Simulating Tropical Clouds, Dehydration & the Tropopause Layer

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Invited talks are like a wedding

- Something Old
- Something New
- Something Borrowed
- Something Blue

Outline

- Define the TTL: Key Processes & Role of Clouds
- Motivation:
  - Climate forcing: Strat H_2O, Cirrus Cloud Feedbacks
  - Chemistry: Strat O_3 budget: H_2O & VSLS
- TTL processes and representation in models
- Recent work improving TTL simulations
- Outstanding questions

First general Assembly of the WCRP-SPARC project « Stratospheric Processes and their Role in Climate »

Melbourne, 2-6 December 1996

Session 5.
Stratosphere-troposphere transport and mixing

Rapporteur : T. Shepherd

Finally, a significant reason - especially within SPARC - for being interested in STE in the extratropics concerns the downward transport of ozone, and this is becoming the object of global budget analyses (A. Gettelman).

(Gettelman, Holton and Rosenlof, 1997, JGR: Mass Fluxes of O3, CH4, N2O and CF2Cl2 in the Lower Stratosphere Calculated from Observational Data)

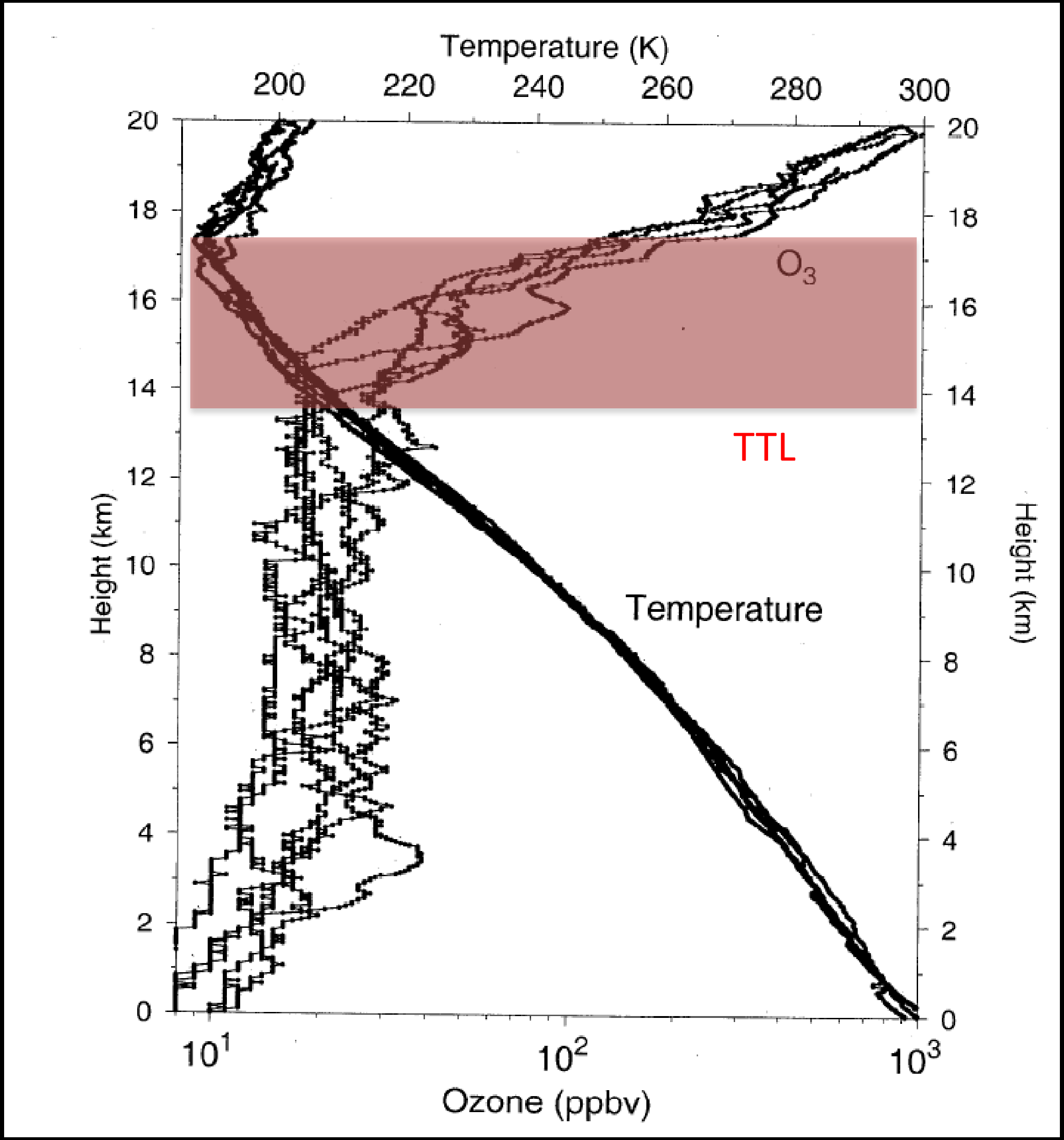
Tropical Tropopause Layer

Sharp ‘Cold Point’
Ozone increases 3km below it

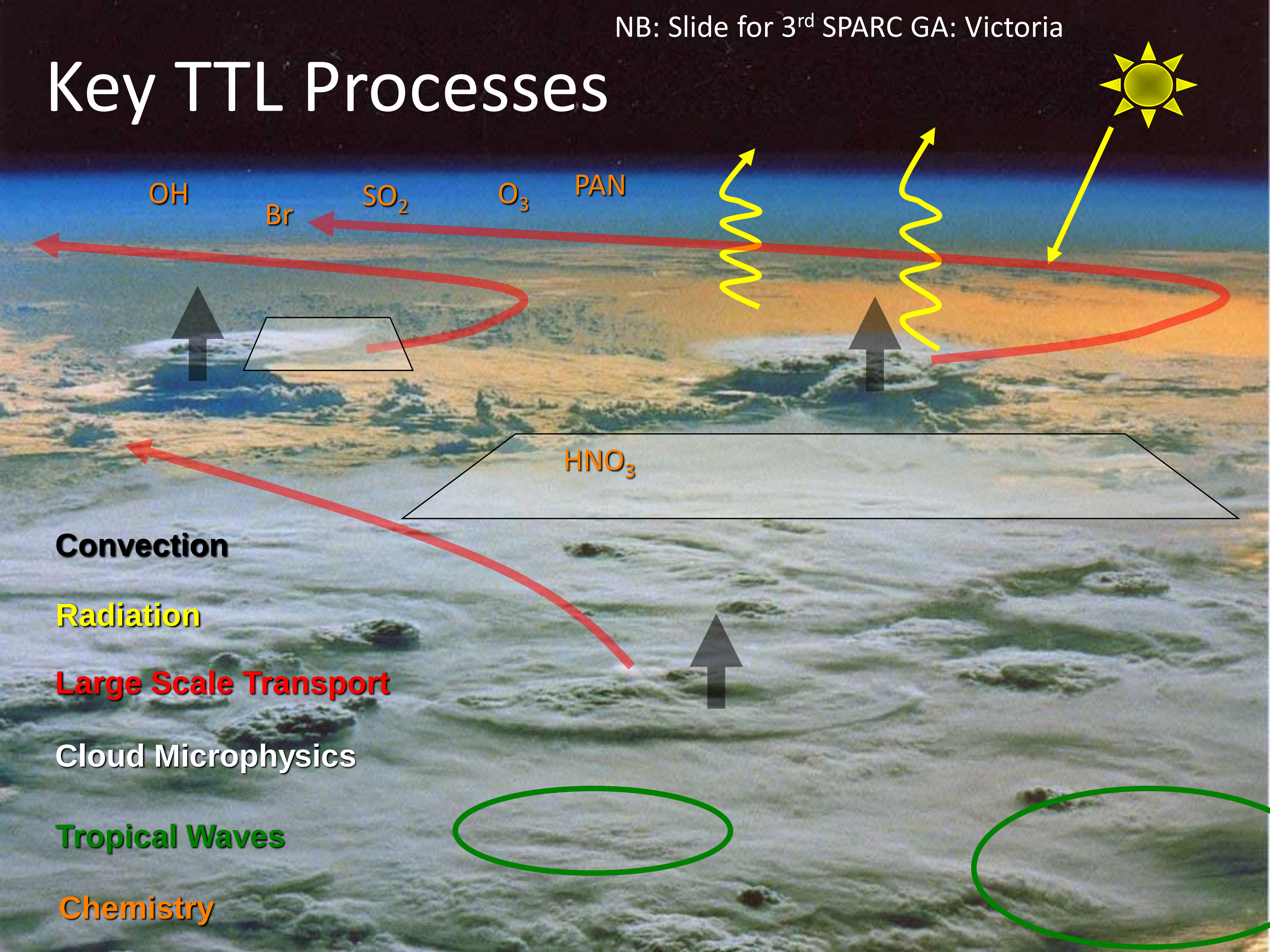
What is going on?

TTL idea goes back at least to Atticks & Robinson, QJRMS, 1982

Soundings: Samoa, March 1996



Folkins et al 1999

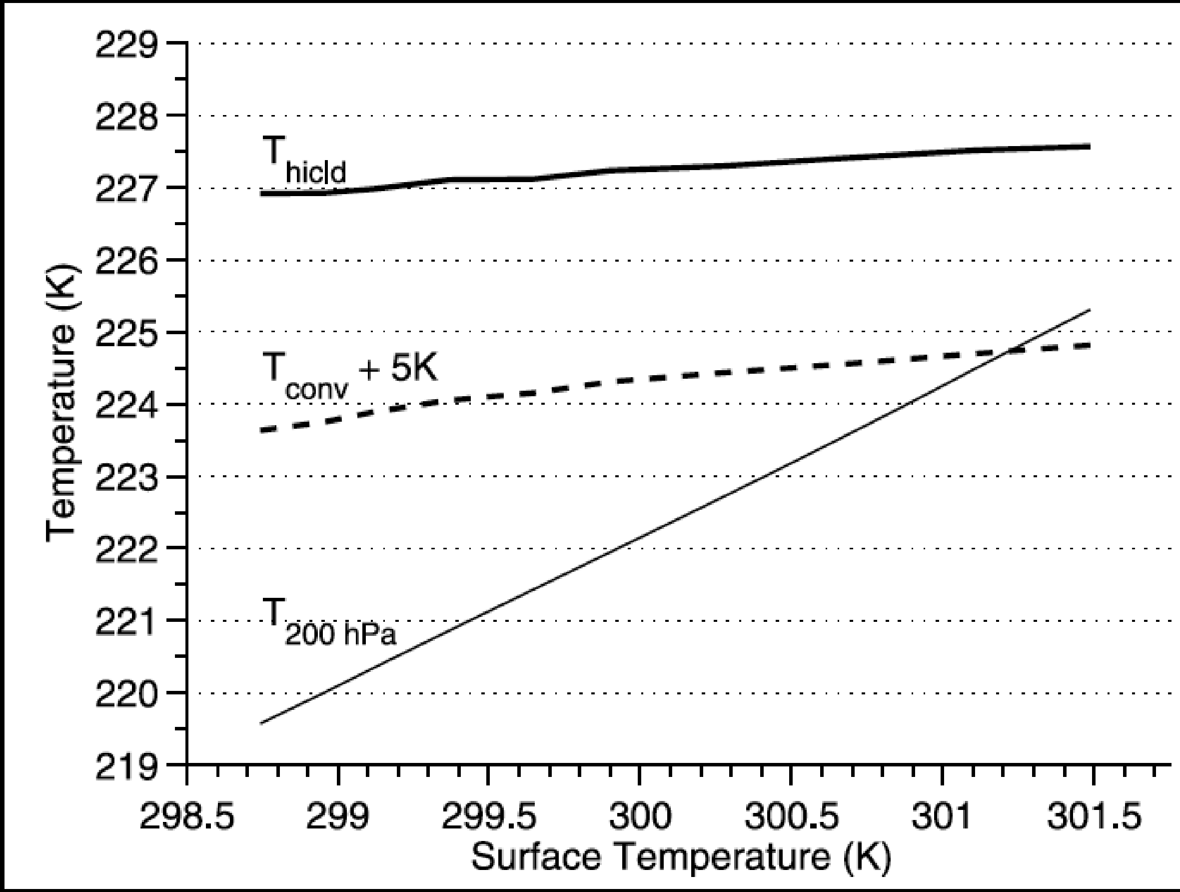


NB: Slide for 3rd SPARC GA: Victoria
Key TTL Processes
OH
Br
SO_2
O_3
PAN
HNO_3
Convection
Radiation
Large Scale Transport
Cloud Microphysics
Tropical Waves
Chemistry

