Ice Microphysical Changes in WACCM6 and CAM6

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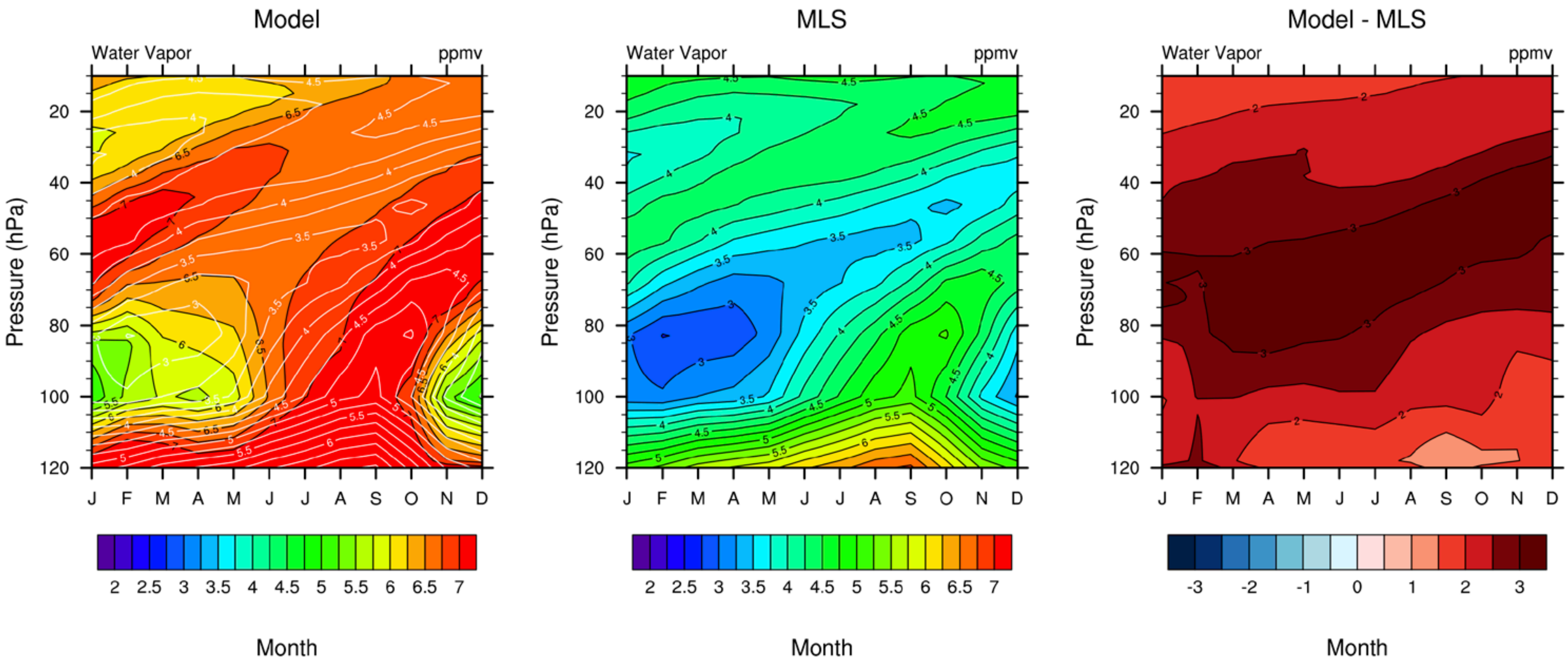
SD-WACCM5.5 did not look good

SD-WACCM5.5 (Control) : EQ, H_2O

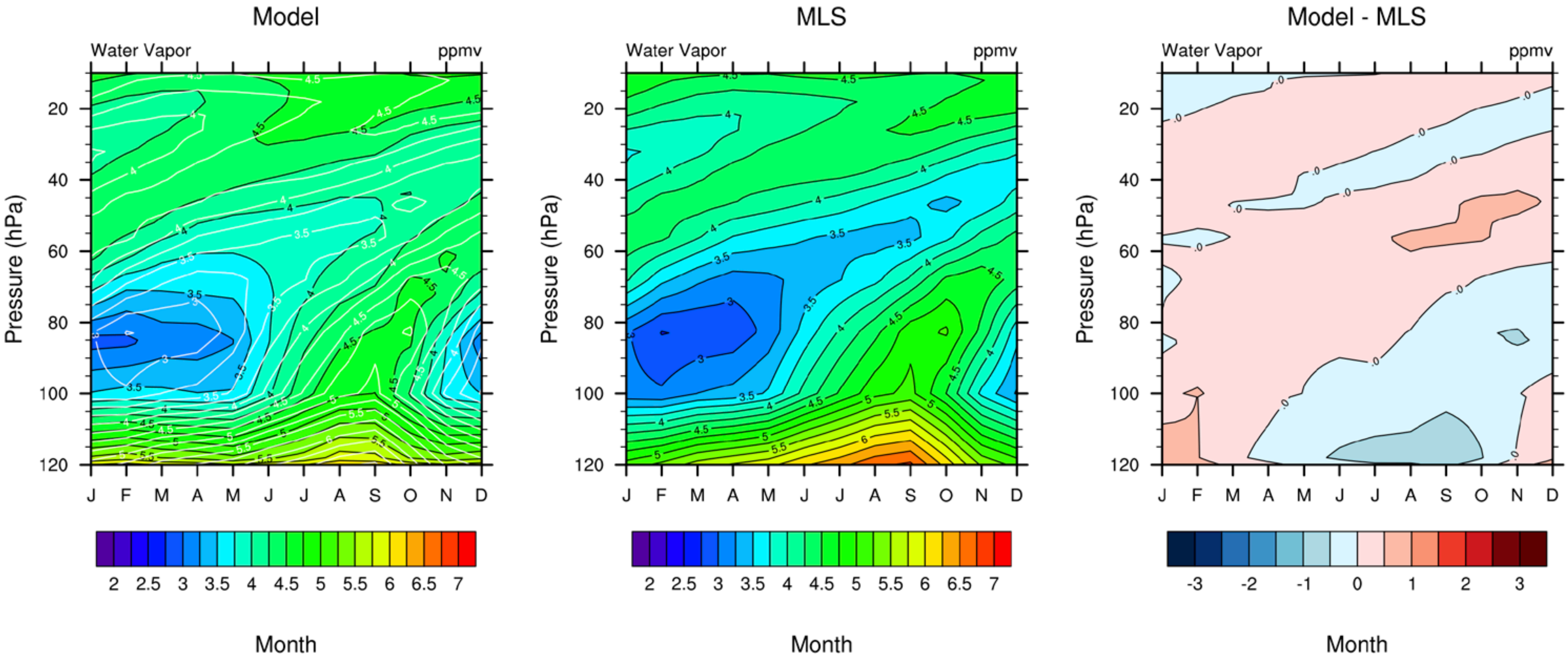


Too wet (+ 3 ppmv)

