Constraining TTL Thermal Structure

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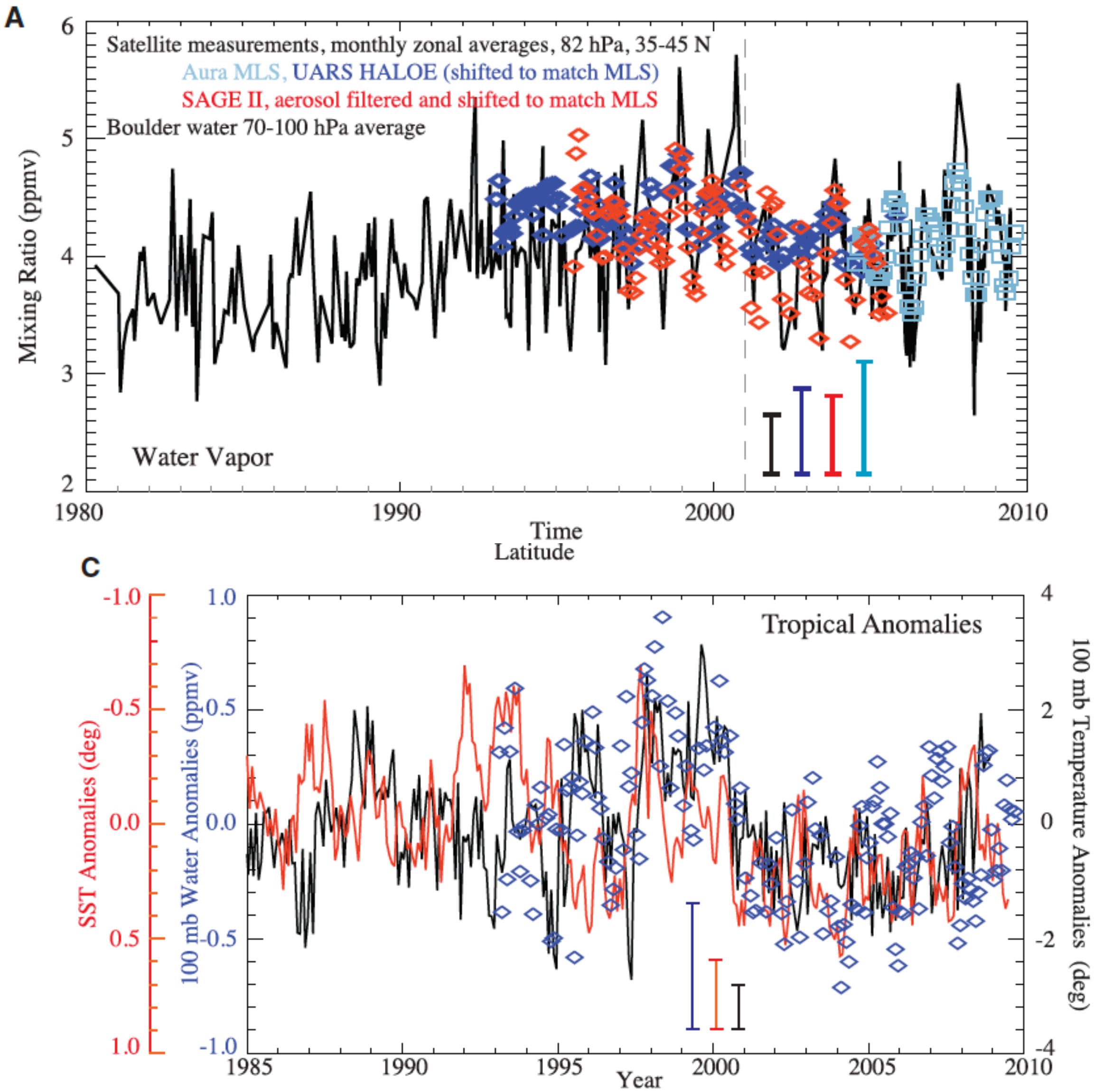
Outline

- Motivation
- Model Simulations
- What determines tropopause temperature
- What is the balance in models?
- What is needed/How Can ATTREX help