Motivation: Cirrus Cloud Feedbacks

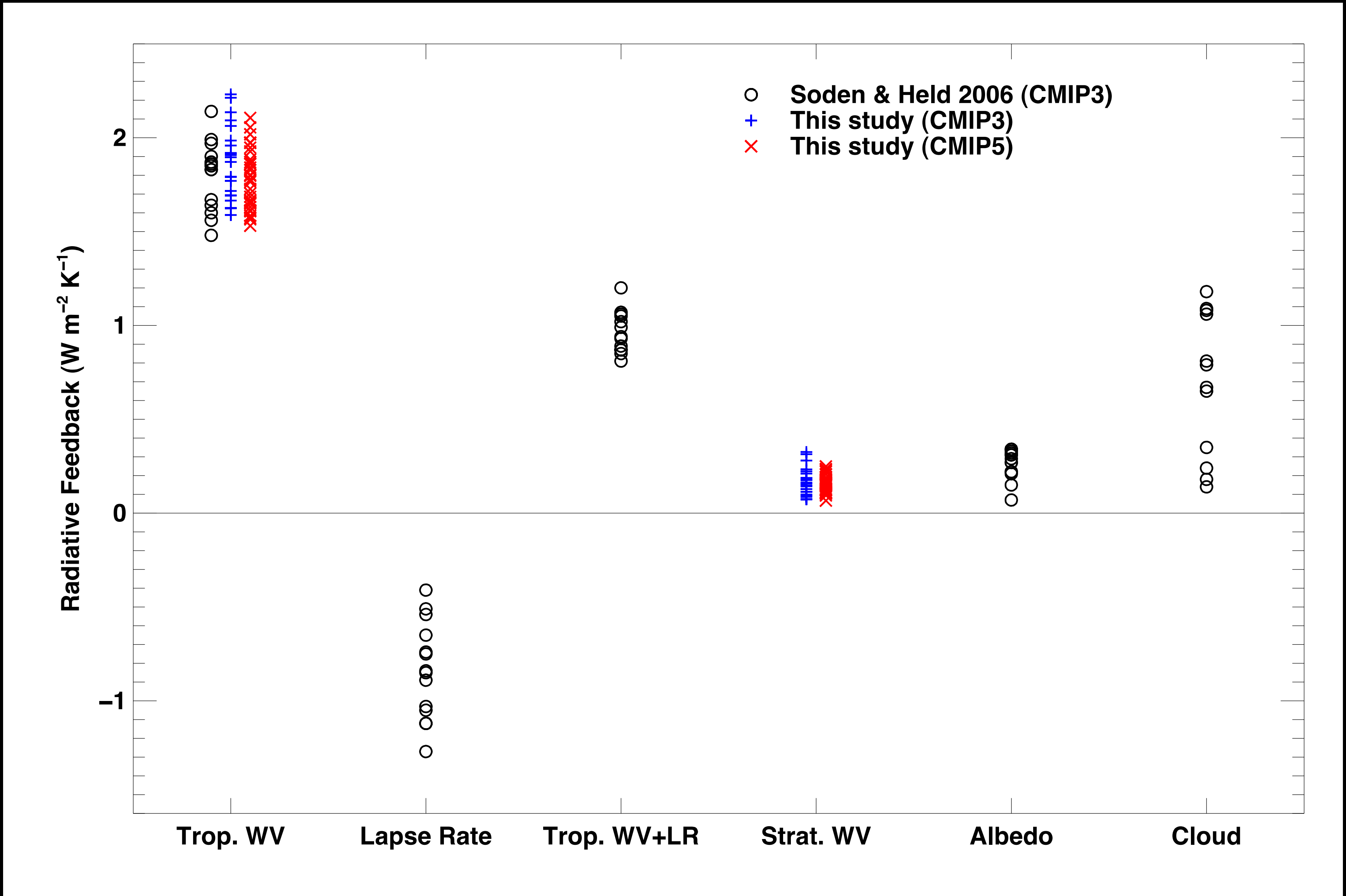
Simulated high clouds have nearly constant radiative temperature, but rise in height (lower pressure). Thus for a warmer surface, cloud emission is constant (it does not rise) and LW cloud forcing increases: a positive feedback

This seems to work (and be stable) in GCMs.



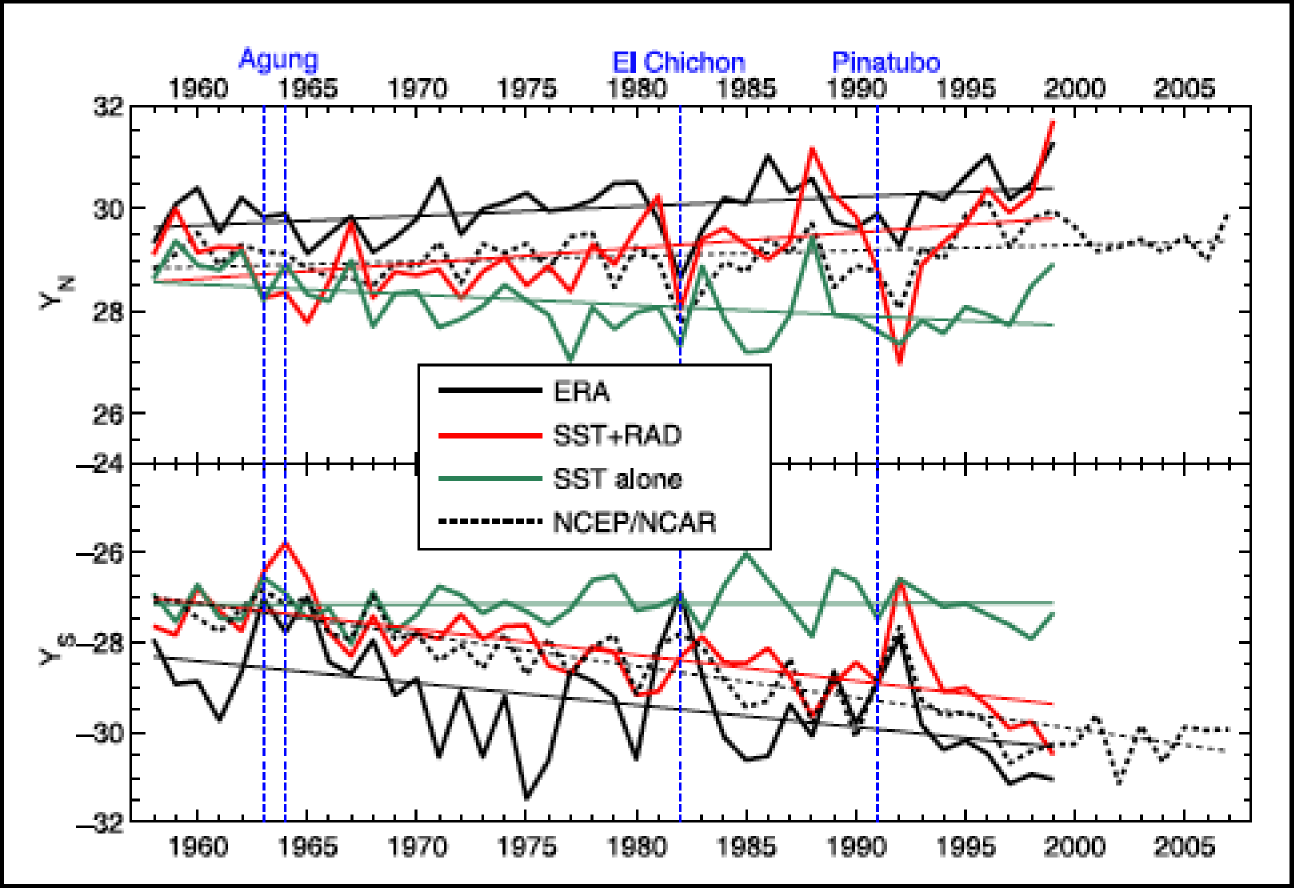
Zelinka and Hartmann, 2010

Motivation: Stratospheric WV Feedback



Portmann, in Prep

Motivation: Changing Circulations

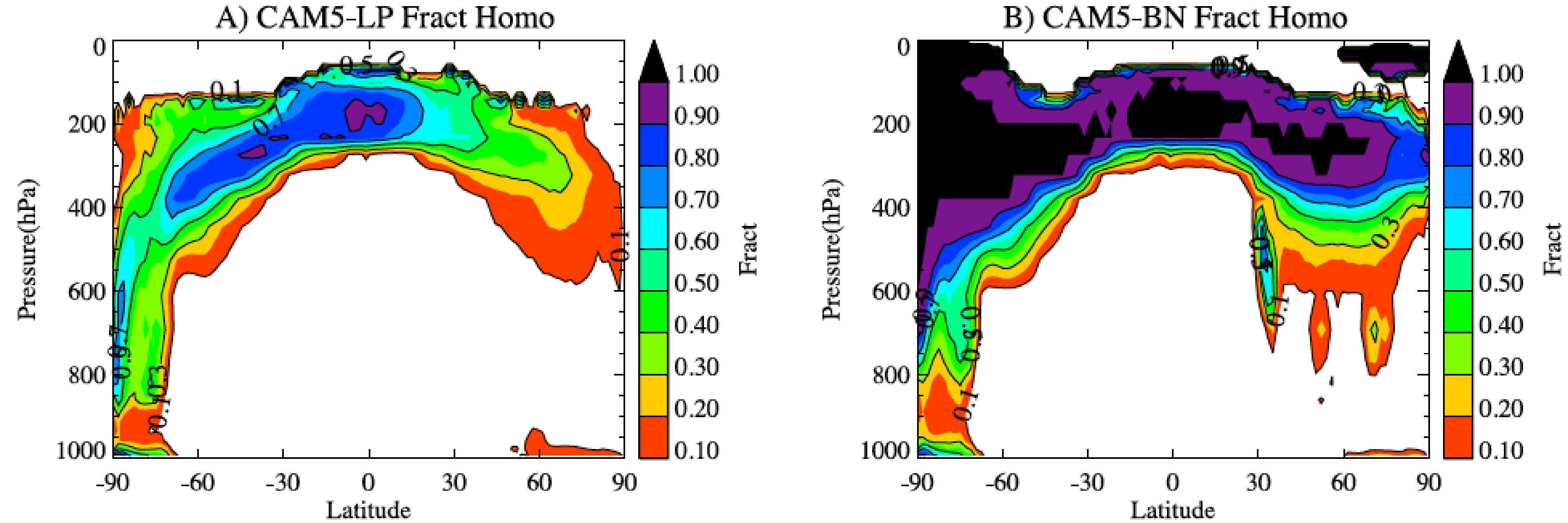


Lu et al 2009

Only GHG and O_3 changes (radiative effects) drive poleward motion of sub-tropical tropopause break: Not SST changes

