘not inconsistent’ with constant RH hypothesis
(Gettelman & Fu, 2008)

Summary of Obs

- H_2O feedback is almost always positive when analyzed using variability: Annual Cycle, ENSO, Volcanoes
- When the atmosphere (especially the upper troposphere) is warmer, it is wetter
- Models & Obs indicate RH ~ constant
- No evidence for ‘drying’

Other Feedbacks

- H_2O is not the only ‘feedback’
- F_{H2O} related to other ‘feedbacks’
- Most importantly: Lapse rate feedback

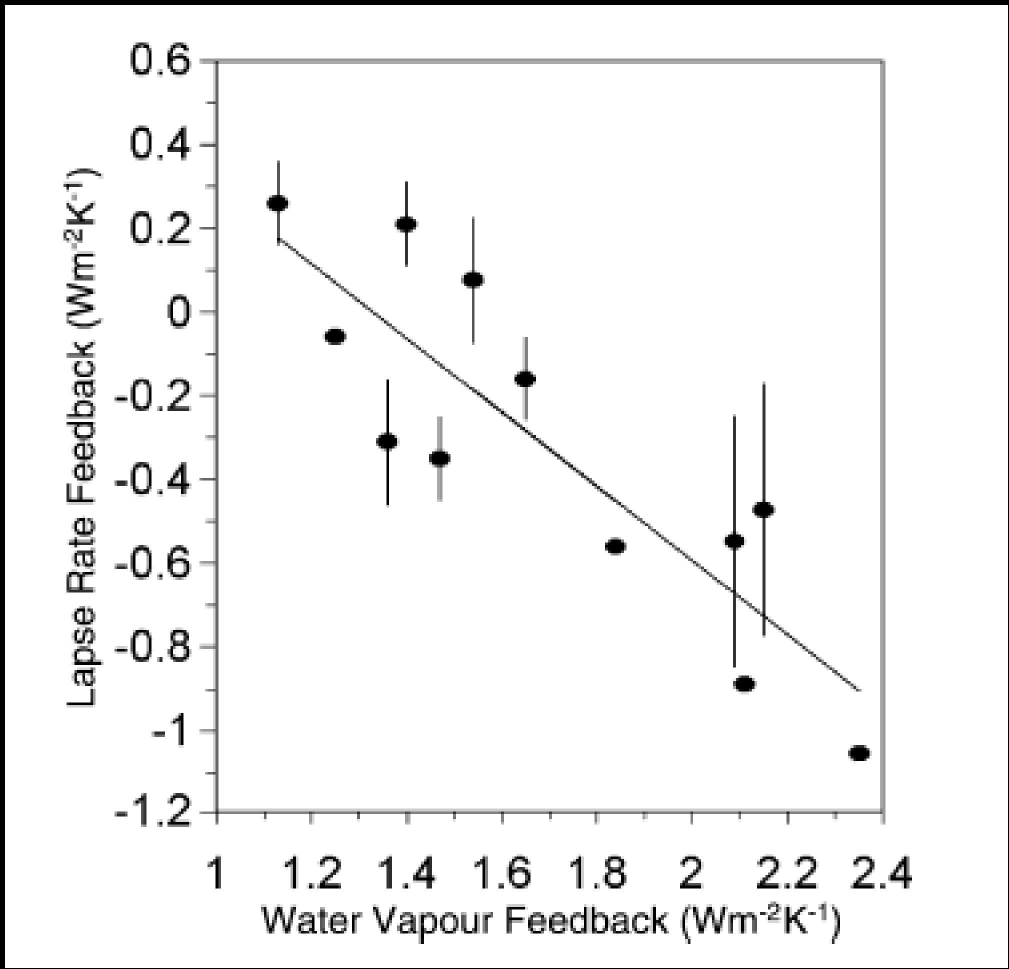
Note: Cloud feedbacks are the ‘elephant in the room’ (next week is elephant week)

Lapse Rate Feedback

Γ (-dT/dz) affects LW emission

- Smaller Γ → more emission to space
  - smaller greenhouse effect
  - more emission higher up (higher T)
- Warmer T_s → smaller Γ (warmer moist adiabats are less steep)
- This is a negative feedback
- LW emission is due to H_2O: so this is coupled with F_{H2O}