TTL Temp determines Strat H_2O

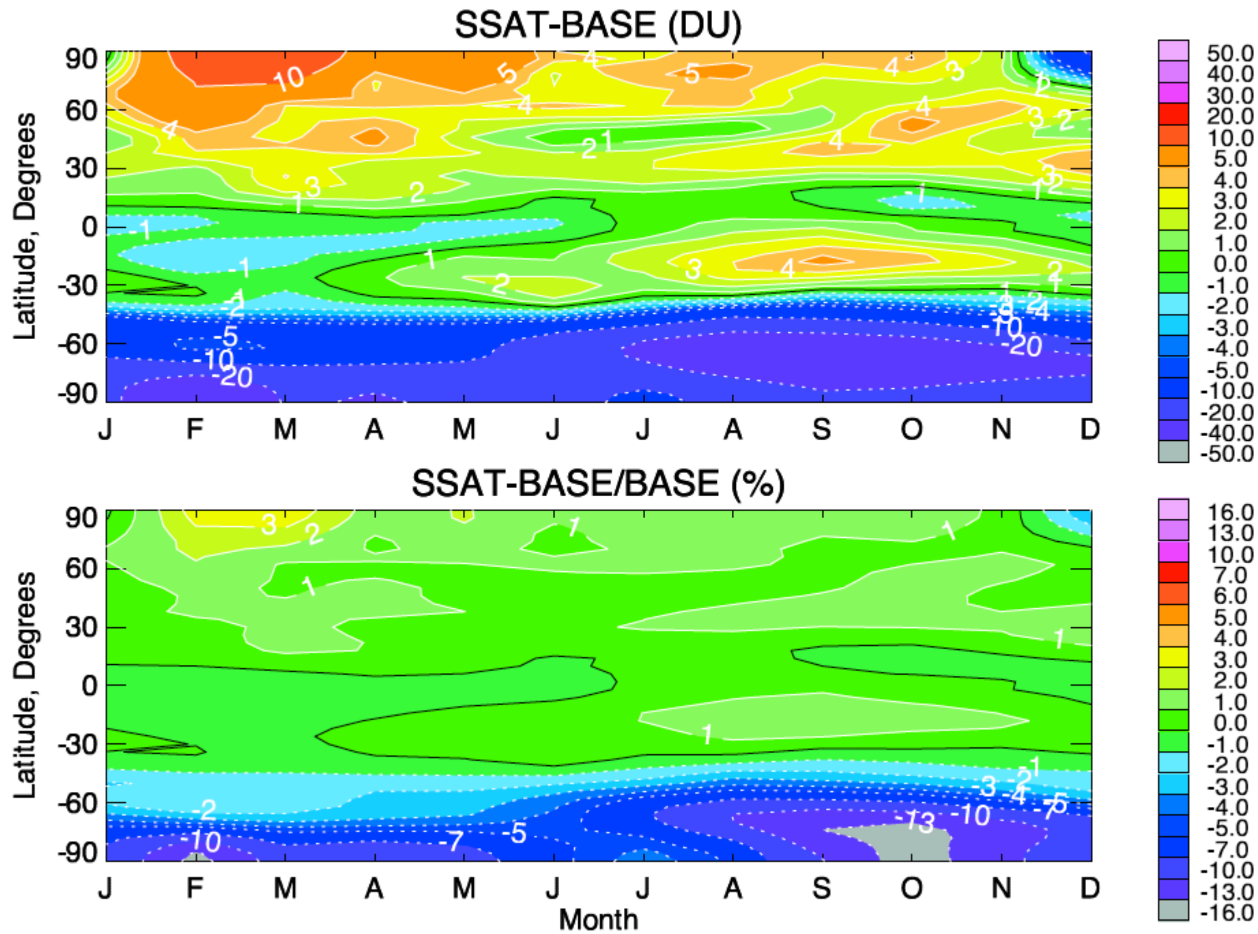


Top: Observed H_2O

Bottom: Tropical Temp, H_2O, SST

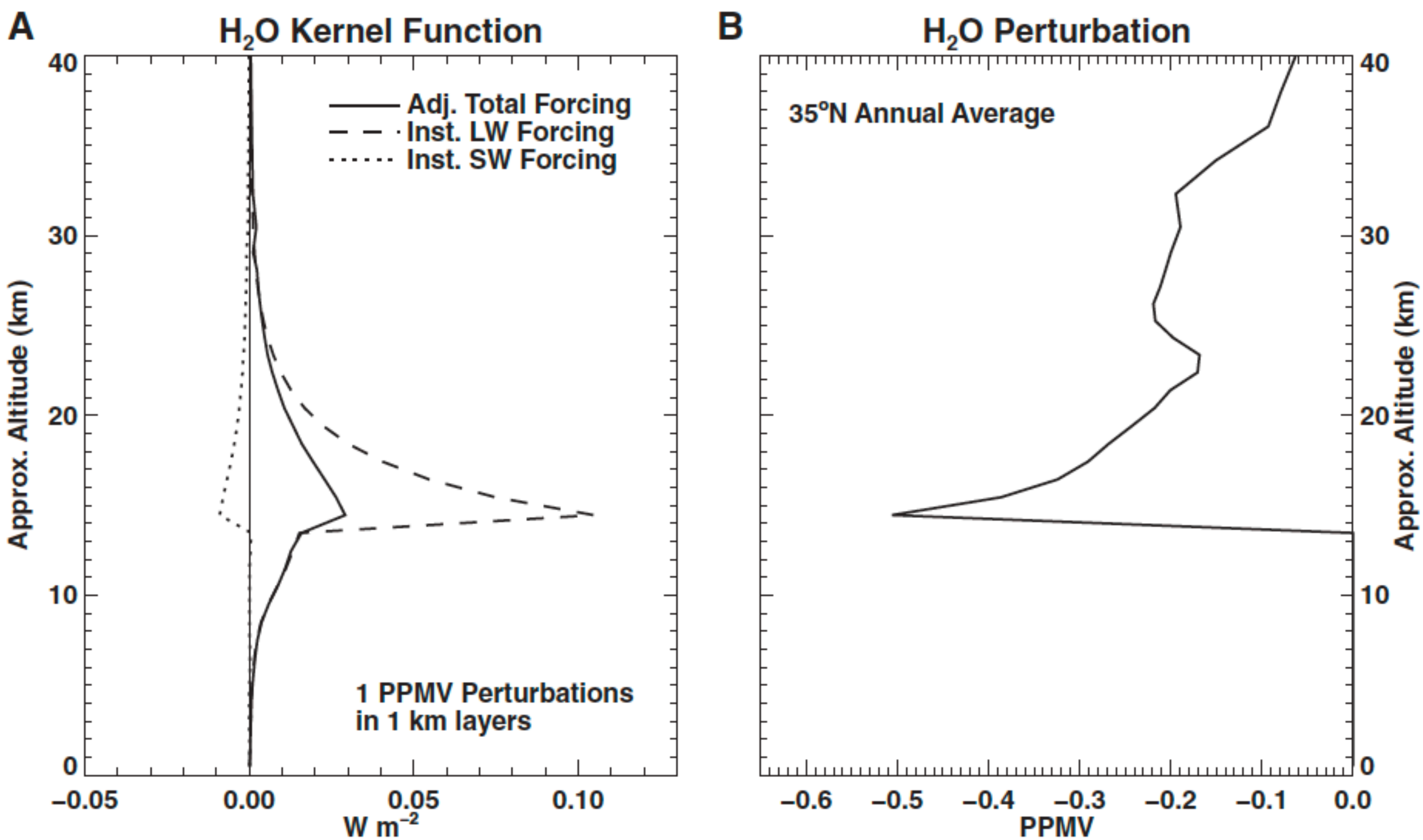
Solomon et al 2010

Strat H_2O Affects Chemistry



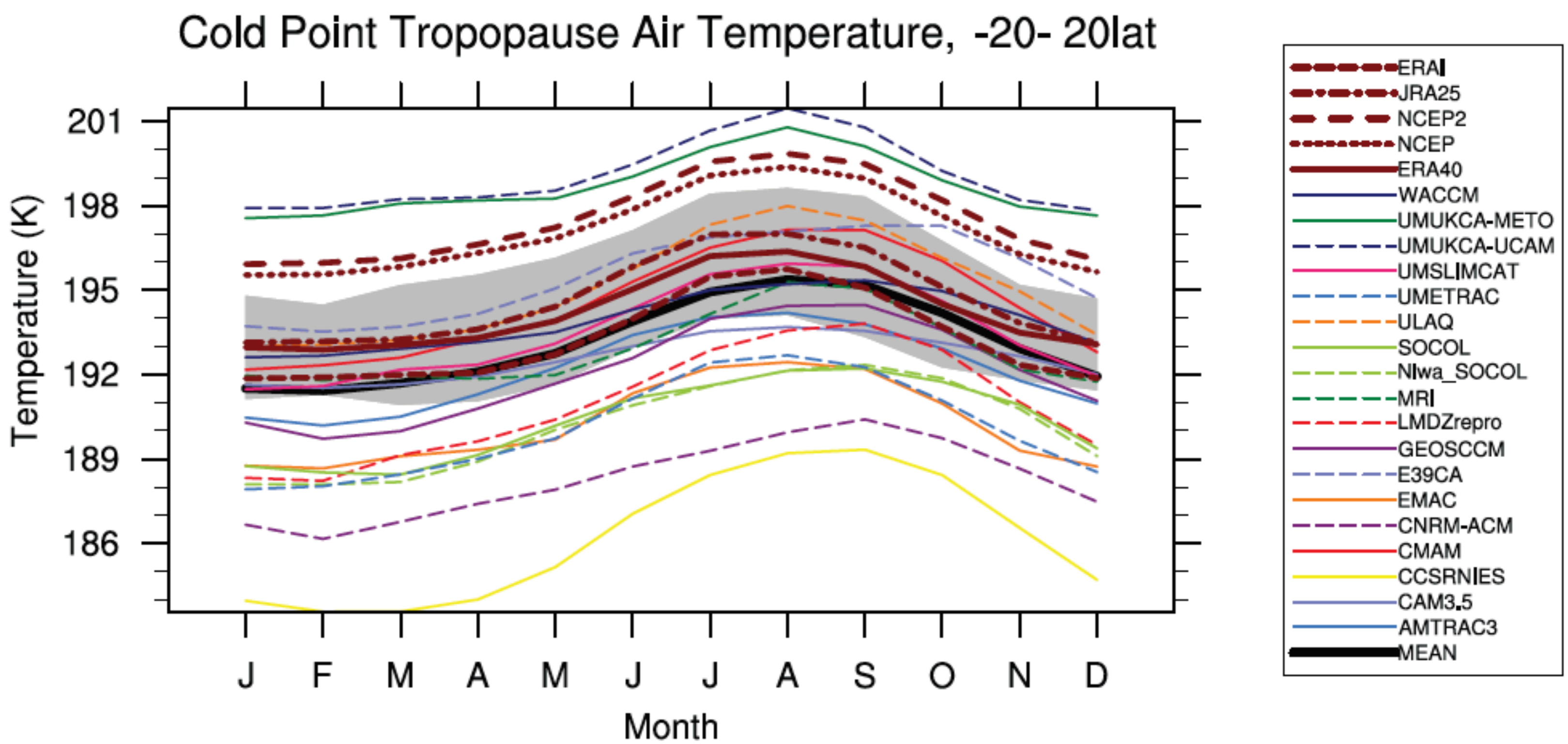
Effect of ~20% increase in H_2O by allowing supersaturation (Gettelman & Kinnison 2007)
(combination of a temperature & chemistry effect)