Motivation: Ice-Aerosol Interactions

Different representation of cirrus clouds for same climate effect
Uncertain effects of anthropogenic ice nuclei (Sulfate, Black Carbon)



Gettelman et al 2012

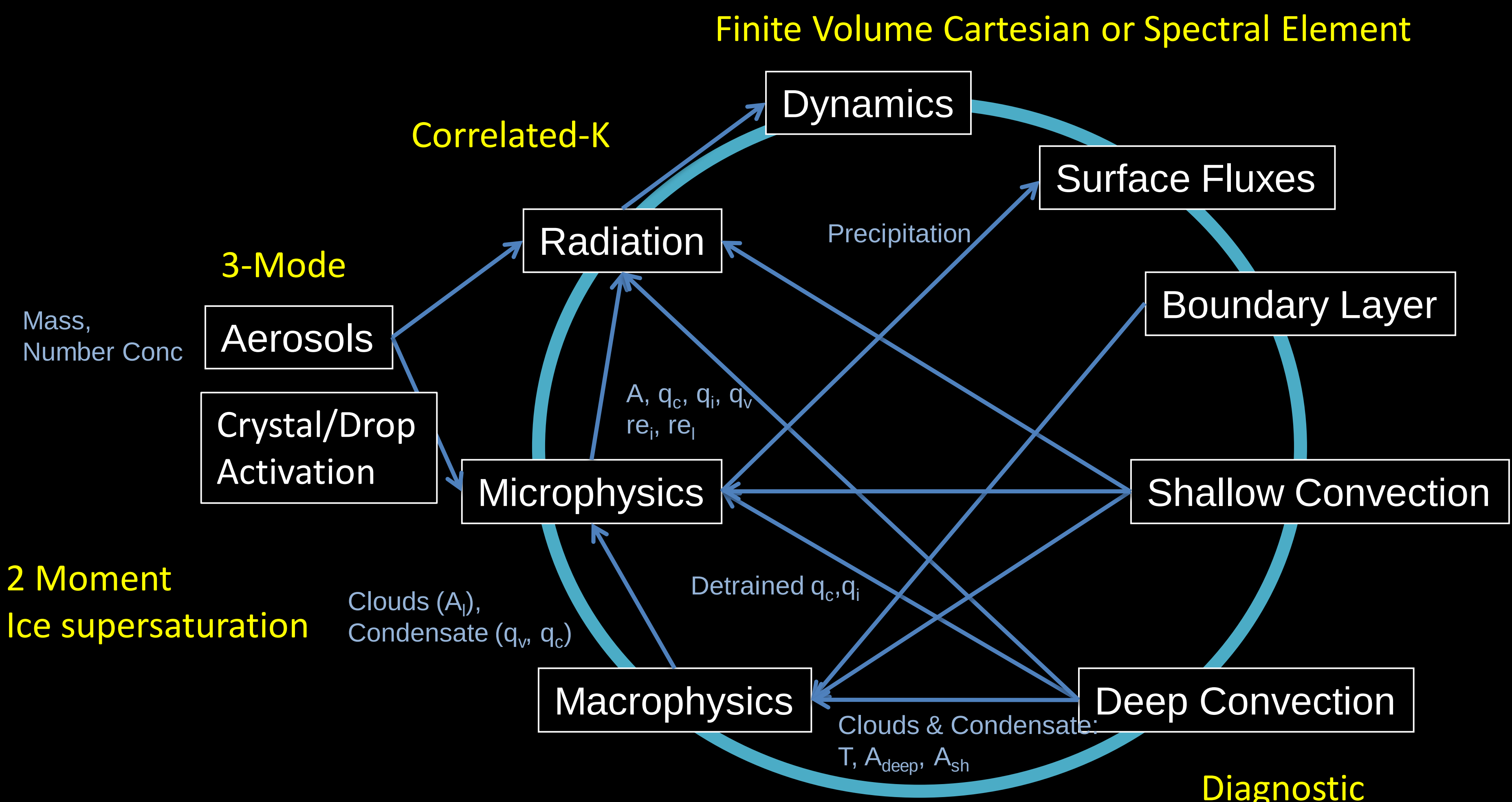
NCAR ESM Simulations with different ice nucleation Schemes
Very different balance of what processes maintain cirrus clouds
May respond differently to climate forcings (feedbacks).

Goal of Global Modeling

- Focus on Climate and Chemical effects
- Represent Key Processes
  - Many are ‘sub-grid’ scale
- Estimate how will they change given forcing to chemistry and climate
- Disadvantage: Large spatial scales
- Advantage: Large spatial scales (closure)

How GCM clouds work (& don't) in 1 slide…

NCAR CESM1 (CAM5): IPCC AR5 version (Neale et al 2010)