Free Running and Specified Dynamics are different

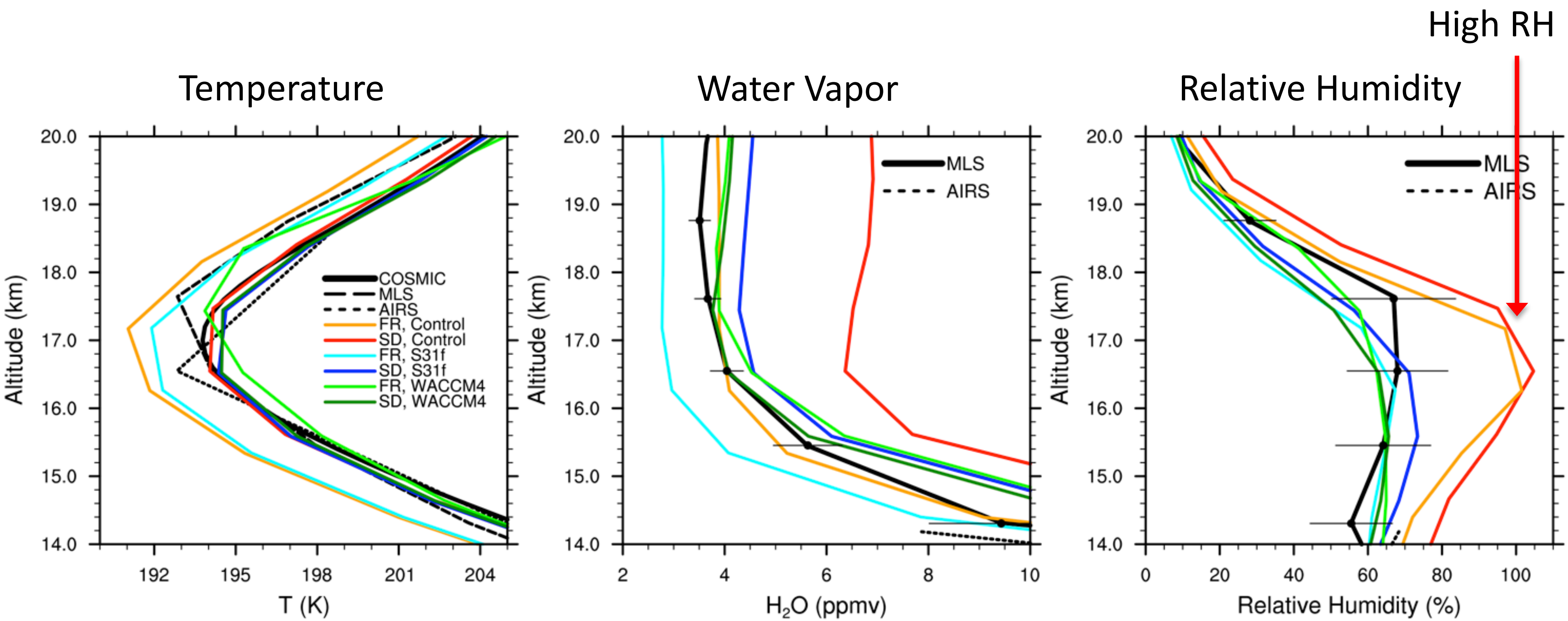
WACCM4 has good UTLS water vapor

SD-WACCM4 (REFC1) : EQ, H_2O



Free Running and Specified Dynamics are similar

High Relative Humidity in WACCM5.5



FR-Control SD-Control FR-Modified SD-Modified FR-WACCM4 SD-WACCM4

Wide range of water vapor values

CESM5.5 FR models (FR-Control, FR-Modified) are cold, different behavior in FR and SD

CESM5.5 Control models (FR-Control, SD-Control) have high RH

FR & SD-WACCM4 have better T, more consistent FR & SD

SD-Modified has RH and H_2O like WACCM4

Need Subgrid-scale Growth

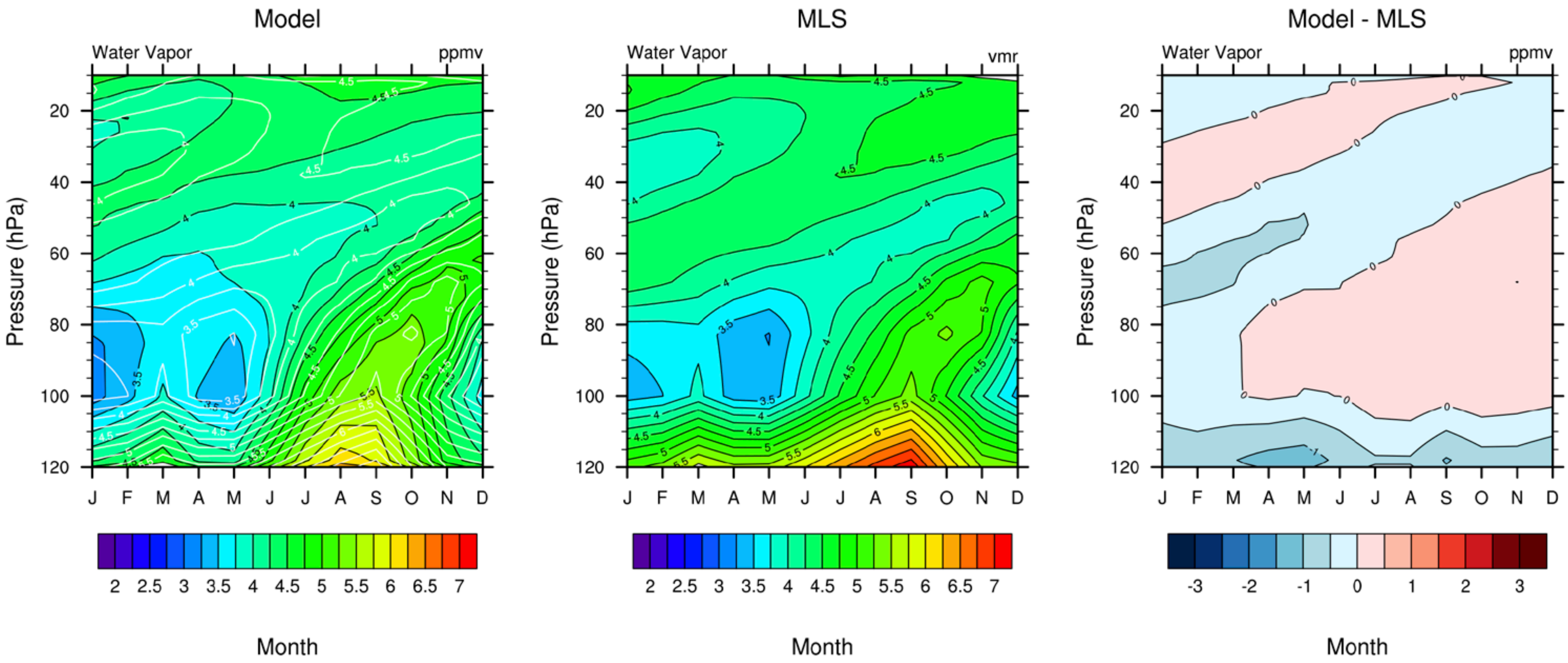
- Problem #1: Subgrid variability not handled for ice clouds. Growth was using gridbox average RH even when cloud fraction < 1.