UTLS H_2O Affects Radiative Forcing



Solomon et al 2010

Simulating TTL Thermal Structure

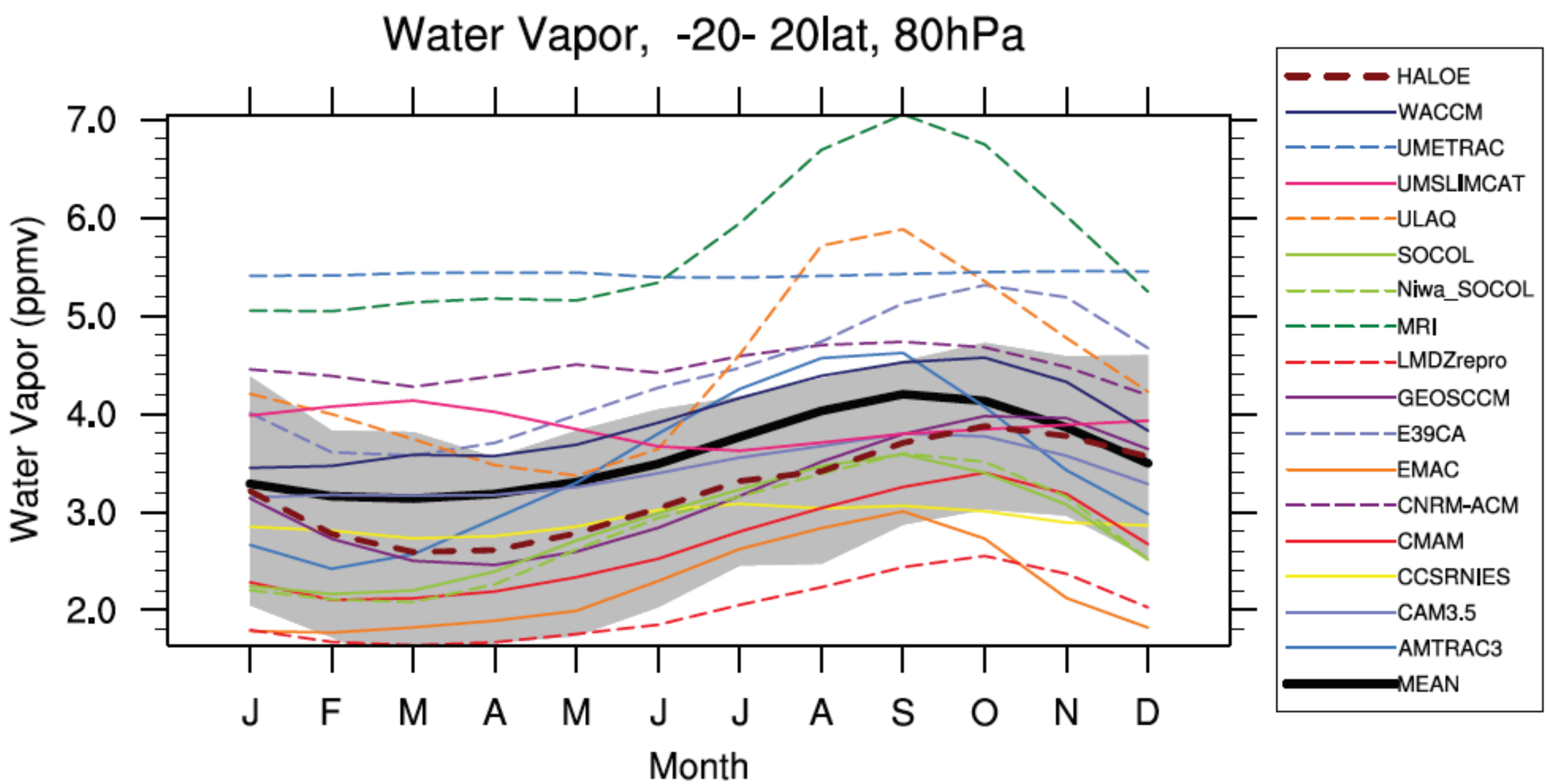


SPARC Assessment of CCMs, Ch7 & Gettelman et al, 2010 (JGR)

Throw out outliers and spread is still ~6K in the mean!

Note: this is better than CCMVal 1: ~10K.

Simulated LS Water Vapor

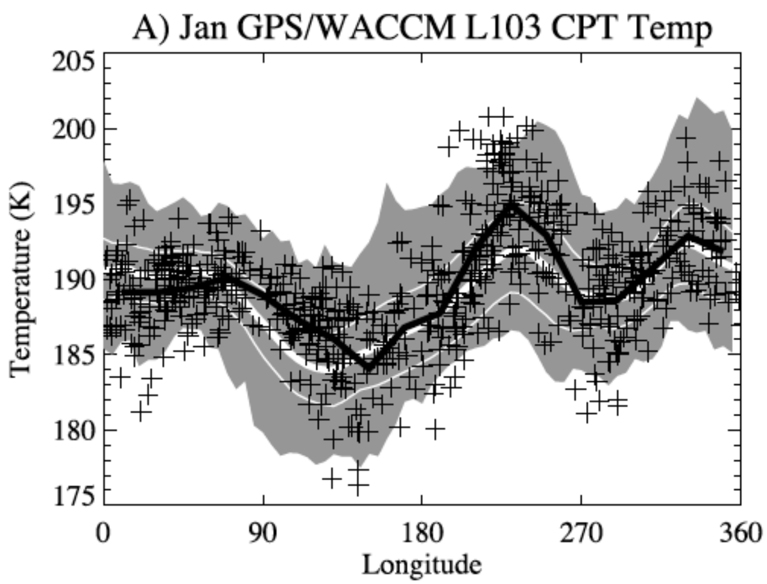


SPARC Assessment of CCMs, Ch7 & Gettelman et al, 2010 (JGR)
Without outliers, generally within HALOE range.
Note seasonal shift by ~2 months