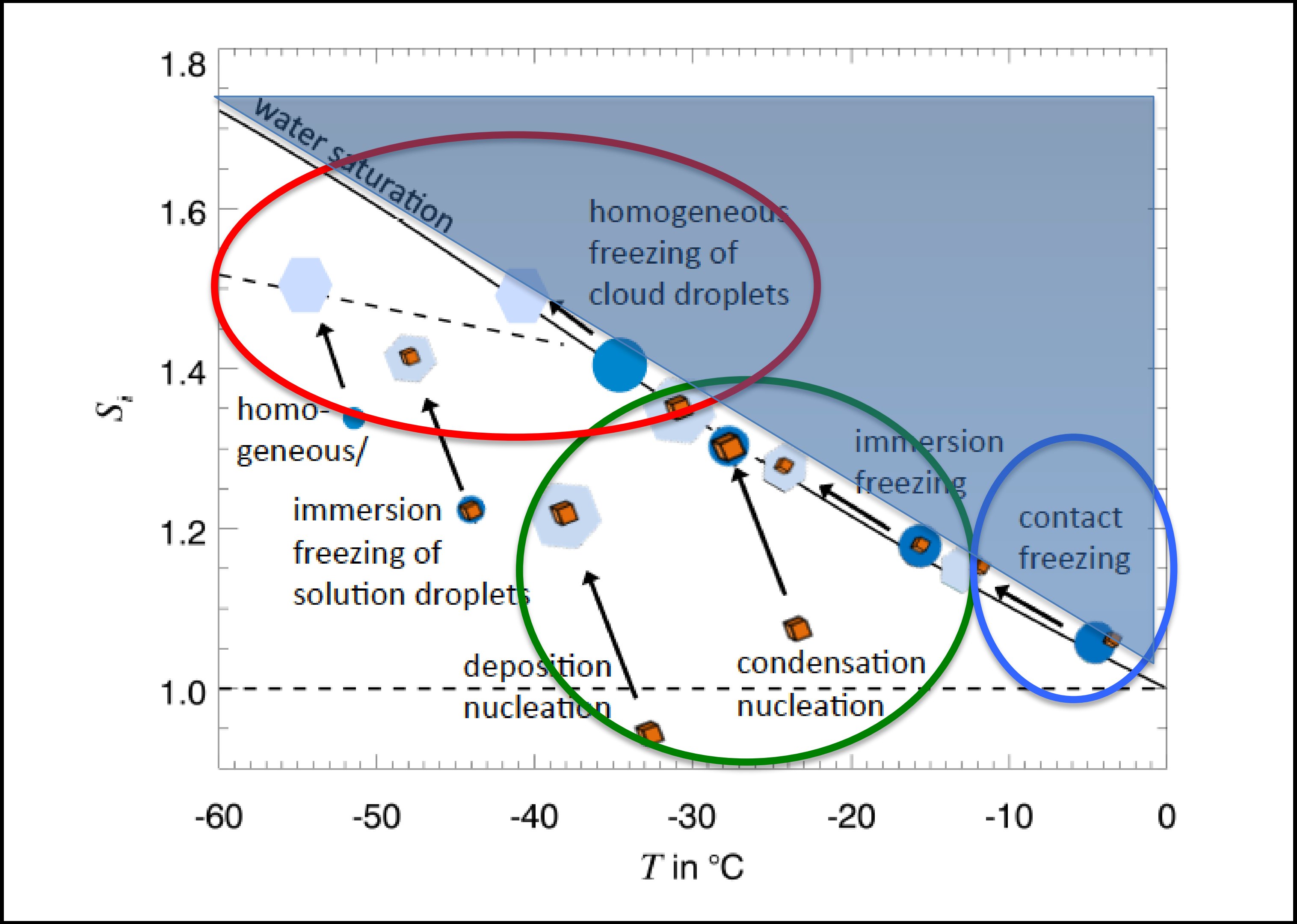


A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor

State of Global Models: Processess

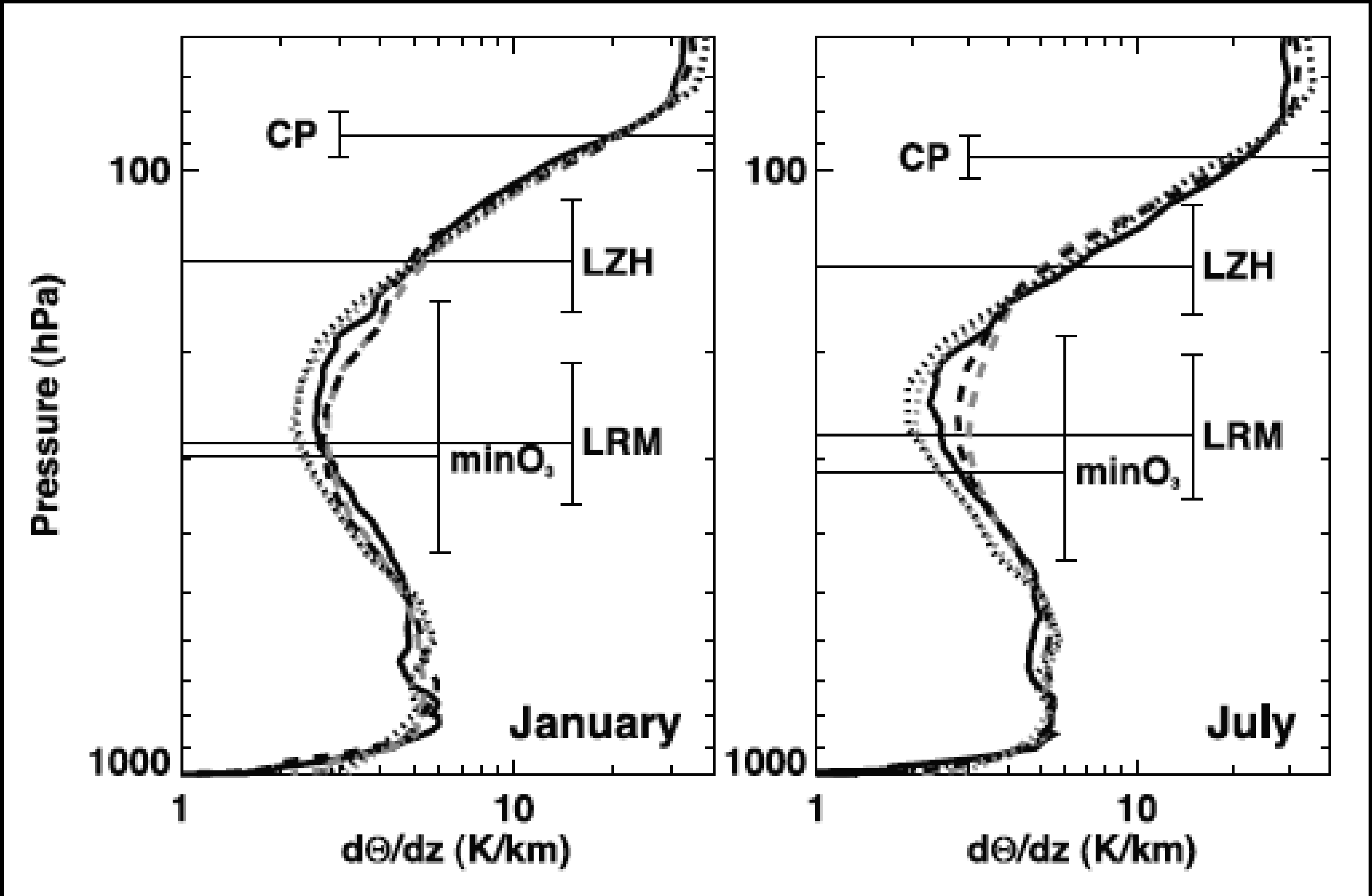
- Radiation: Clear Good, Clouds: See Micro
- Chemistry: Gas Phase Good (different levels)
- Transport: General Circulation Good, small scale mixing: See waves
- Tropical Waves: large scale Good. GW parameterized (uncertain)
- Convection: Integrated effects good, small scale transport not good
- Microphysics: Bulk okay, details and ice nucleation not well understood

Ice Nucleation Processes



$S_{ice} > 1$, close on water saturation. Retain Empirical for mixed phase
Introduce ice nucleation for homogenous, heterogeneous, contact freezing

Simulating TTL structure



Solid: Sondes
Dotted: WACCM
Thin Dot: CAM
Dashed: CMAM
Gray: TTL Avg
Black: @ stations

Lapse rate profiles from GCMs:

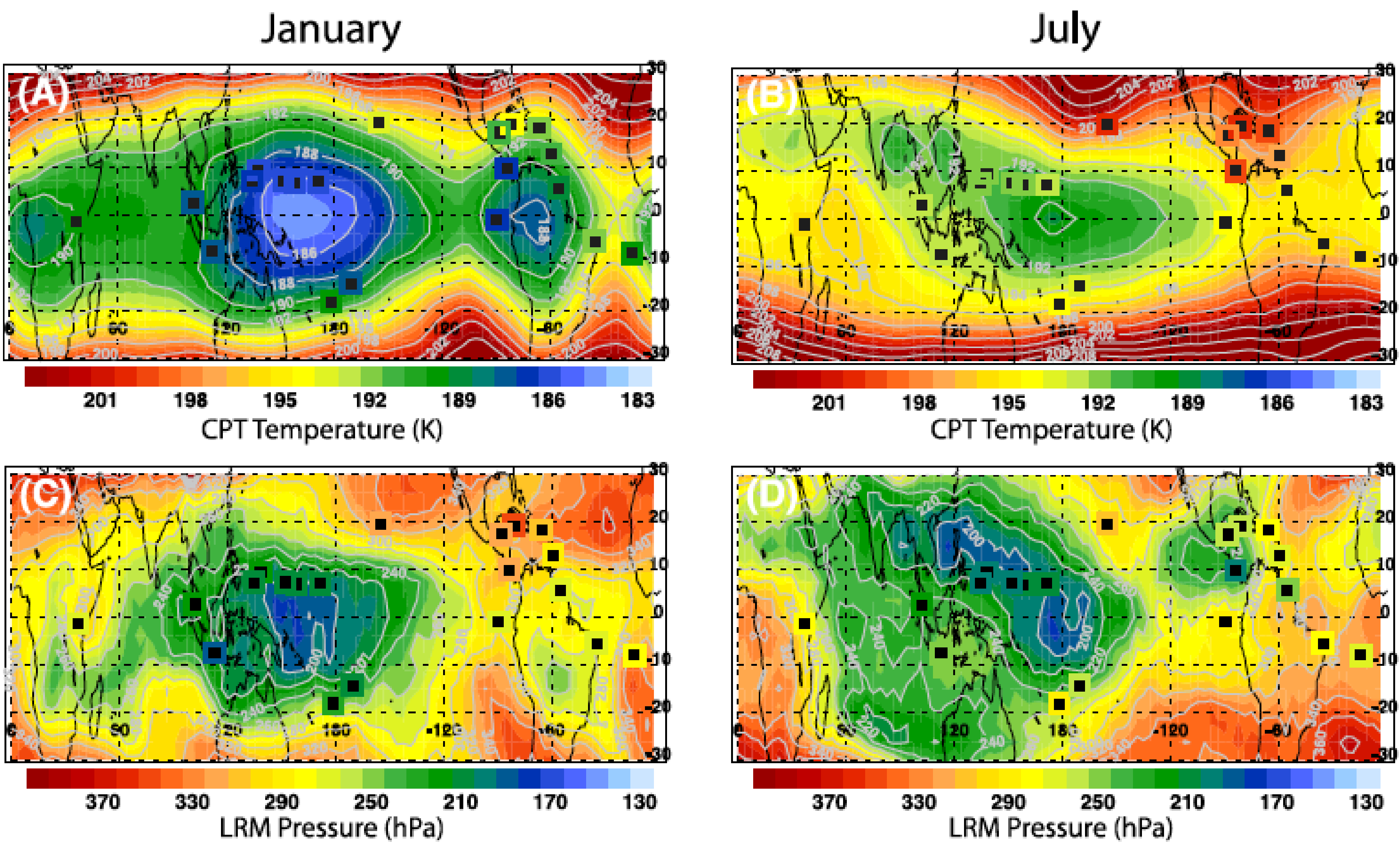
Min O3 similar to Min LR (LRM)

Gettelman & Birner, 2007, JGR, Fig 3

Simulated TTL Structure

Gettelman & Birner, 2007, JGR, Fig 5

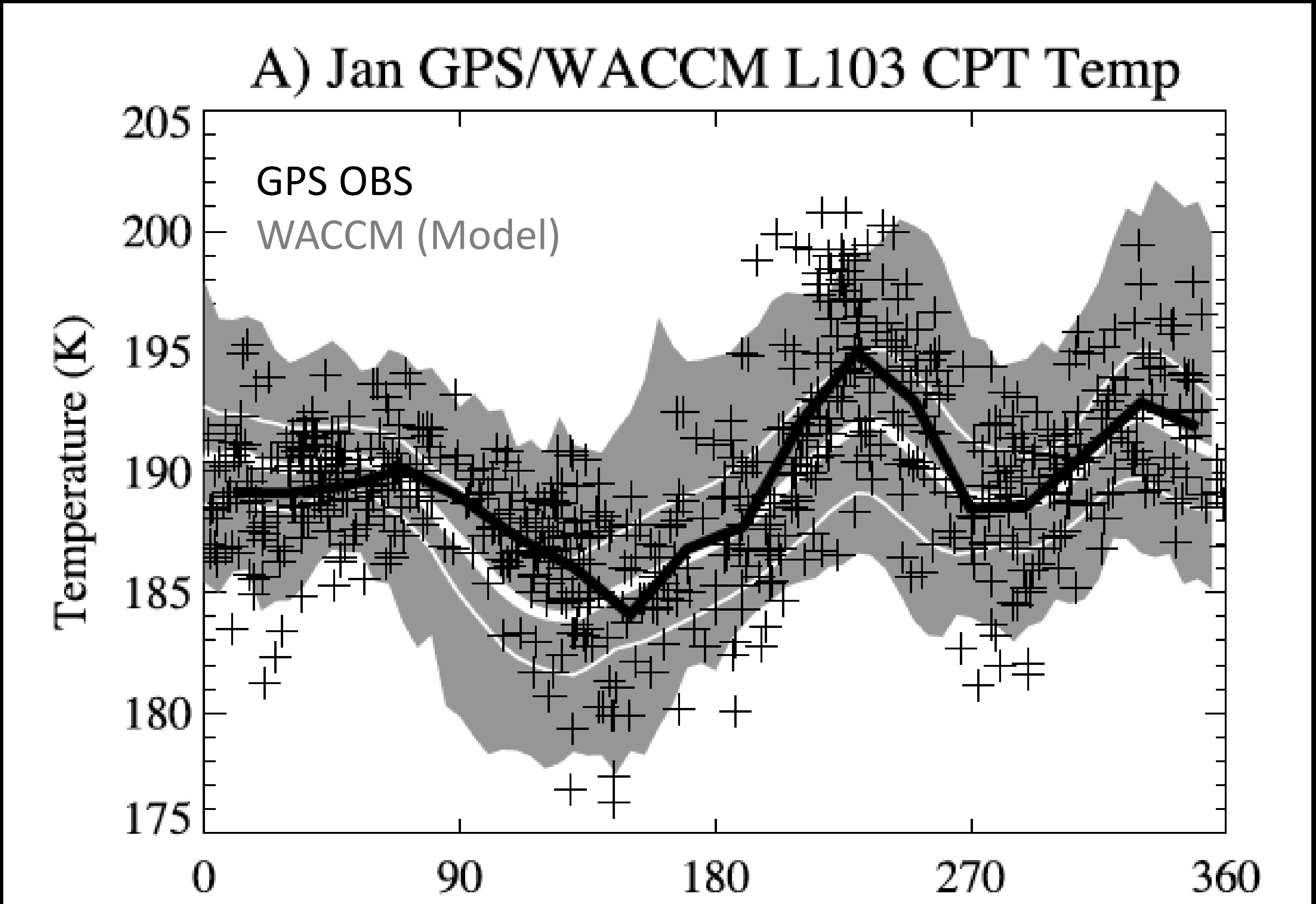
Contours: CMAM GCM, Squares: Sondes



High Frequency Variability (Waves)