- Solution: Introduce a subgrid-scale factor that adjusts the water vapor saturation used for growth based upon cloud fraction:
  - Respect subgrid ice cloud parameters during ice growth
    - AIST, RHMINI, RHMAXI
  - Introduce QSATFAC (water vapor saturation factor) to MG microphysics to indicate the saturation to use for growth
    - QSATFAC = (1 - AIST) x RHMINI + AIST x RHMAXI
    - Qsat,eff = QSATFAC x Qsat
    - Supersaturation = 1 / QSATFAC

- Also had some issues with CLUBB:
  - RHliq > 1
  - Energy fixer was dehydrating the stratosphere

Water vapor is much improved

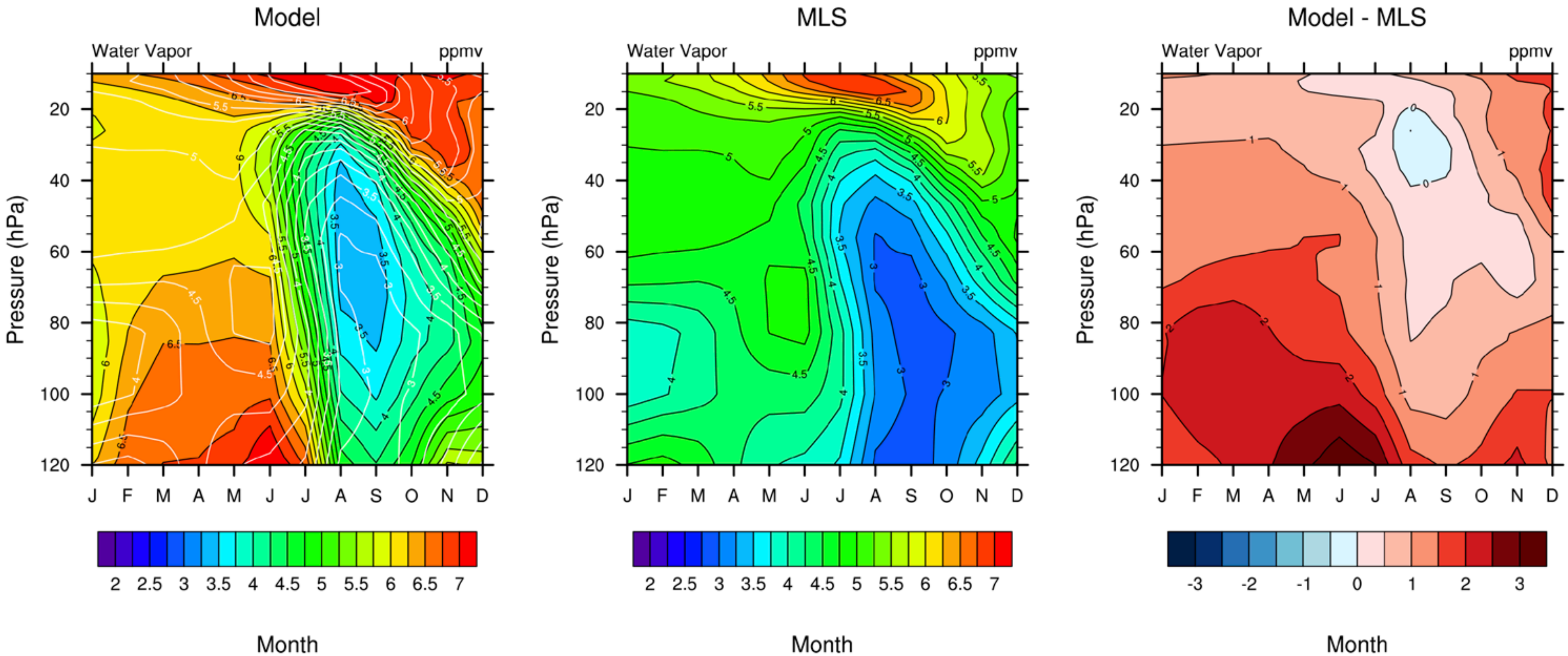
SD-WACCM6 : 2011, EQ, H_2O



NOTE: Includes all changes not just QSATFAC

SD-WACCM5.5 SP was also too wet

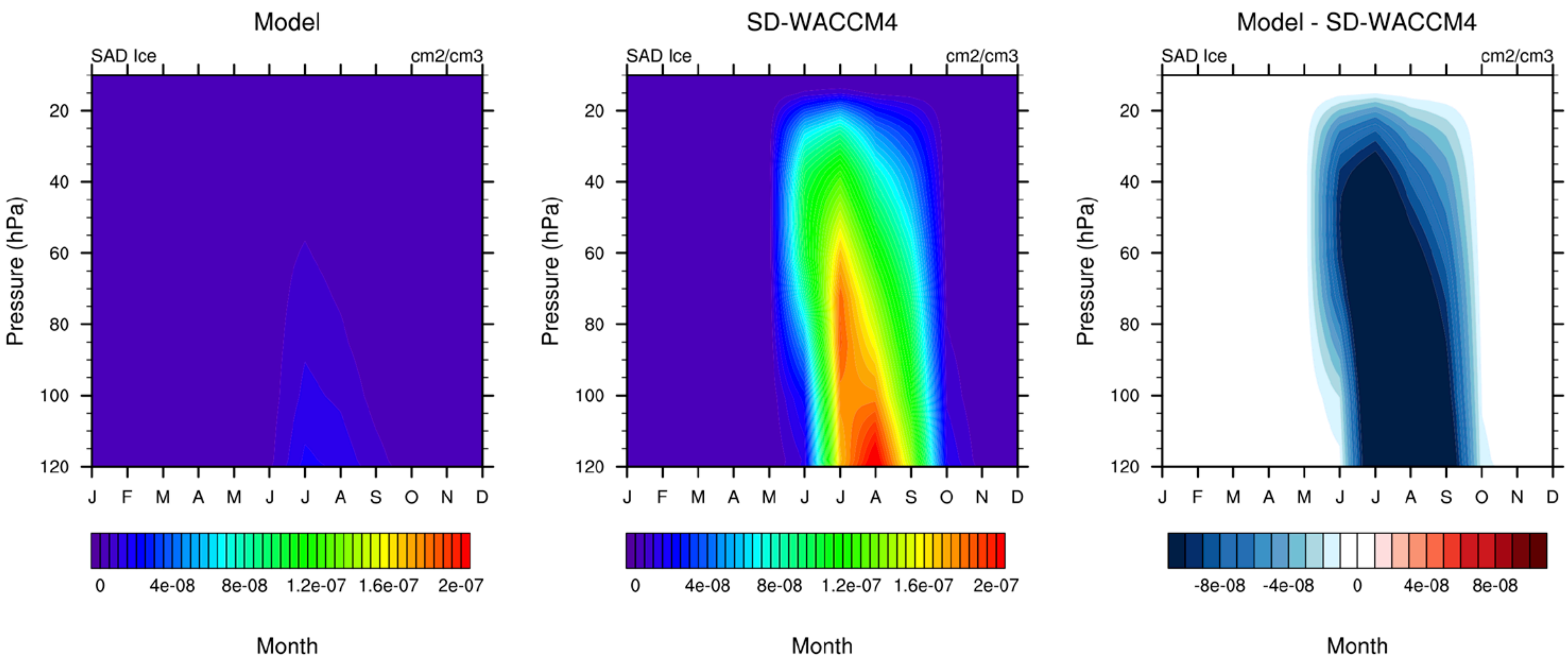
SD-WACCM5.5 (Control) : SP, H_2O



Some winter dehydration

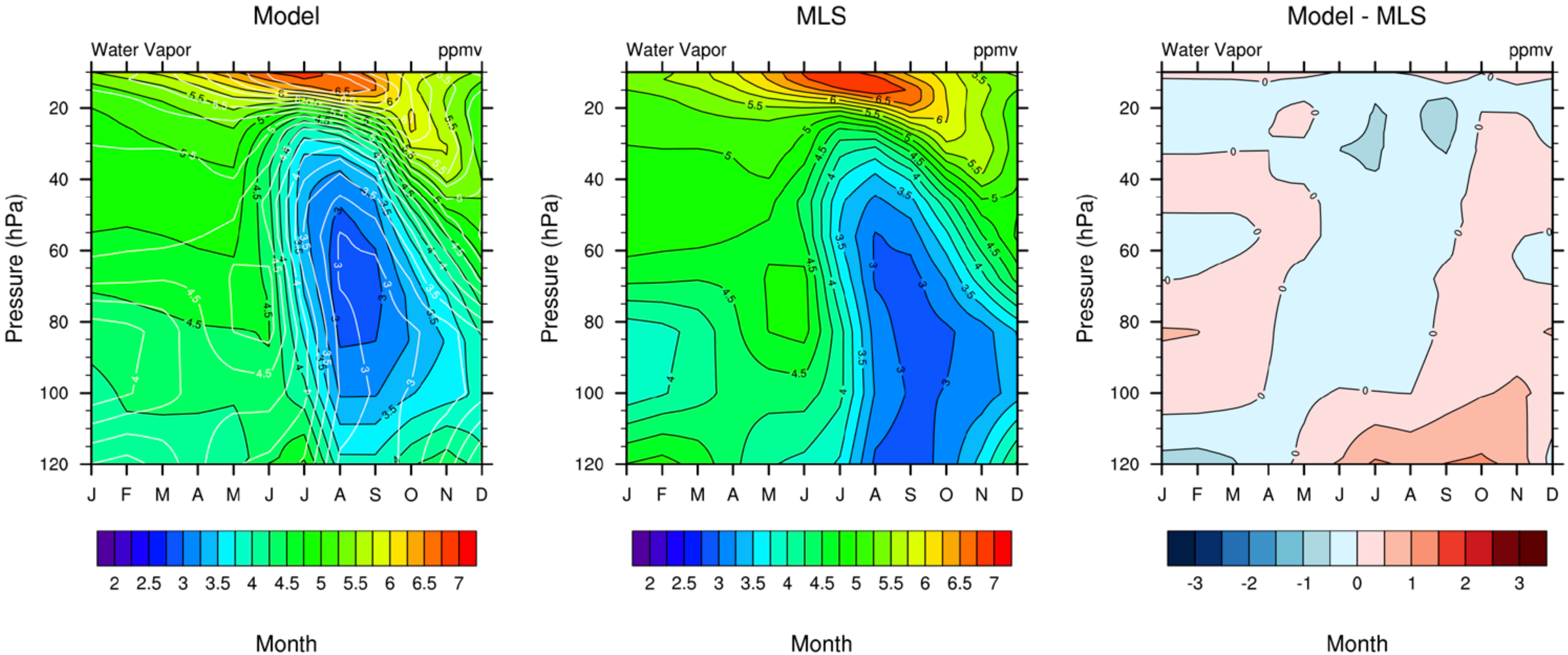
… but has very little PSC ice surface area

SD-WACCM5.5 (Control) : SP, SAD_ICE



Too small by factor of 10
Particles too large?
Not enough nucleation?