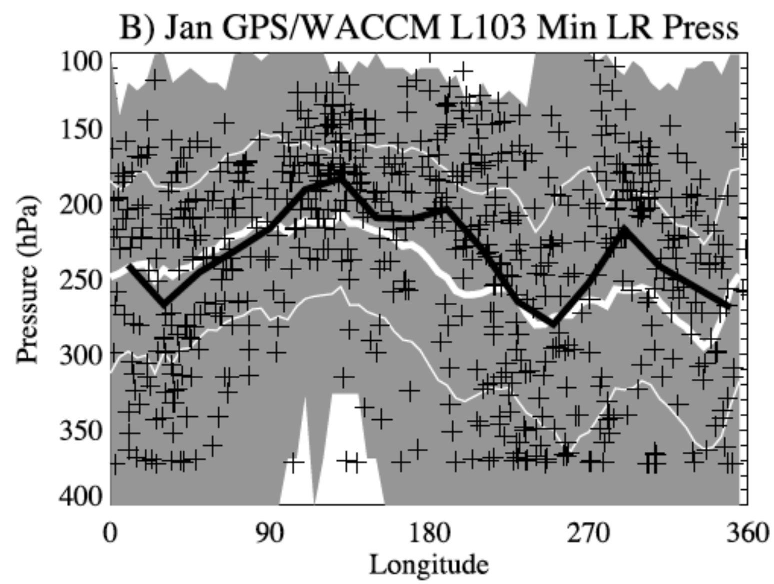
TTL Temp Variability

Reproduce Large scale (>200km) High Frequency Variability

TTL Top

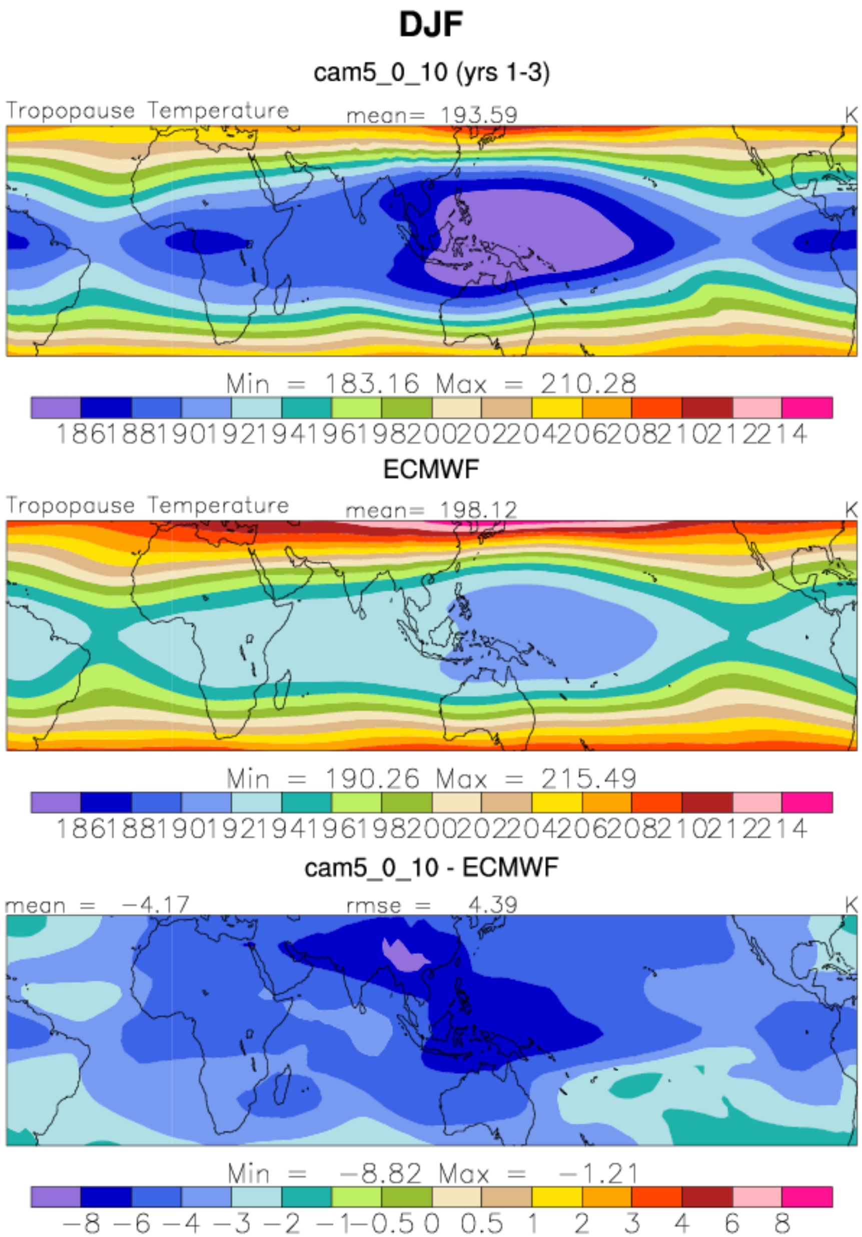


TTL Bottom



Gray: Model 2σ, white model mean. Black Crosses and Line: GPS RO temperatures
Gettelman & Birner, 2007

CAM5: Latest Climate Model



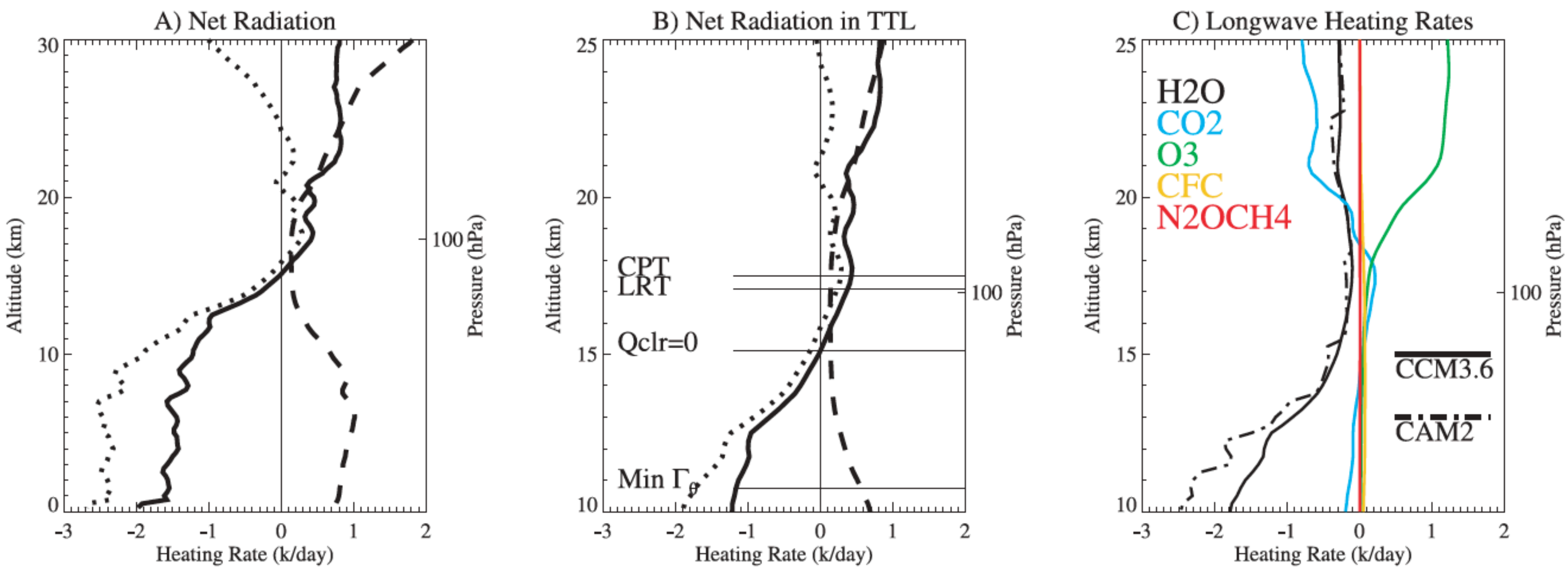
- Seasonal mean ~4K colder than ECMWF reanalyses (DJF)
- Ann mean is ~3.5K cold
- Model is ‘un-optimized’ for CPT
- Need to optimize: hopefully for the right reasons!

What determines Tropopause Temp?

- Radiative convective equilibirum
- Dynamics ‘creates’ the TTL
  - Brewer-Dobson circulation
- Radiation helps (CO_2): Thuburn & Craig 2002
- Cloud heating also helps
  - Biggest uncertainty…