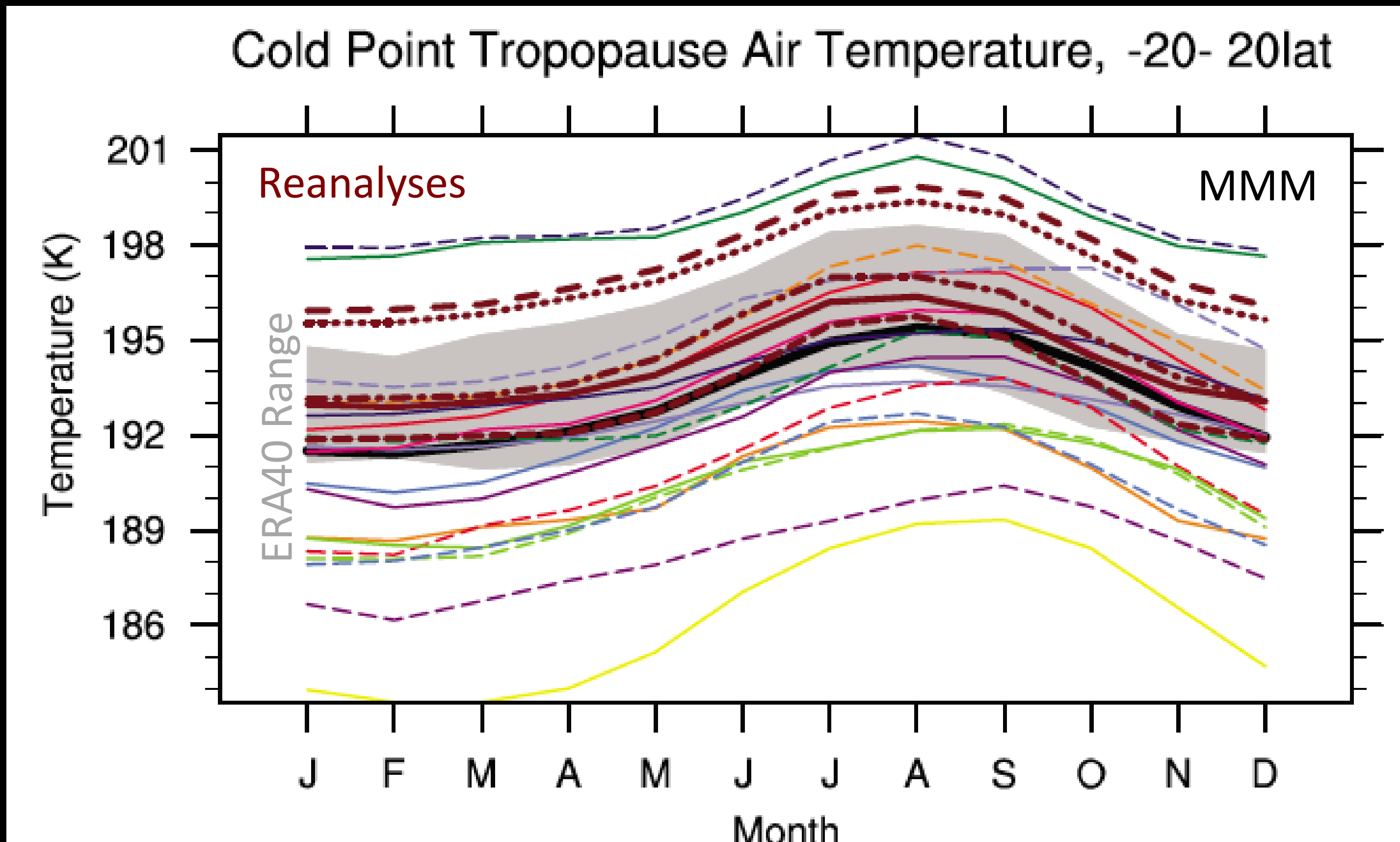
High vertical resolution model (300m)

Can reproduce cold point variability. But: limited by resolution



Gettelman & Birner, 2007

Range of Models (CCMVal2)

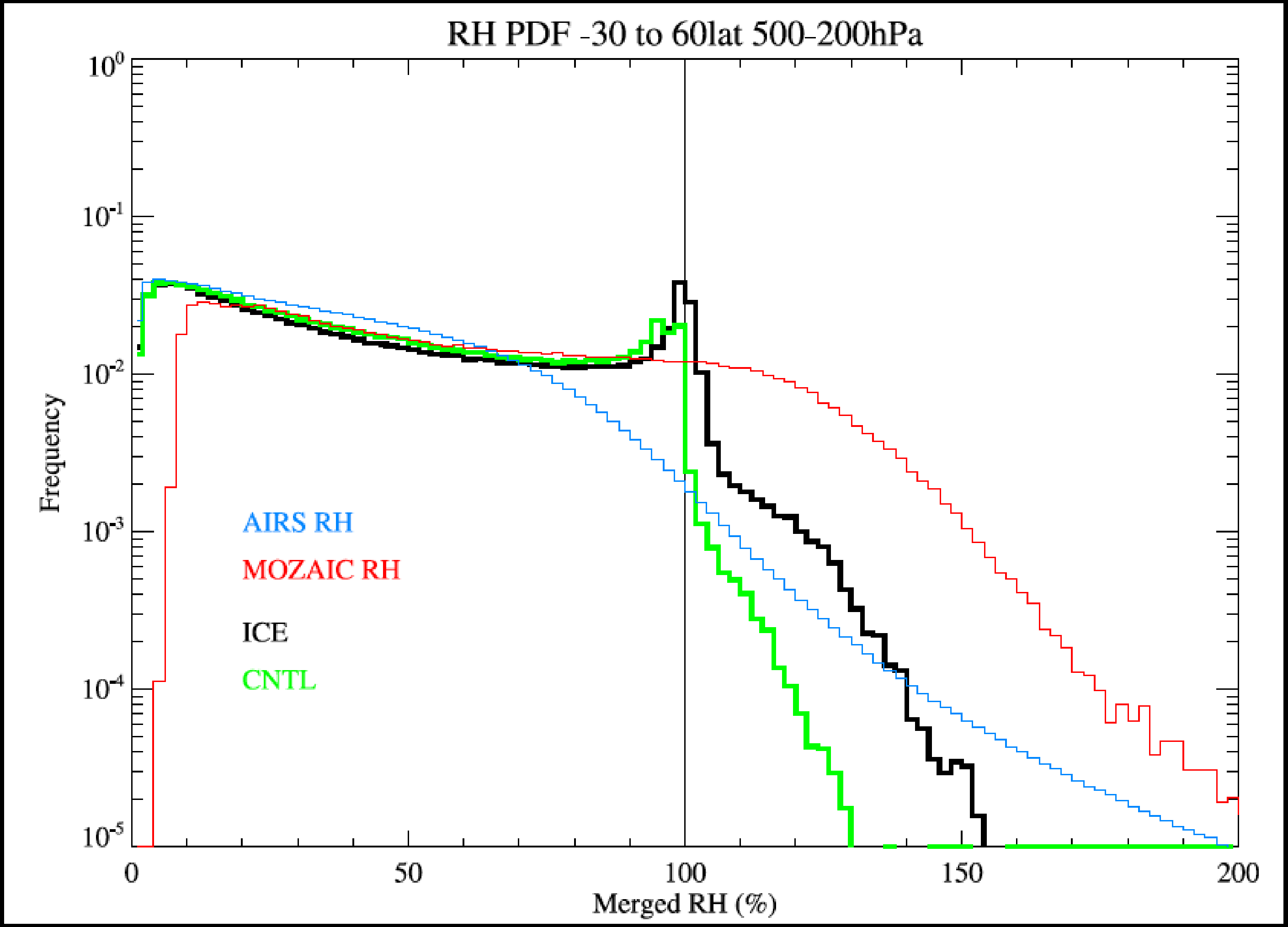


Gettelman et al 2010

GSUM	0.5	0.4	0.5	0.3	0.7	0.1	0.3	0.5	0.5	0.4	0.5	0.4	0.4	0.6	0.4	0.6	0.5	0.5	0.6	1.	0.5	0.4	0.7	0.5
GV	0.8	0.8	0.9	0.8	0.9	0.	0.8	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.	0.8	0.8	0.9	0.8
GC	0.3	0.3	0.4	0.2	0.5	0.4	0.2	0.4	0.4	0.3	0.5	0.3	0.3	0.4	0.4	0.5	0.6	0.5	0.3	1.	0.6	0.5	0.4	0.3
GM	0.4	0.	0.2	0.	0.7	0.	0.	0.4	0.1	0.	0.3	0.	0.	0.6	0.	0.6	0.	0.	0.7	1.	0.	0.	0.7	0.5

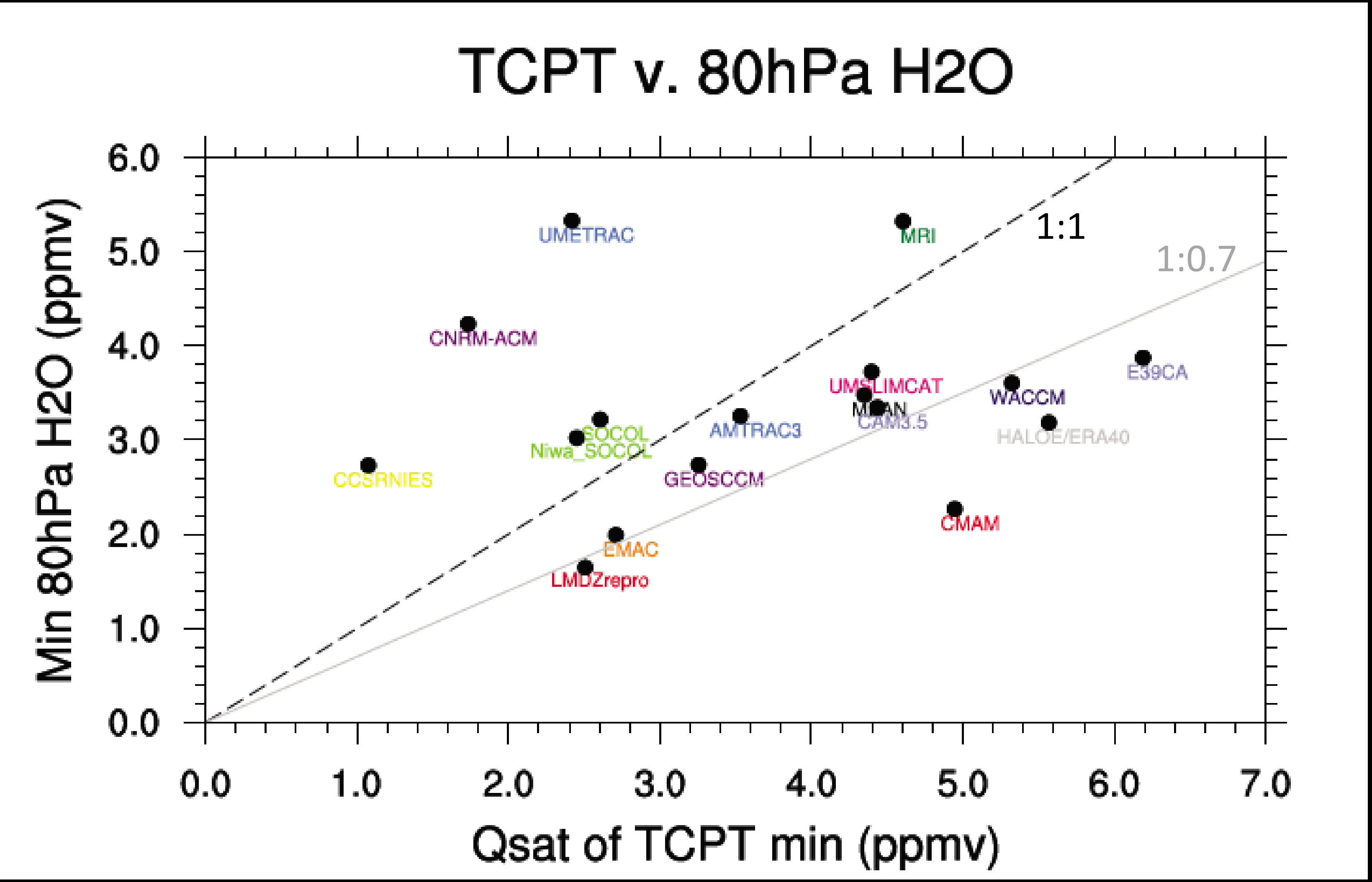
Grade: 1. 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.