Simulated F_{H2O} v. F_{Γ}

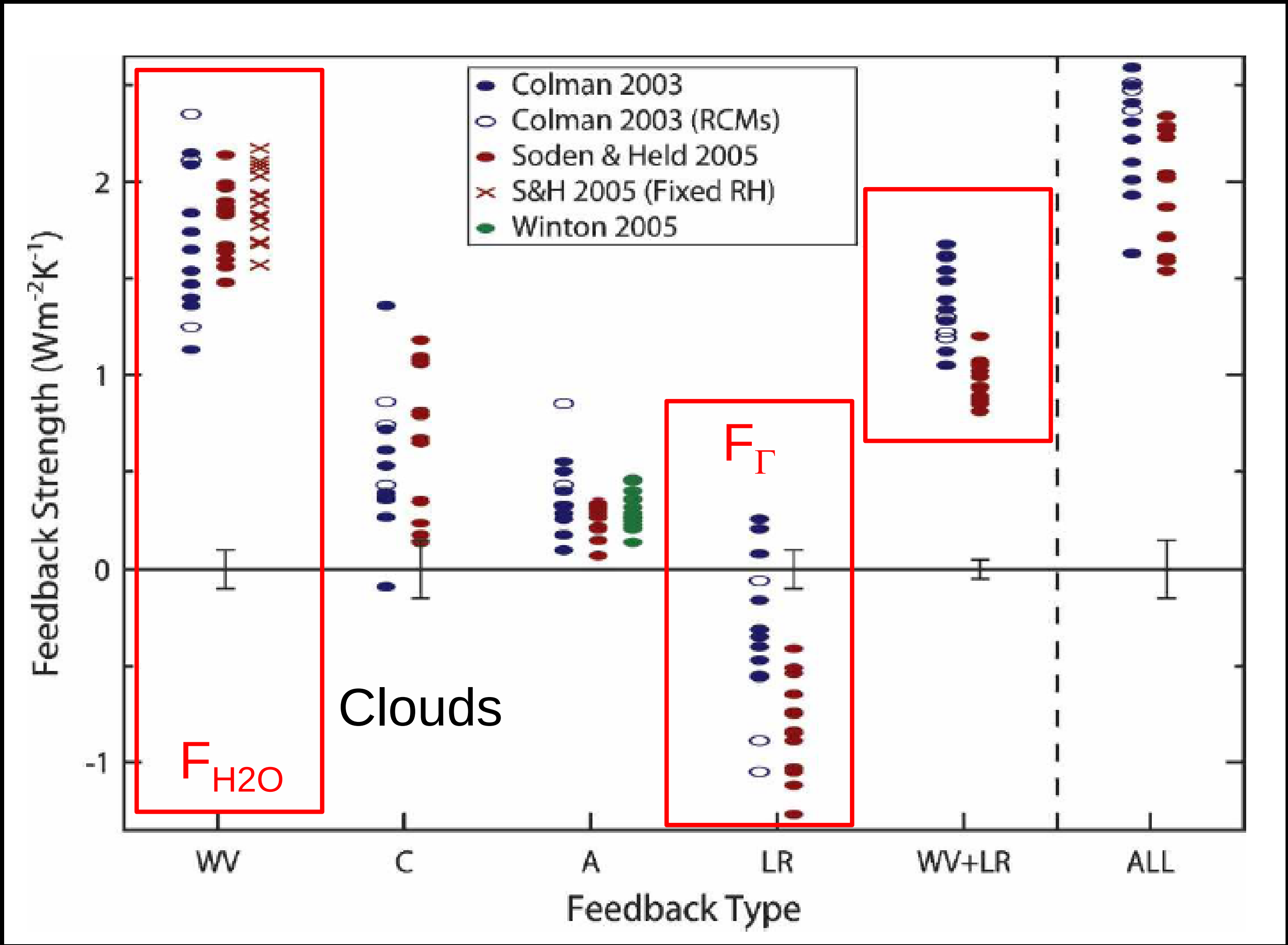


Coleman 2003

Why Anti-Correlated?

+ΔH2O → +ΔLW emission (more sensitive to Γ)

Feedbacks in models



Bony et al 2006, J. Climate

Conclusions/Discussion

- Models & observations appear to be convergent regarding water vapor feedbacks
- Works for most scales examined
- Could there be negative feedbacks
  - E.g. Lindzen?
- Thoughts? Why or why not?
- What further tests could be run?

Final Note

- Quantitative theory not obvious
- Cloud Feedbacks are much less certain
- Biggest uncertainty in models
- On to Joao…