Radiative Equilibrium

- Heating Rates: Gettelman et al 2004

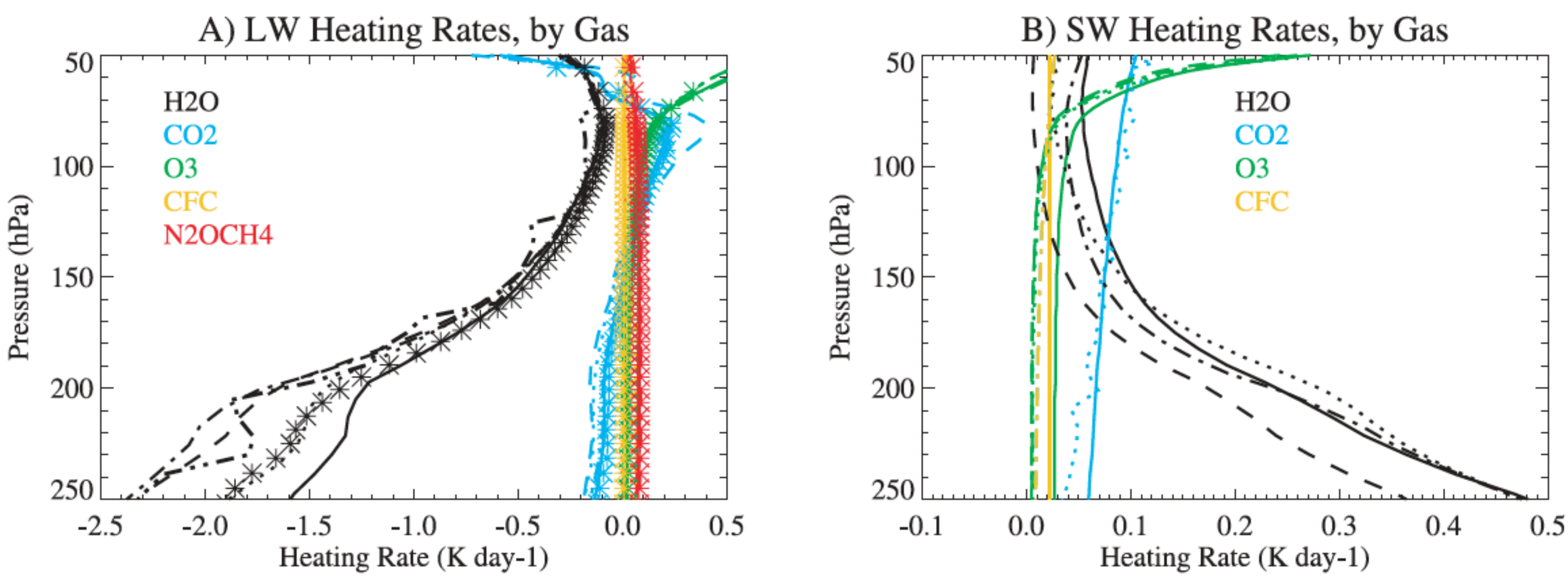


TTL is a balance of LW cooling (H_2O) then heating from O_3 (SW & LW)
At CPT: CO_2 LW heating does matter

Radiative Equilibrium (2)