WACCM4 has good SP H2O & dehydration

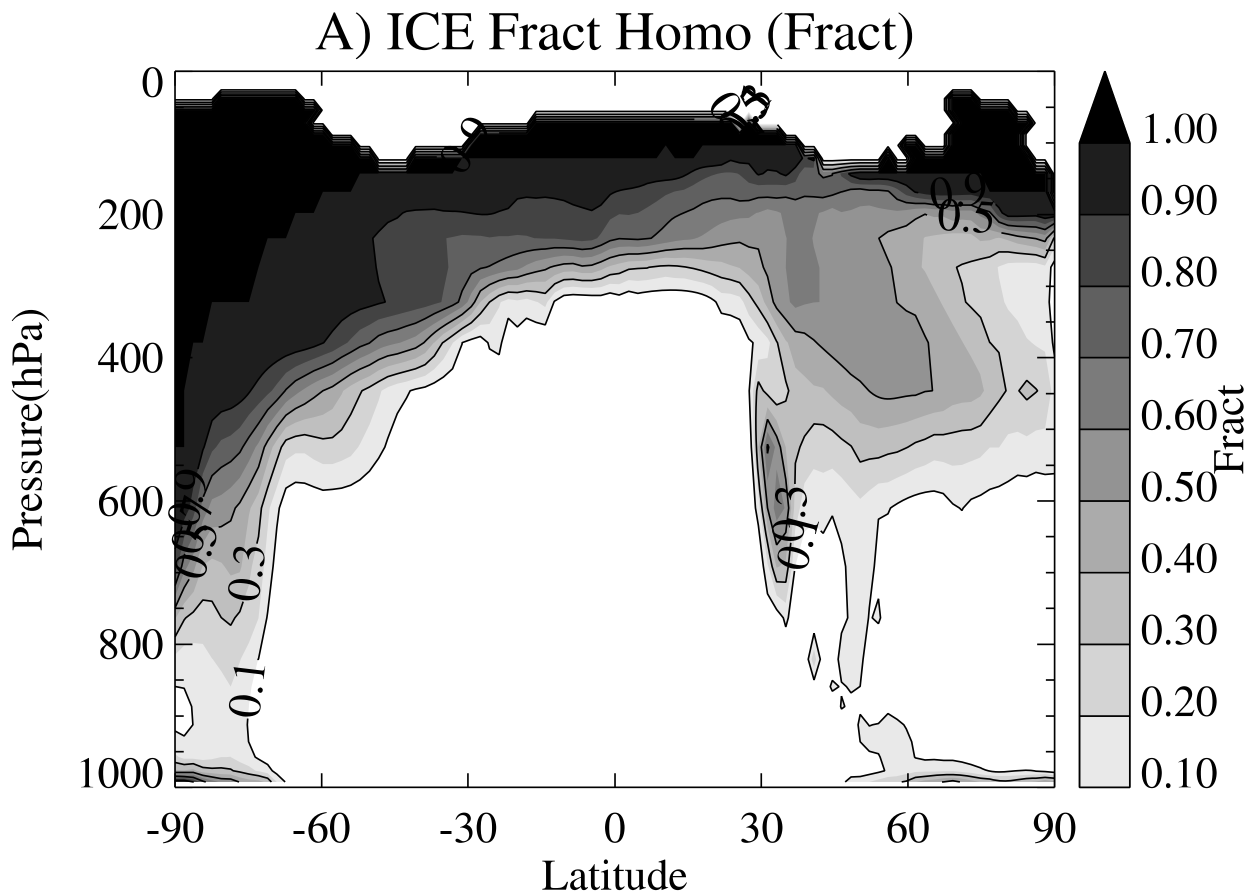


Want more nucleation and smaller ice particles in the stratosphere

- Problem #2: Not enough ice forming. Too few ice particles that are too big and sediment too fast.

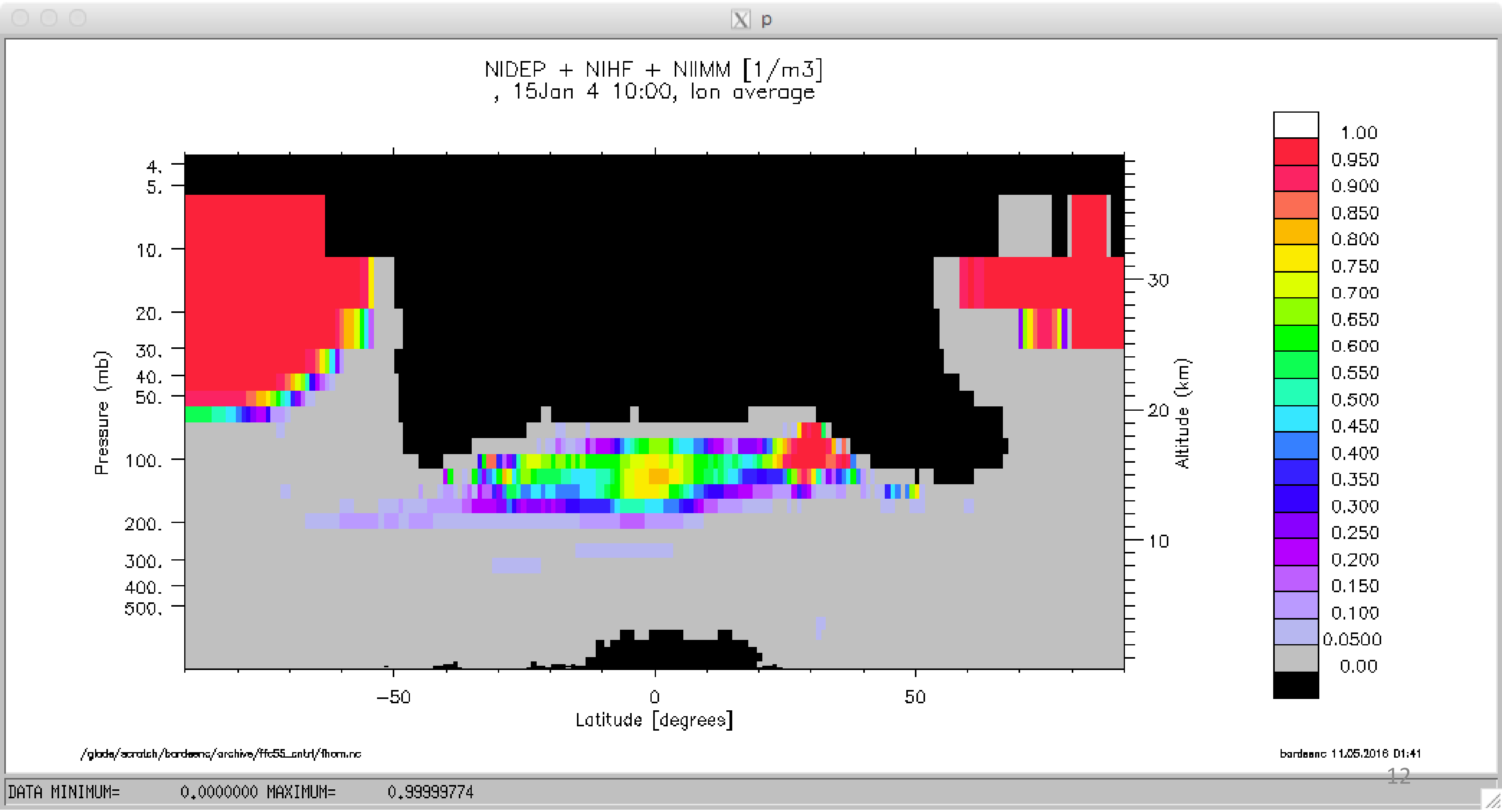
- Solutions:
  - Support smaller particles
    - Change minimum ice particle size to 1 μm from 10 μm
    - Use Stokes fall velocity assuming bulk ice density for small ice particles (r < 20 μm)
  - Increase ice nucleation
    - Freshly nucleated particles start at 1 μm
    - Use corrected coarse dust fraction for heterogeneous nucleation
    - Move IN to cloudbourne during heterogenous nucleation
    - Don’t assume nucleation happens only in-cloud (i.e. don’t assume RH=1)
  - Include accumulation and coarse mode sulfates for nucleation in the polar stratosphere
  - Use different macrophysics settings in the stratosphere
    - RHMINI = 1