Simulated Ice Supersaturation



Gettelman et al 2010, JGR

Integrated Dehydration

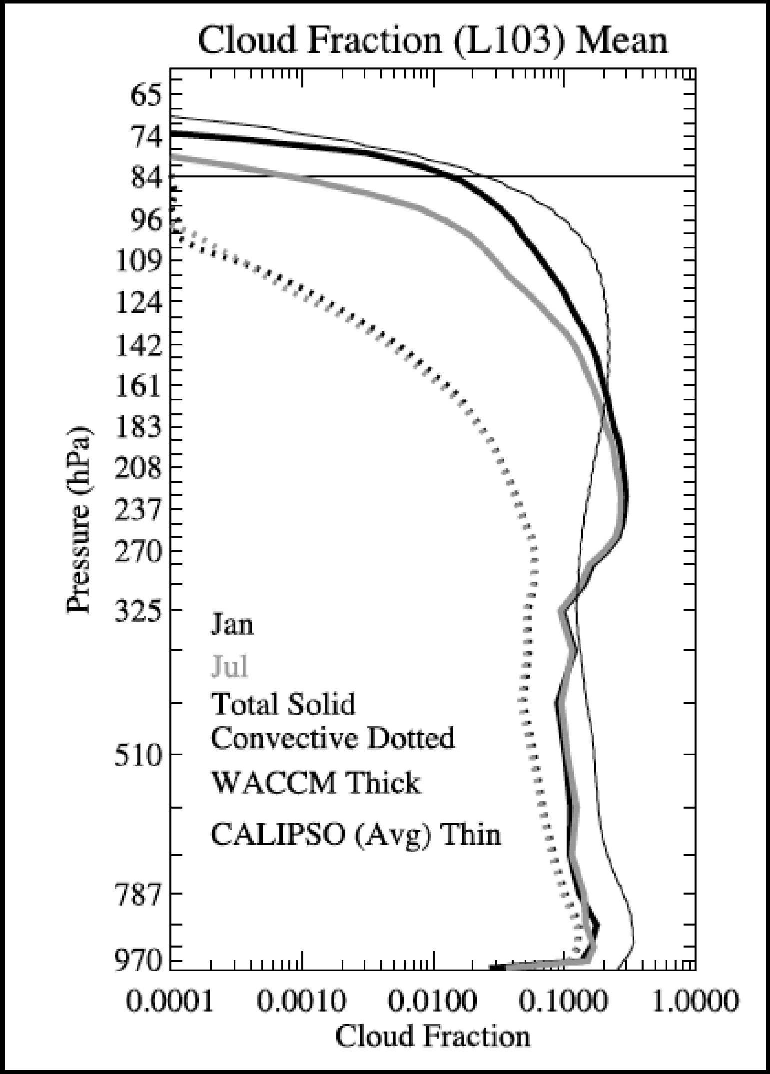


Gettelman et al 2010

Integration of processes: Transport, Dehydration & Microphysics

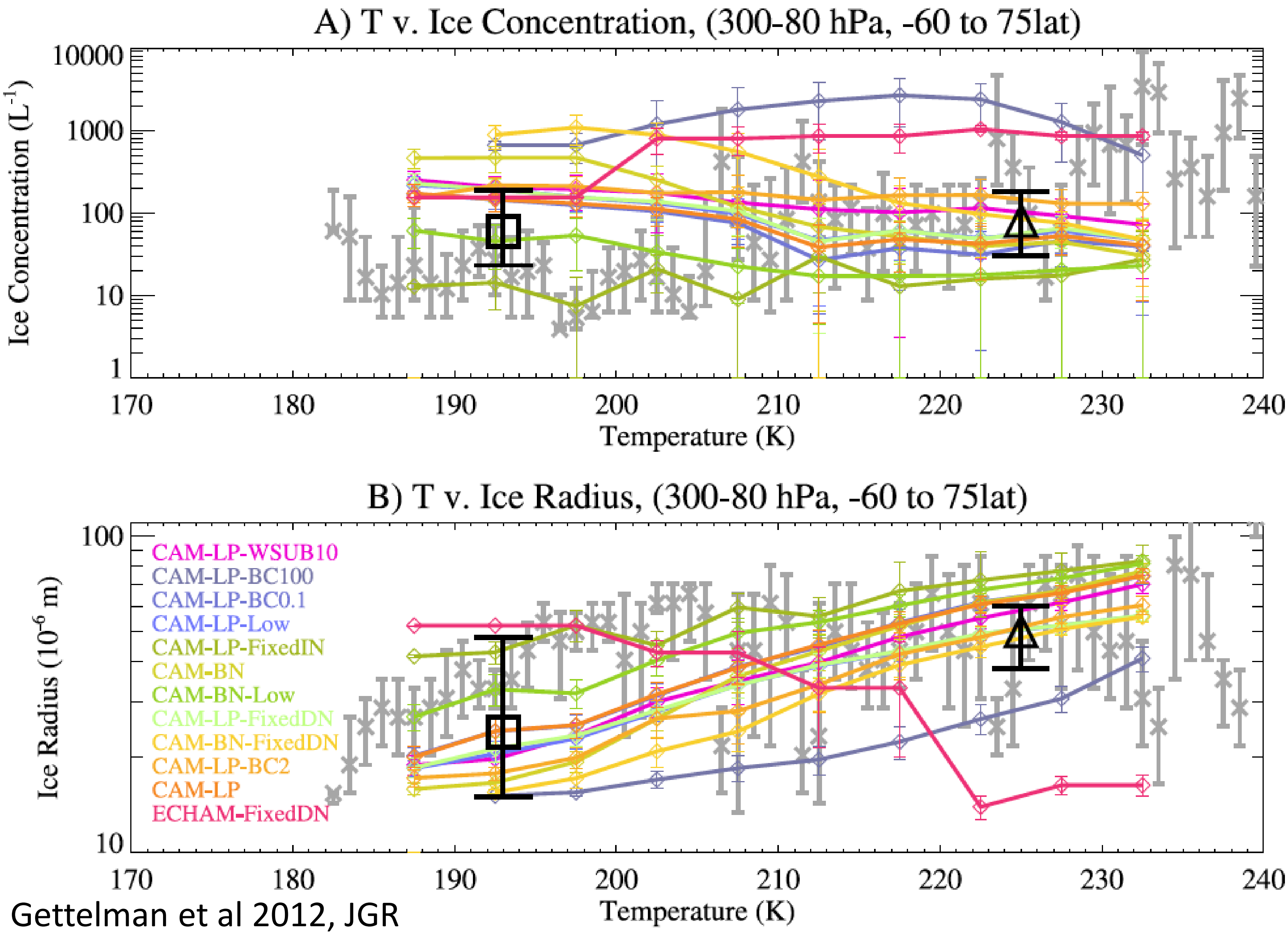
Simulating TTL Clouds (Global Models)

- Models do 'okay' on gross measures of cloud occurrence.
- Not for the right reasons…
- Also note: WACCM levels are high vertical resolution (300m) in TTL