- Heating Rates: Gettelman et al 2004

  Colors=Gases Linestyles=Different models

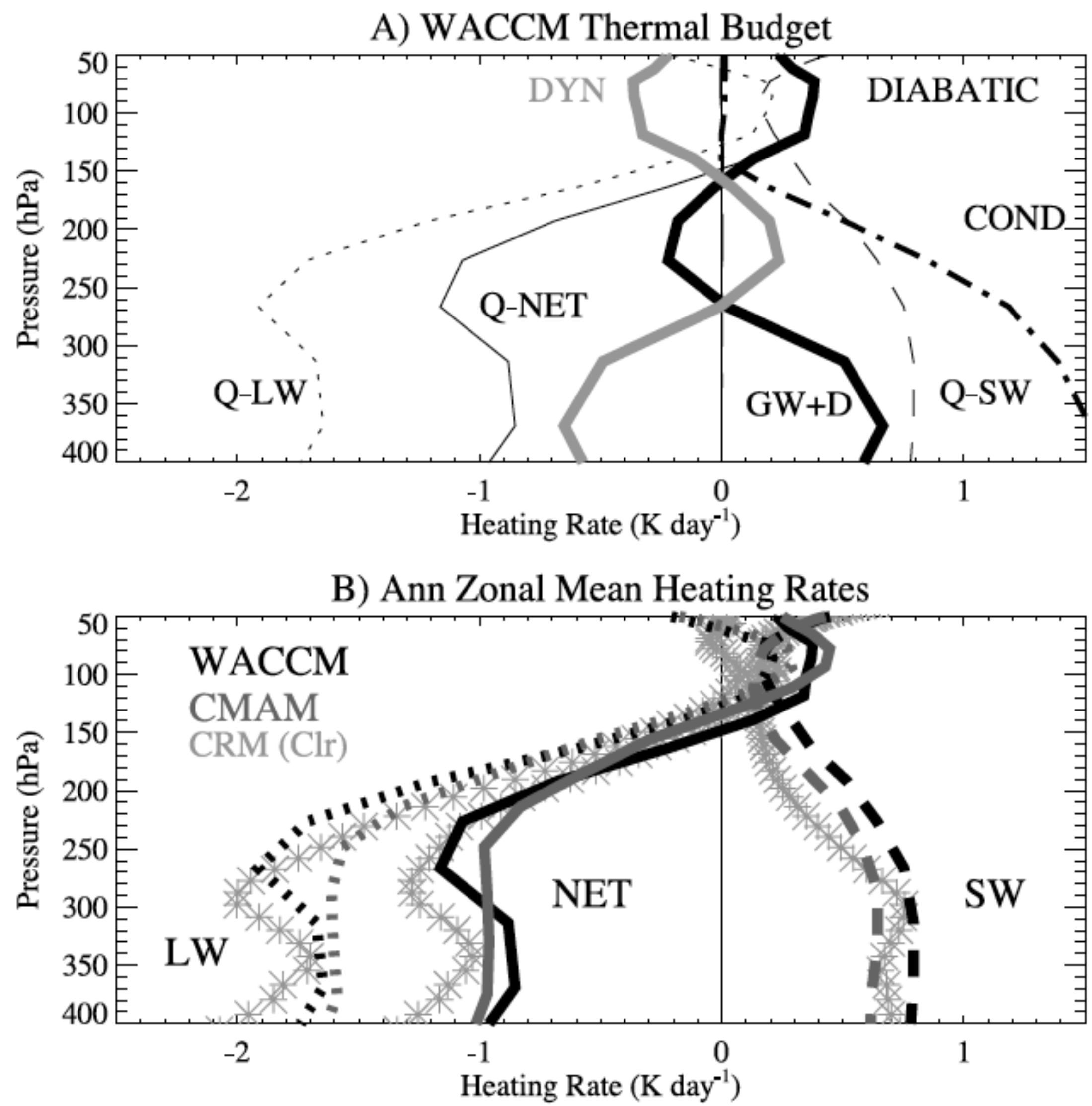


H2O has the biggest LW uncertainty: complex radiative transfer

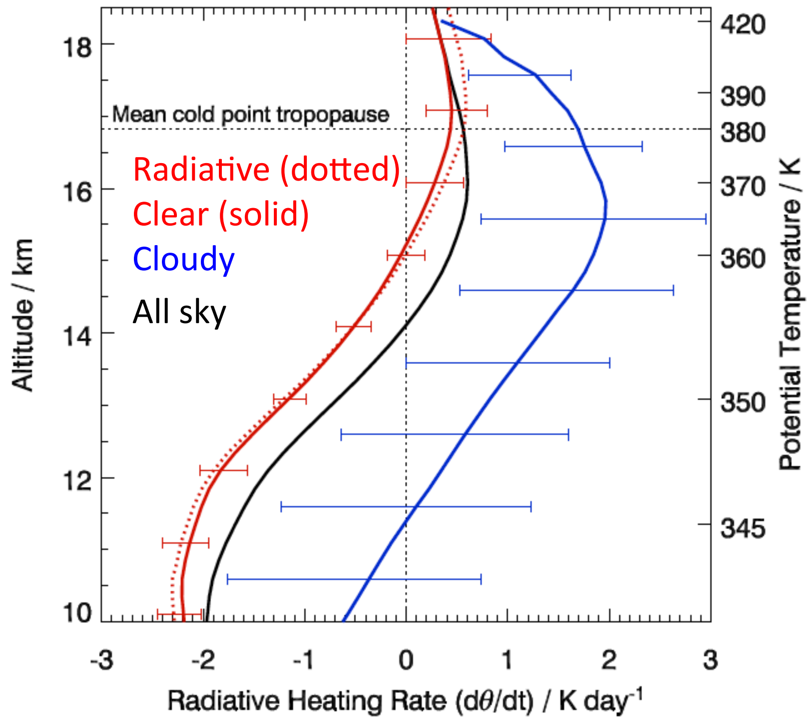
Role of Dynamics

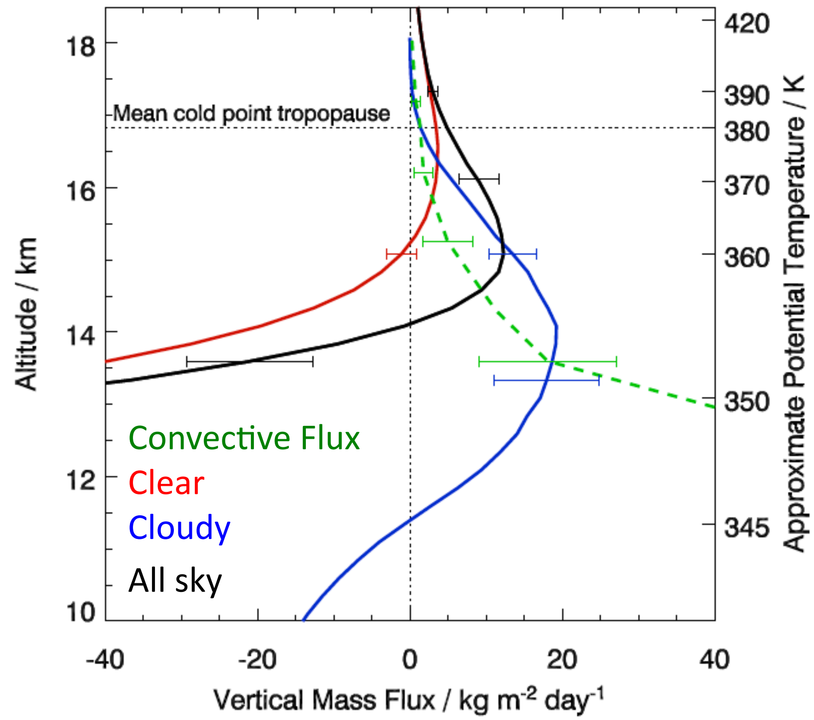
- Dynamic forcing balanced by diabatic heating/cooling
- Condensation balances LW Radiative Cooling
- Radiation in Models Stable
- Except for water vapor

Gettelman & Birner 2007



Impact of Clouds (1)

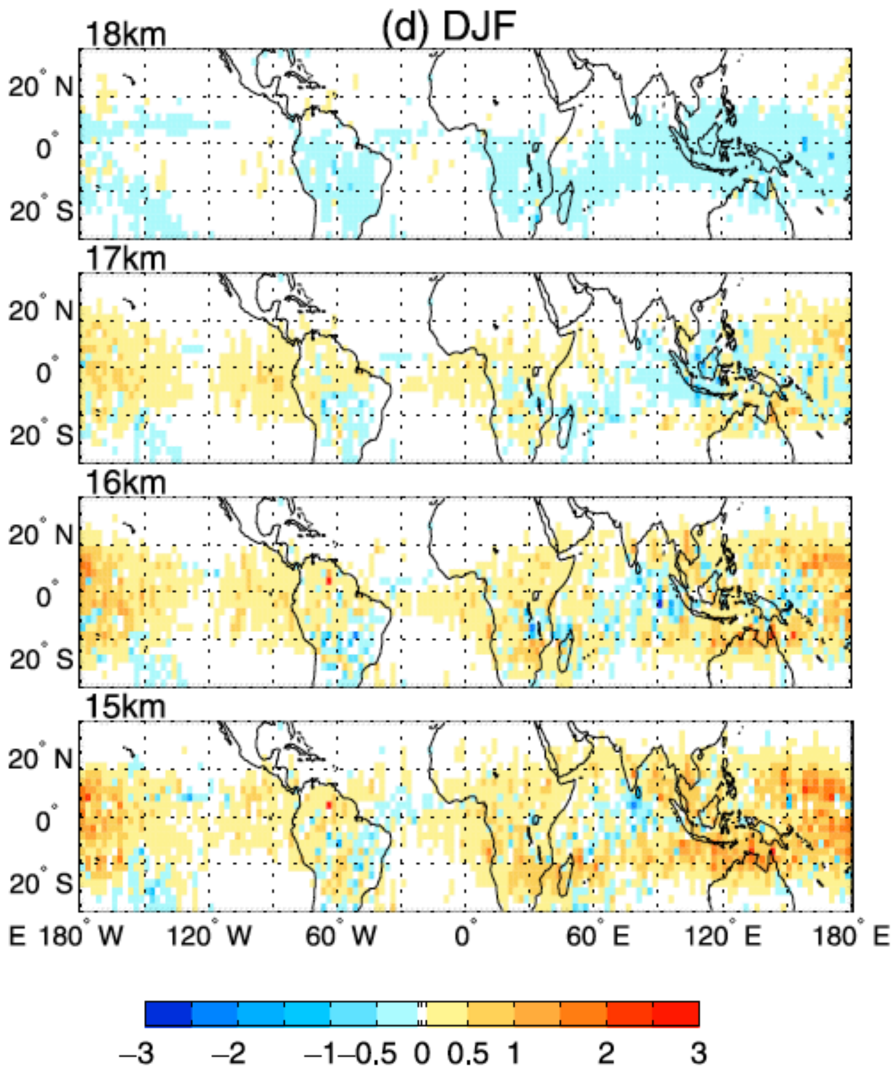


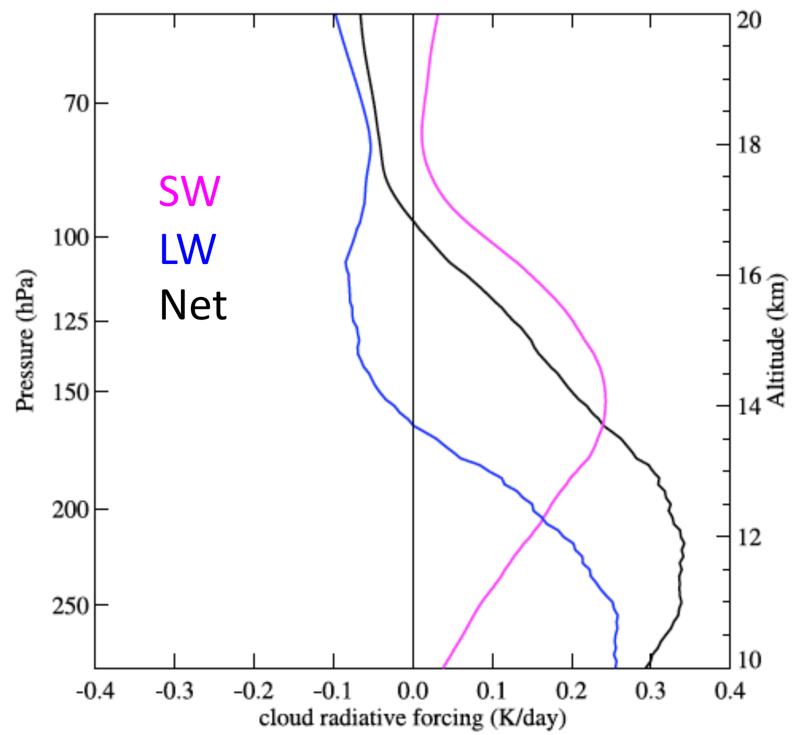


- Cirrus clouds heat TTL (lower Q_{clr}=0)
- Corti et al 2006, ACP
  - Convective flux from Gettelman et al, 2002