Fraction Homogeneous Freezing FR-CAM5.1



[Gettelman et al., 2010]

Fraction Homogeneous Freezing NIHF/(NIDEP+NIHF+NIMM) FR-CAM5.5 (Control)



Nucleation #1: Determination of IN

- Heterogeneous nucleation is assumed to be using dust fraction of coarse mode:
  - IN = Mdust/(Mdust+Mseasalt)*Ncoarse
- However, this neglects coarse sulfates, so should have been:
  - IN = Mdust/(Mdust+Mseasalt+Msulfate)*Ncoarse
- Since Msulfate > Mdust > Mseasalt in the UTLS, this resulted in very high IN values when they should have been very low

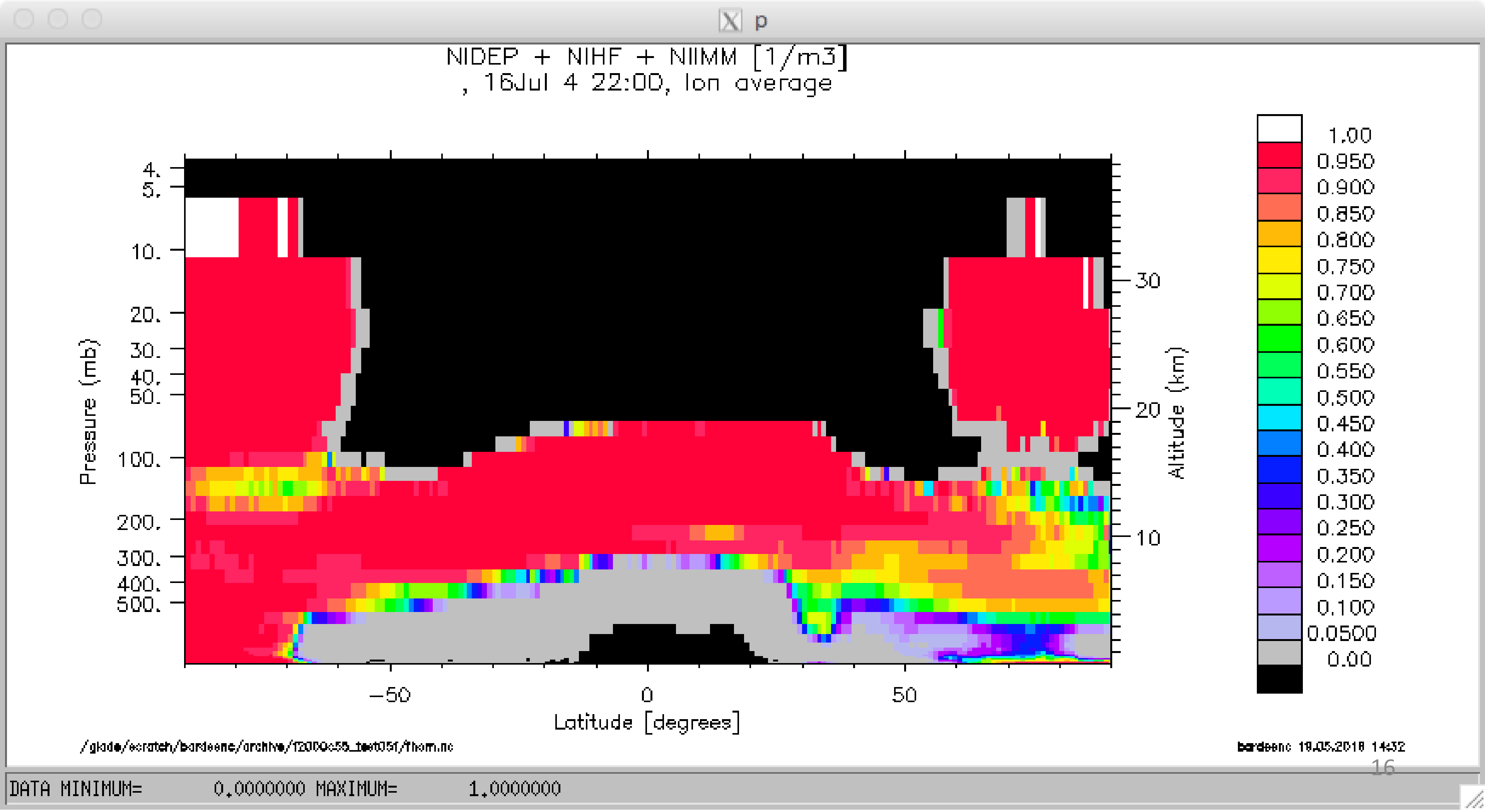
Nucleation #2: Pre-existing Ice

- WACCM6 uses “pre-existing ice”, meaning that the ice concentration includes all previously nucleated ice particles, so nucleation is for new ice particles.
- Heterogeneous IN are scarce and should be used up (moved to cloudbourne) when nucleation happens, but this was only implemented for liquid clouds and thus the same IN were available the next timestep.
- This also had a side effect that if droplets froze, the CCN would be released and would not remain in the ice.
- Implemented moving coarse dust IN from interstitial to cloudbourne after heterogeneous nucleation, which reduces the amount of heterogeneous nucleation.