Gettelman & Birner, 2007, JGR, Figure 10

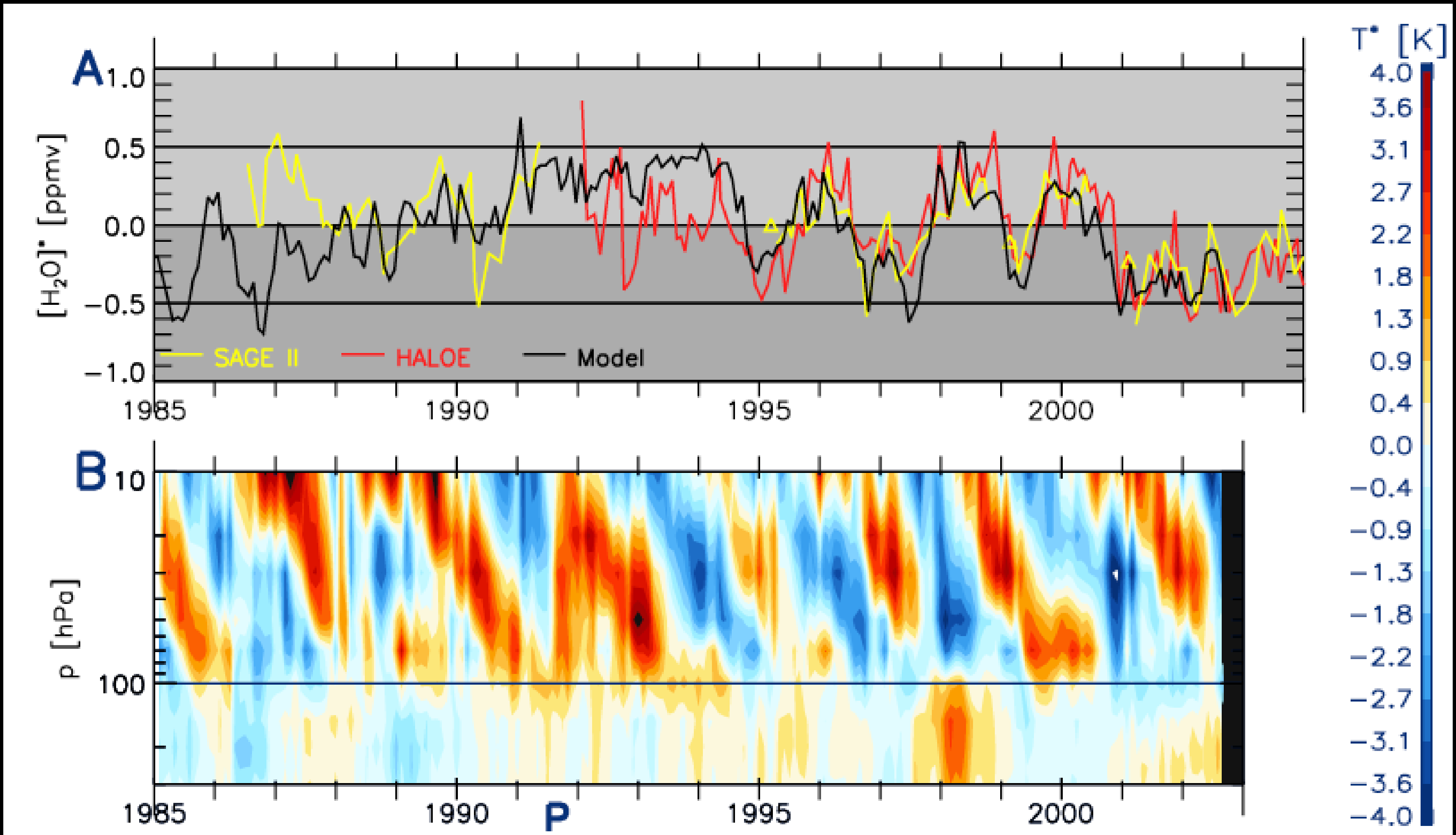
Simulations: Ice Number v. T



Gettelman et al 2012, JGR

Interannual Variations of Temp & H_2O

Temperature and Water Vapor are Coupled



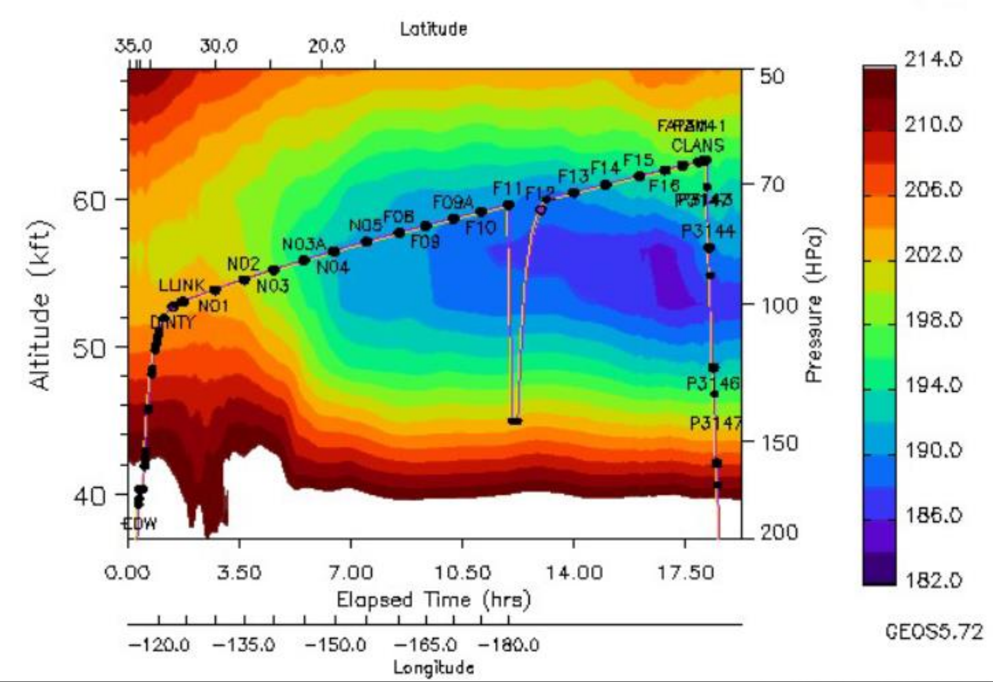
Fueglistaler & Haynes, 2005, JGR, fig2

Summary: Where we are

- Structure of TTL can be reproduced
  - Mean and ‘high frequency’ variability
  - Resolution (Horiz & Vertical) limiting
- Clouds and Dehydration are well simulated
  - Climate and transport effects of convection (okay)
  - Have not discussed transport in detail
- Cirrus clouds ‘okay’
  - Microphysics uncertain in TTL
  - Result: Quantifing Climate effects uncertain
  - Need to better quantify microphysics, indirect effects and feedbacks
- So now what?