Clouds (2): Net Heating Rates…

CALIPSO + rad transfer Code Yang et al 2010, JGR





Thin cirrus (t<0.3) heat at 15-17 km ~0.5K/d, little effect at 18km

All sky number similar to Corti et al

Clouds (3): TC4 In-Situ heating

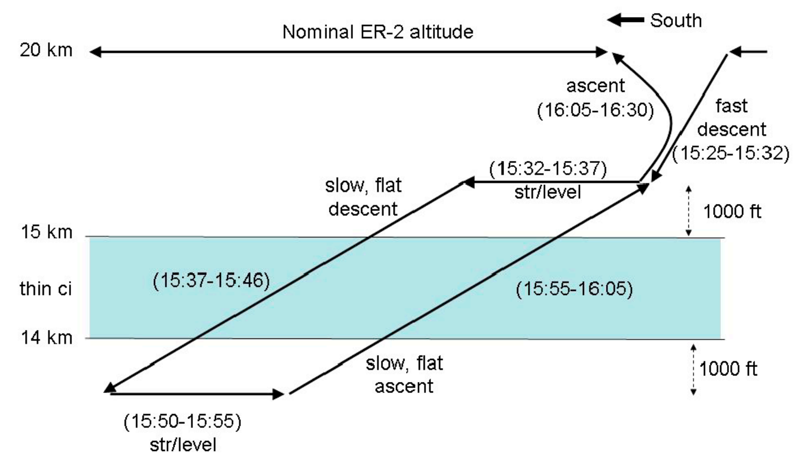
Observe divergence of radiative fluxes

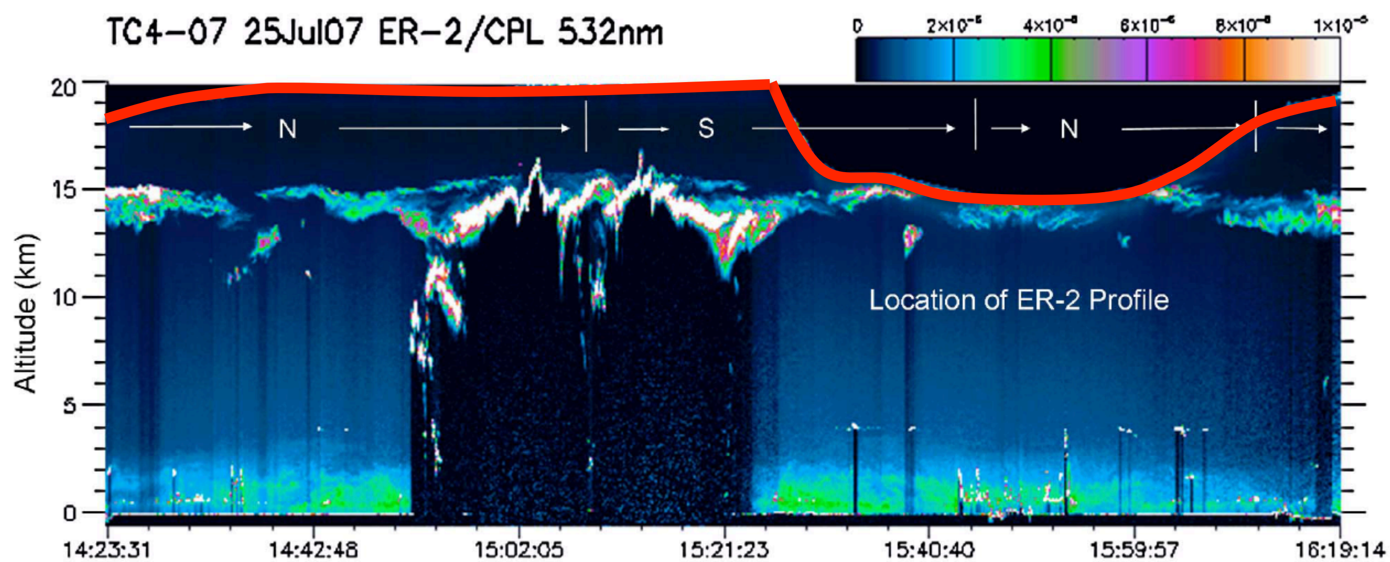
Above and below a cloud during TC4

Bucholtz et al 2010

$$\left(\frac{\partial T}{\partial t}\right) = \frac{g}{c_p}\frac{\nabla F}{\Delta p}$$ =2.5-3.2 K/d

τ = 0.03



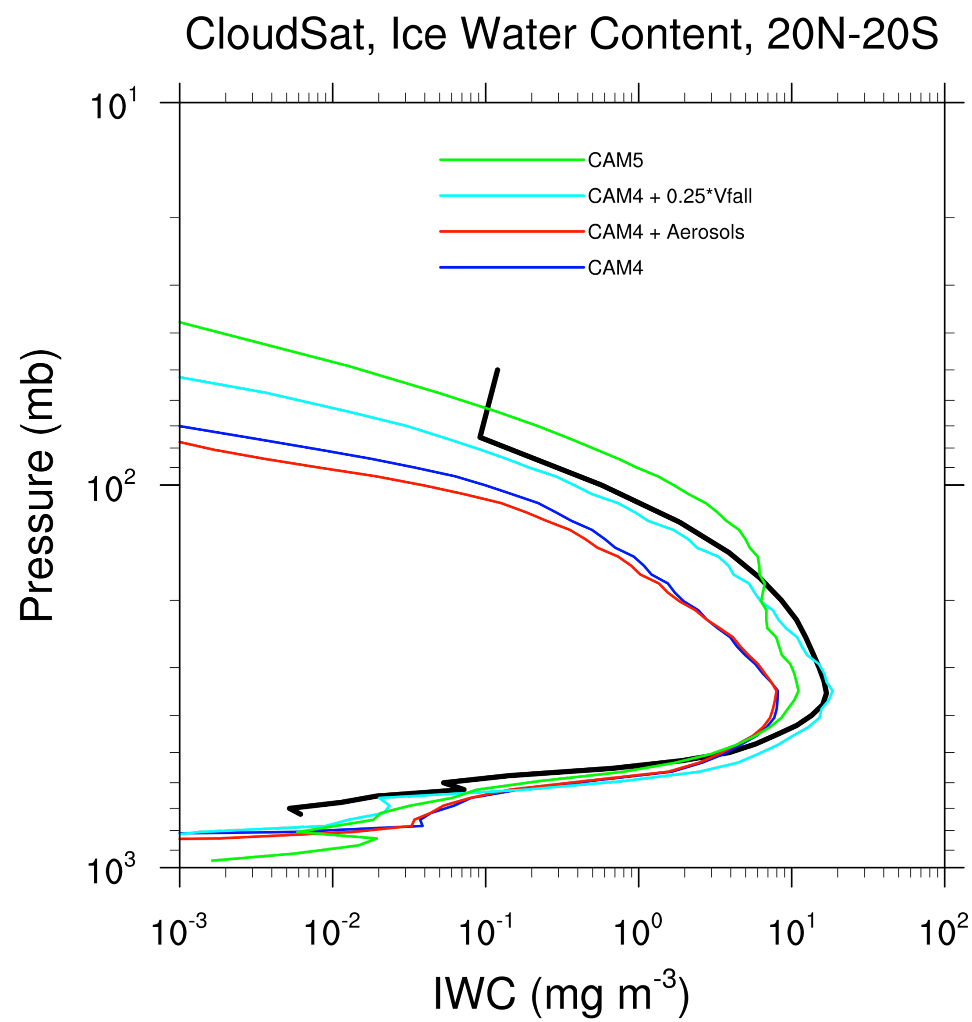


Model Balances/Quality

- Radiation in clear sky [good]
- Cloud radiative transfer [okay]
- Large scale dynamics [okay]
- Small scale dynamics [bad]
- Cloud climatologies [bad]
- Cloud (cirrus) ice microphysics [ugly]

Recent CAM/CARMA Results

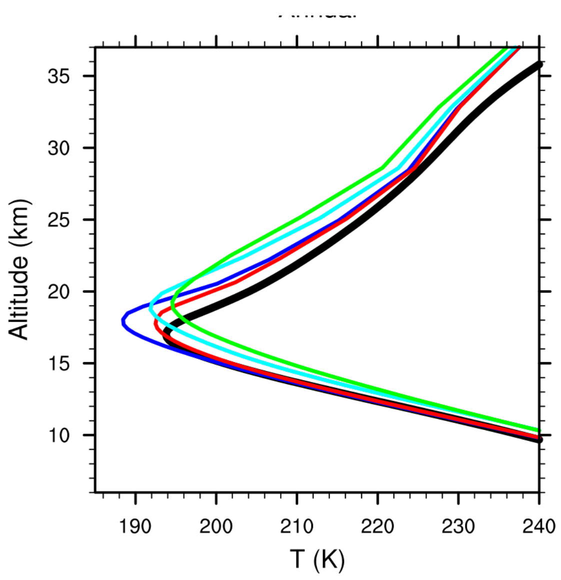
- Black: CloudSat IWC
- Colors: simulations
- Factors of 2 different