Nucleation #3: Homogeneous Fraction

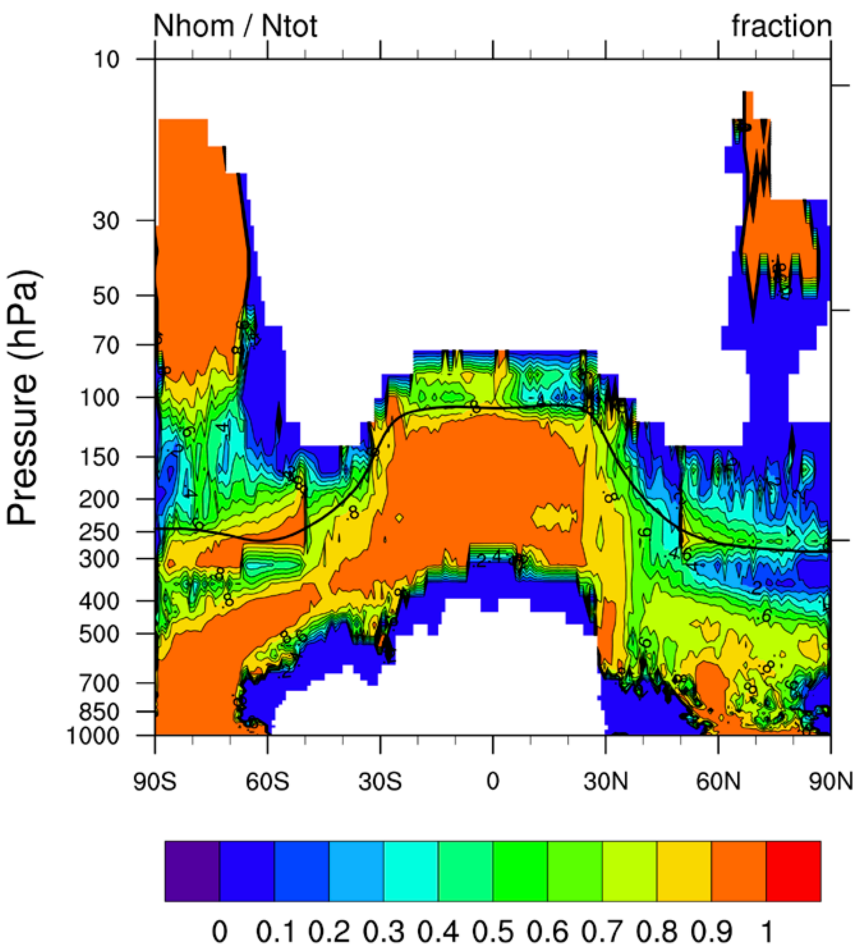
- Nucleation code uses a water vapor PDF to determine the fraction of the grid box that has saturation high enough for homogeneous freezing
- Assumed nucleation only happens in-cloud, and thus assumed RH = 1
- This drastically limited homogeneous freezing in the stratosphere where w is small. Changed to use gridbox average RH for determination of homogenous fraction.

Fraction Homogeneous Freezing NIHF/(NIDEP+NIHF+NIMM) FR-CAM5.5 (Modified)