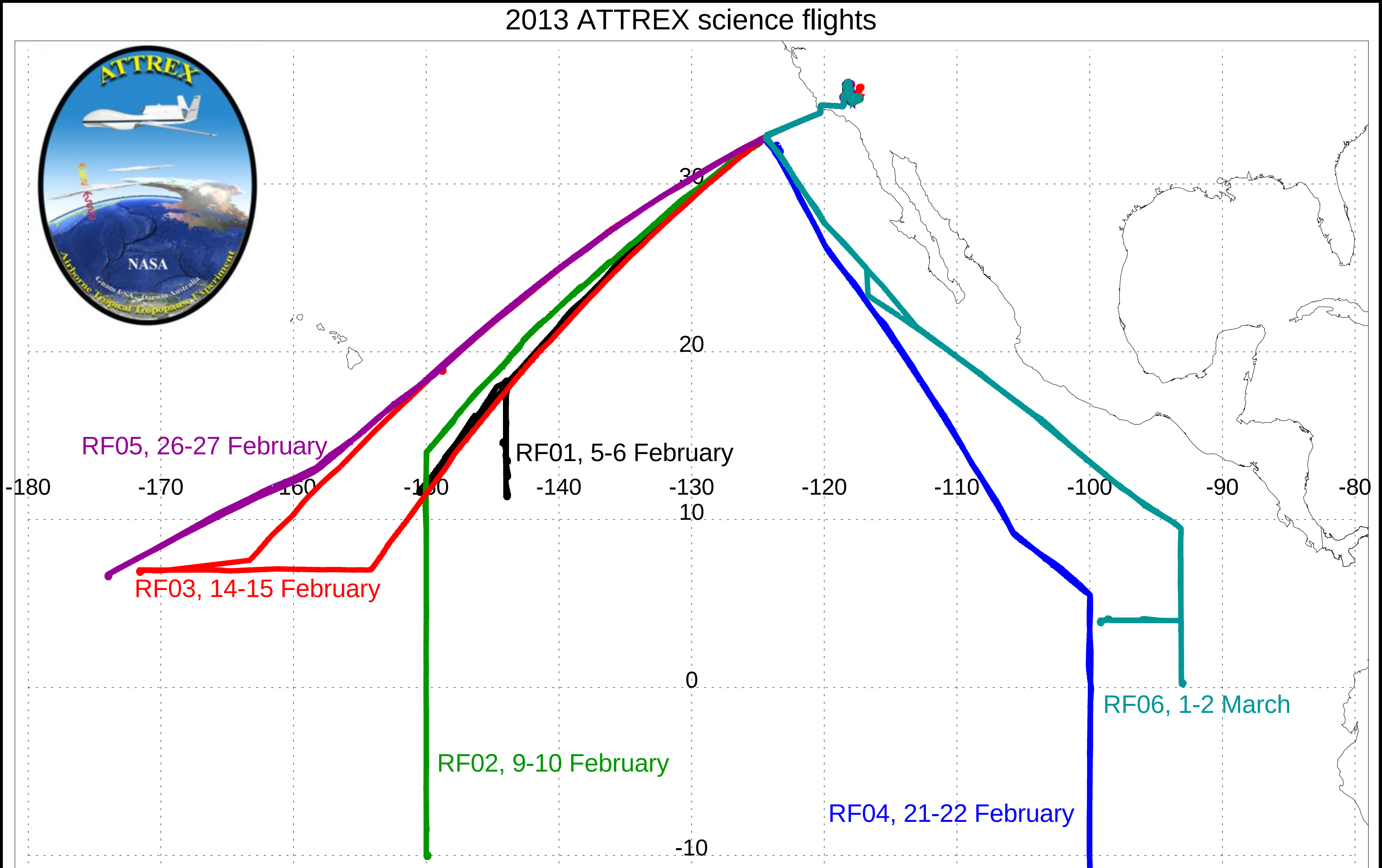
More measurements…

- Really new measurements.
- Current ATTREX flight to Guam



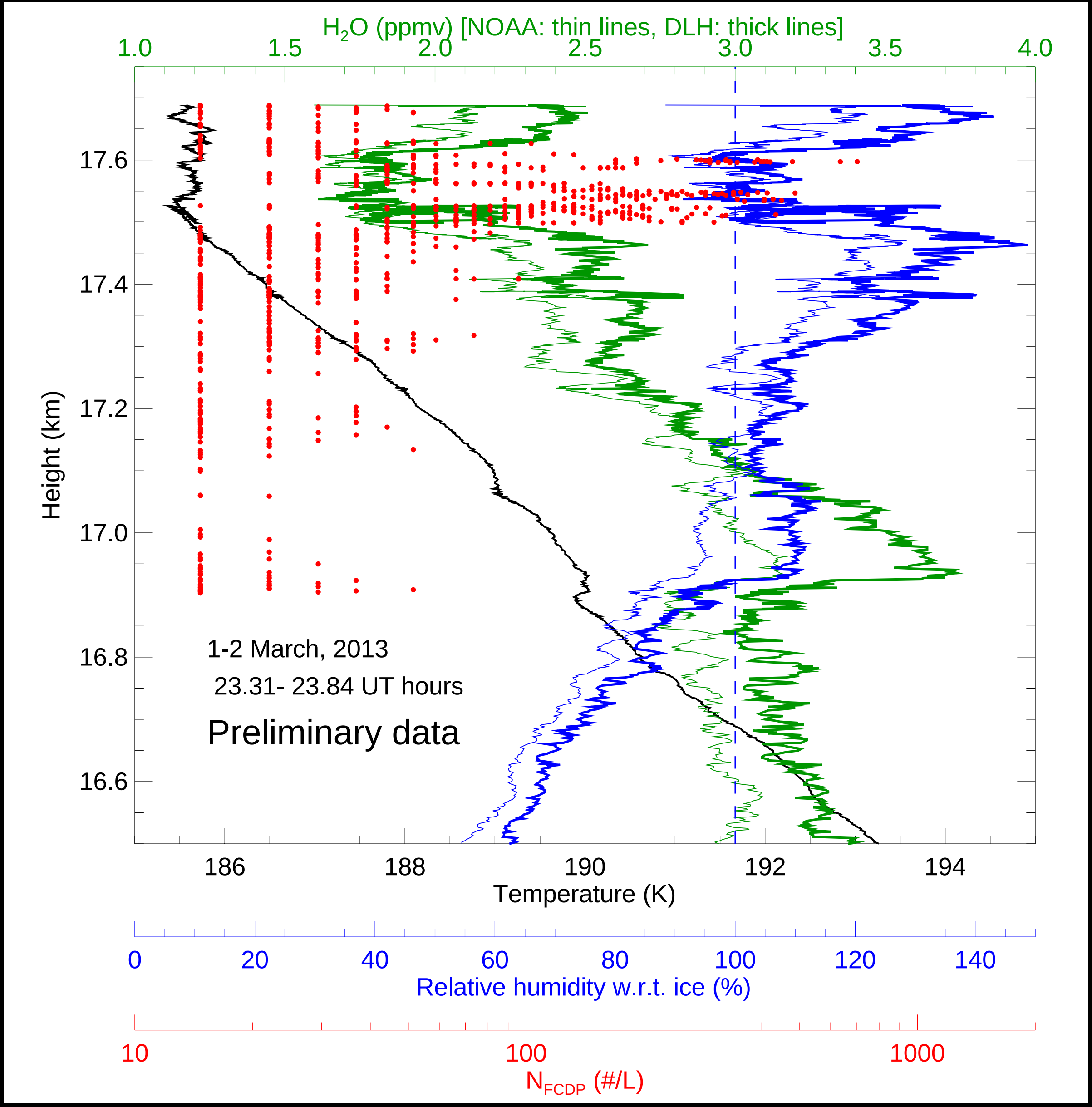
8:45 NZDT

New model analyses: detailed campaign simulations



2013 ATTREX Global Hawk Flights

TTL Cirrus: ATTREX March 2013

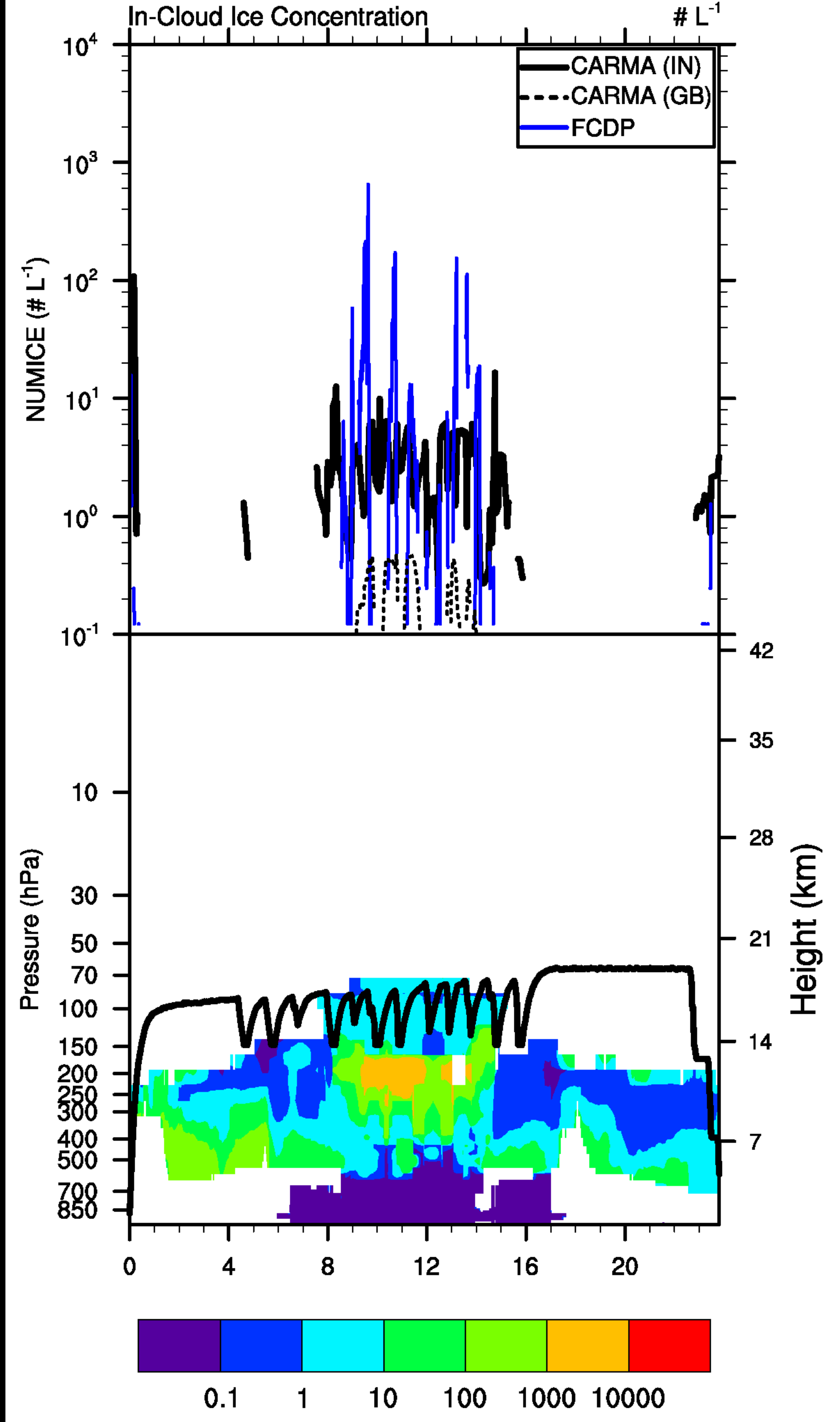


RF06: March 1-2, 2013: Tropical Pacific near the Galapagos

Jensen & Randel 2013

Better Model-Obs Comparisons

- “Fly” Aircraft through a global model
  - Met fields constrained
  - Physics free running
- Compare statistics
- Here: cloud ice concentration
  - ATTREX
  - Two model versions

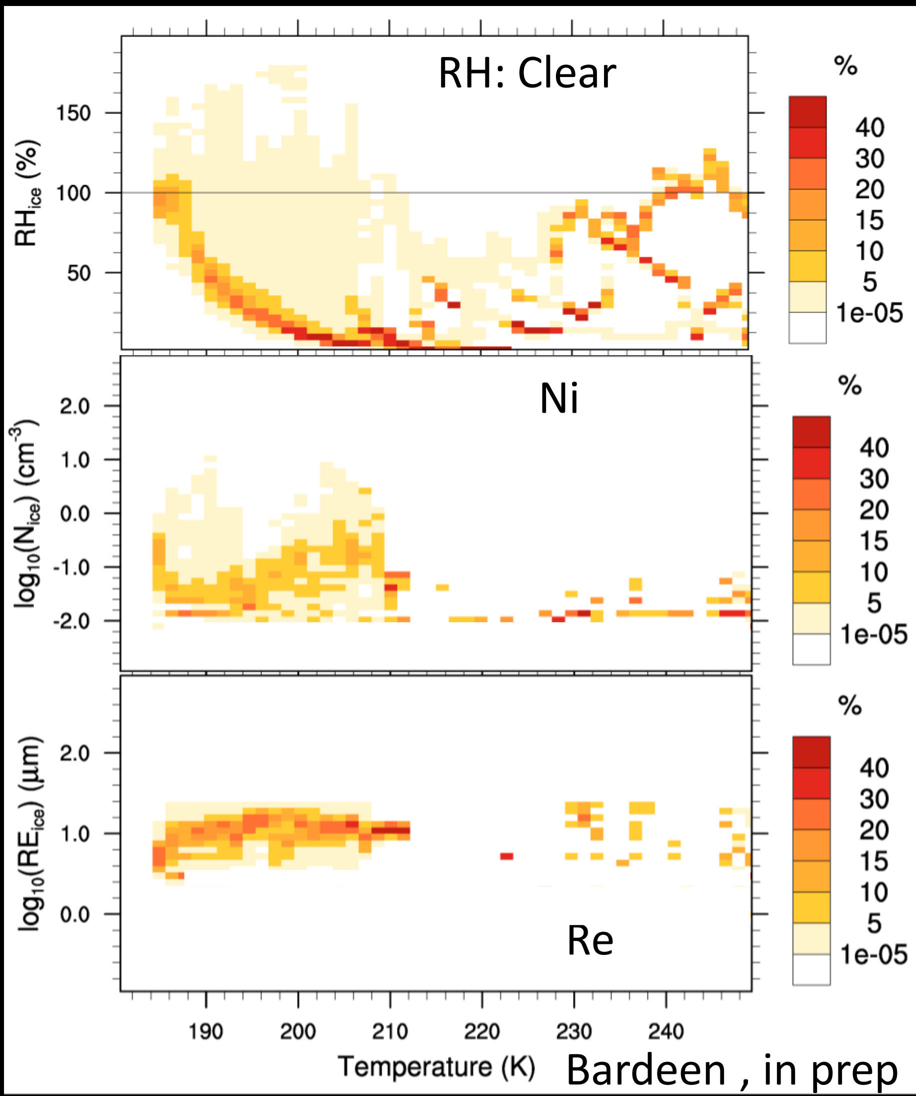


Bardeen, in prep

Simulated TTL Cirrus

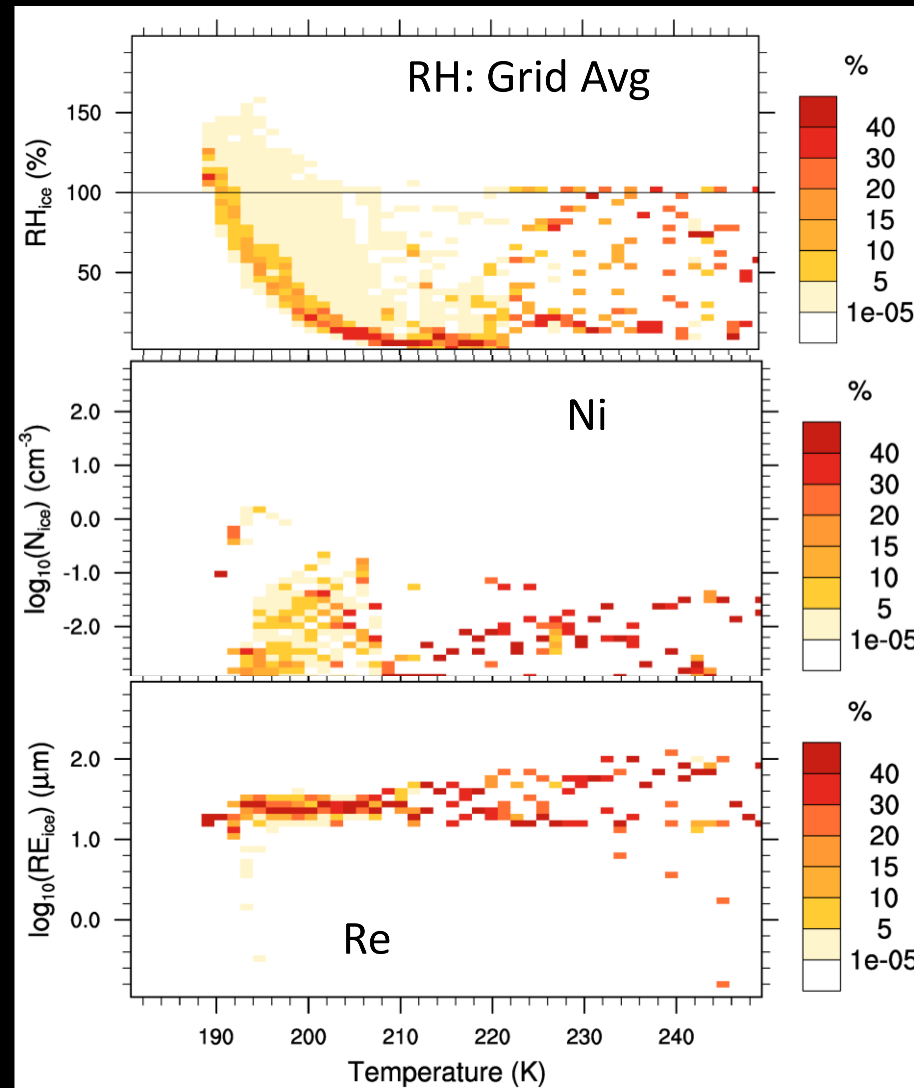
Ice numbers are similar or lower at low T, sizes larger. No high RH at T<190K

OBS: ATTREX 1 & 2



Bardeen , in prep

Model: SD-CAM5



Summary/Conclusions

- Global Models Get TTL structure well
  - Why: processes that govern it well represented
  - Radiation, Bulk Clouds (cirrus)
- Details of cirrus microphysics still uncertain
  - Ice nucleation
  - Can simulate it, but don’t fully understand it
  - Big uncertainties in cloud microphysics: a few Wm^{-2} of forcing.
- Might play into trends?
  - Changing balance of TTL cirrus may matter for climate (lower TTL), stratospheric H_2O (upper TTL),
  - e.g.: Bulk relationship between RH and H_2O above tropopause…change this through ‘efficiency’ of clouds
  - Does the TTL play an active role in tropical ‘broadening’ (shifts in tropopause/jets). Radiative effects of clouds may matter
- Improving models requires new and unique observations
  - Techniques for model evaluation and improvement can take better advantage of measurements