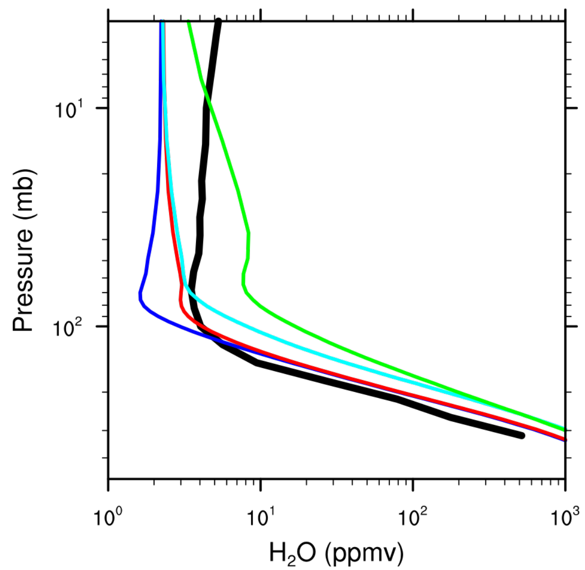
TTL Temperature & Water Vapor

Cloud differences → different heating, Temps and H_2O

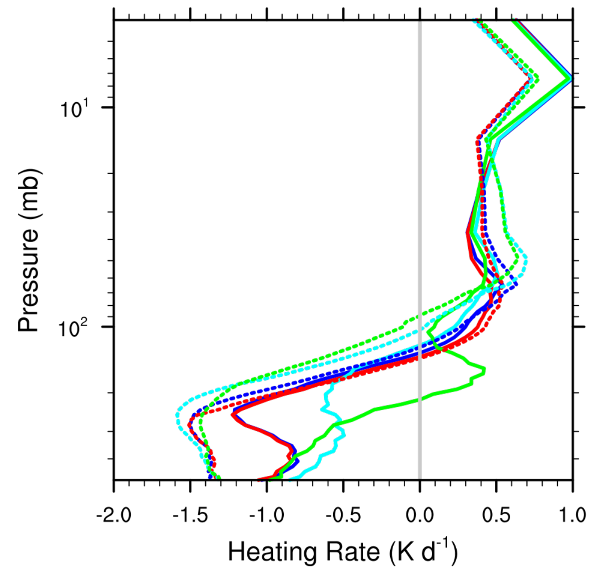
COSMIC T



MLS H_2O



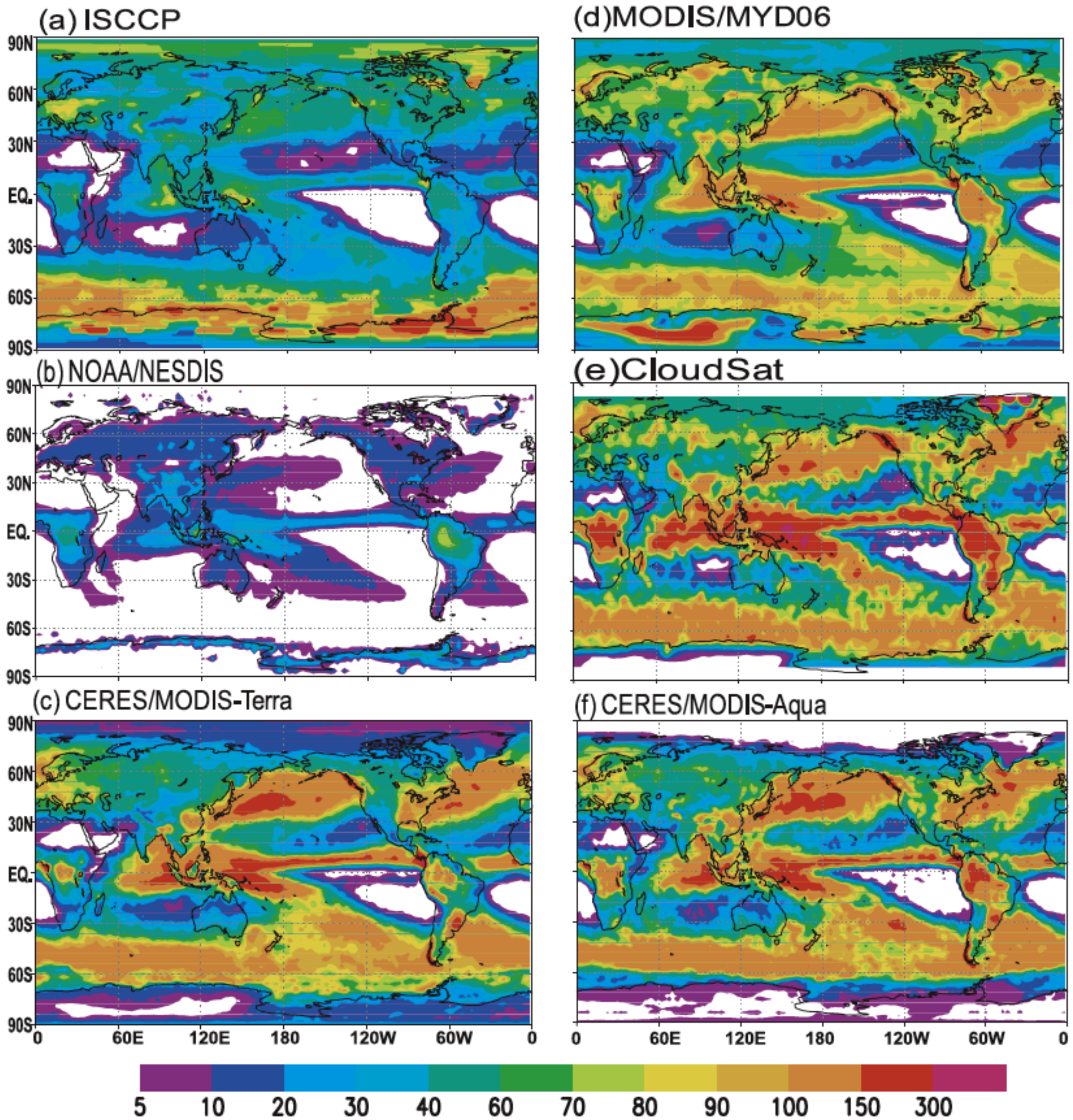
Radiative Heating Rates



CAM5
CAM4 + 0.25*Vfall
CAM4 + Enhanced Aerosols
CAM4

All Sky (solid)
Clear Sky (dashed)

IWP Observations



What do we do? Adjust clouds, usually cloud ice: because observations are uncertain…

IWP 'observations' from Waliser et al 2009

Note: large differences between 'observations'

What is needed

- More Observed Radiative Fluxes
- Thin Cirrus IWC
  - To evaluate satellites & data sets
  - Biggest uncertainty
  - Frequency on long flight legs
- TTL Temperatures and variability
  - Waves, spectrum
  - Evaluate GPS obs, and below those scales

Deriving TTL Heating rates

- Vertical structure of radiative fluxes gives 'clearest' picture (Bucholtz et al)
- Satellites/Aircraft can do similar things with radiative transfer models
  - Vertical profiles of cloud properties and trace gases help
  - Balloons for vertical range of H_2O, O_3, maybe also a backscatter sonde.
  - Useful at Guam in DJF: have thin cirrus overhead

ATTREX Flights/Balloons

- Legs through cirrus cloud: heating rates.
  - Aim below 45kft (=13.7 km, aim at 12km)
  - Then turn and ascend to max alt (slow).
- Downward radiometers at max alt
  - Look down at surface and impact of clouds
  - Synergy with NCAR G5 looking up?
- Radiation & clouds on Lagrangian flights
  - Constrain dynamical and radiative heating
- Balloons
  - Profiles of H_2O, O_3, Cloud backscatter