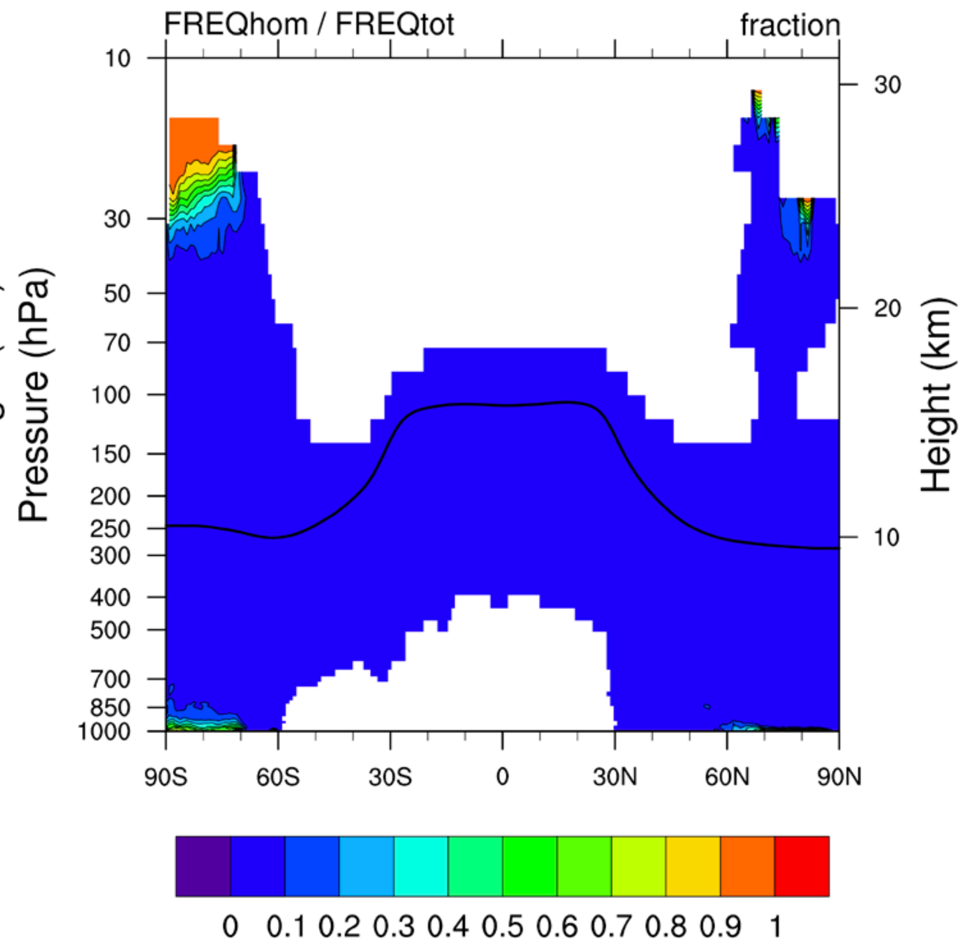


Nucleation in modified SD-WACCM5.5

By Concentration



By Nucleation Events



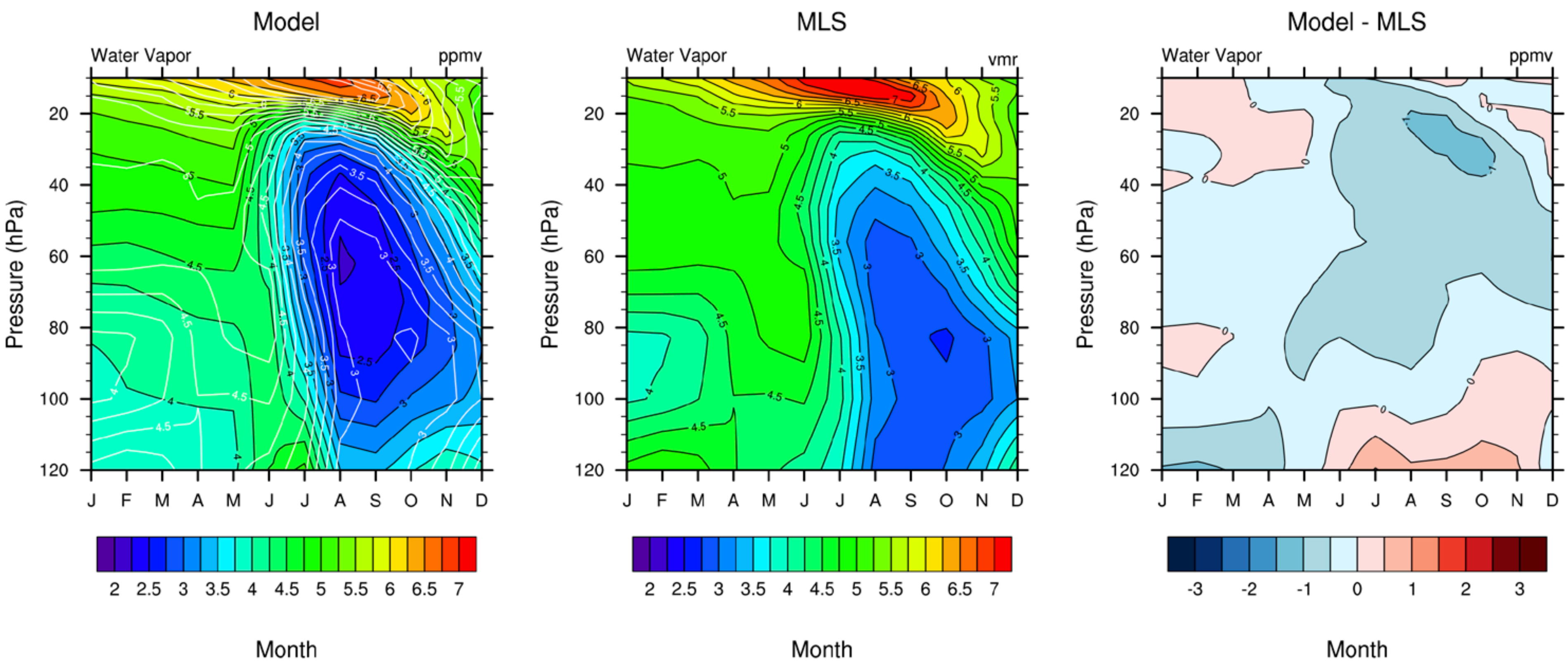
Most ice particles from homogeneous freezing, but …

heterogeneous nucleation happens more often

NOTE: FREQ based on Nhom > 1/L or Nhet > 1e-3/L

Polar dehydration is reasonable

SD-WACCM6 : 2011, SP, H_2O

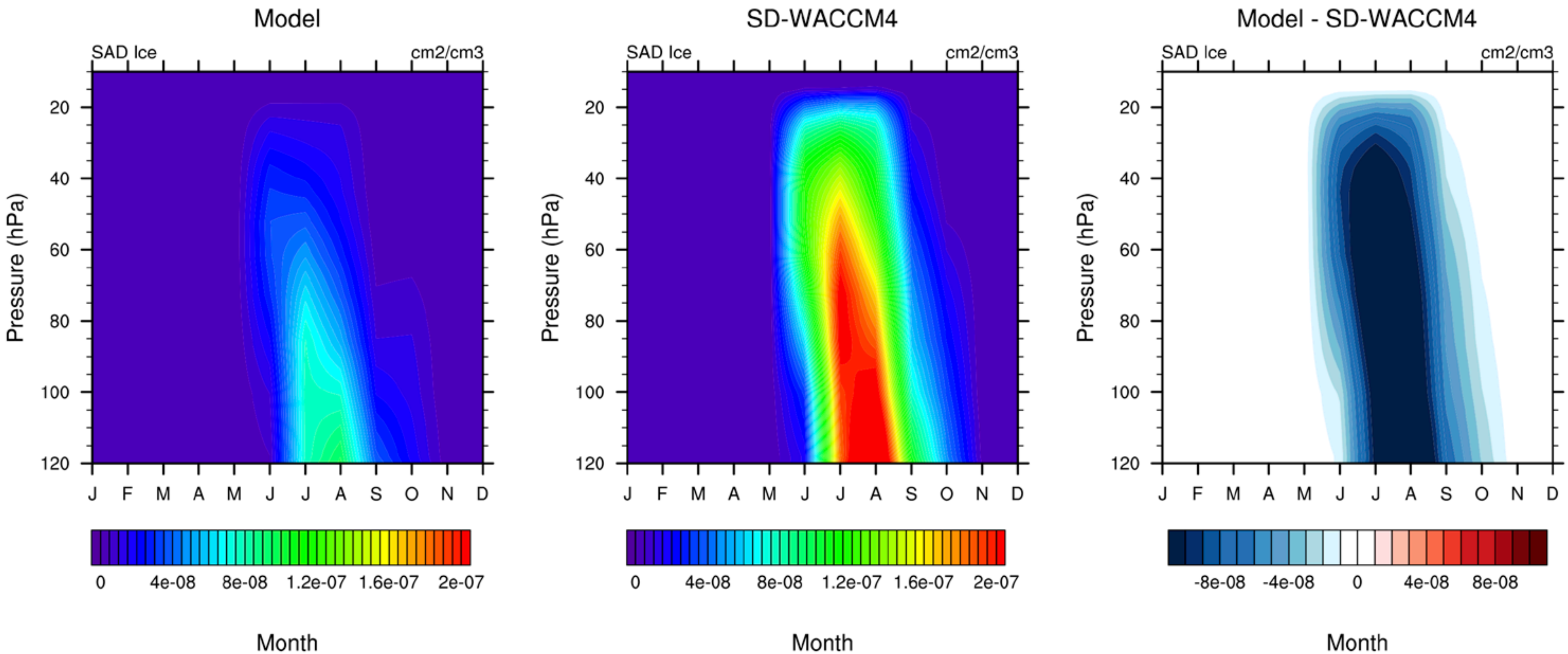


Much improved

A little bit too much winter dehydration, but IC may have been dry

PSC ice is improved, but still low

SD-WACCM6 : 2011, SP, SAD_ICE



Smaller by factor of 2-3, but improved over Control
However, may be too large in SD-WACCM4

Conclusions

- Changes to the CESM ice microphysics have improved stratospheric H_2O and SAD_ICE in SD-WACCM6 and WACCM6.
- Stratospheric water vapor in SD-WACCM6 is now similar to SD-WACCM4.
- Polar SAD_ICE is not well constrained, so smaller values in SD-WACCM6 may actually be better than those in SD-WACCM4. SD-WACCM6 is similar to new PSC modeling results by Zhu.

Cloud Changes

New Features
Tuning
WACCM and CAM-chem tropstrat Only
Not part of this update/optional/bugfix

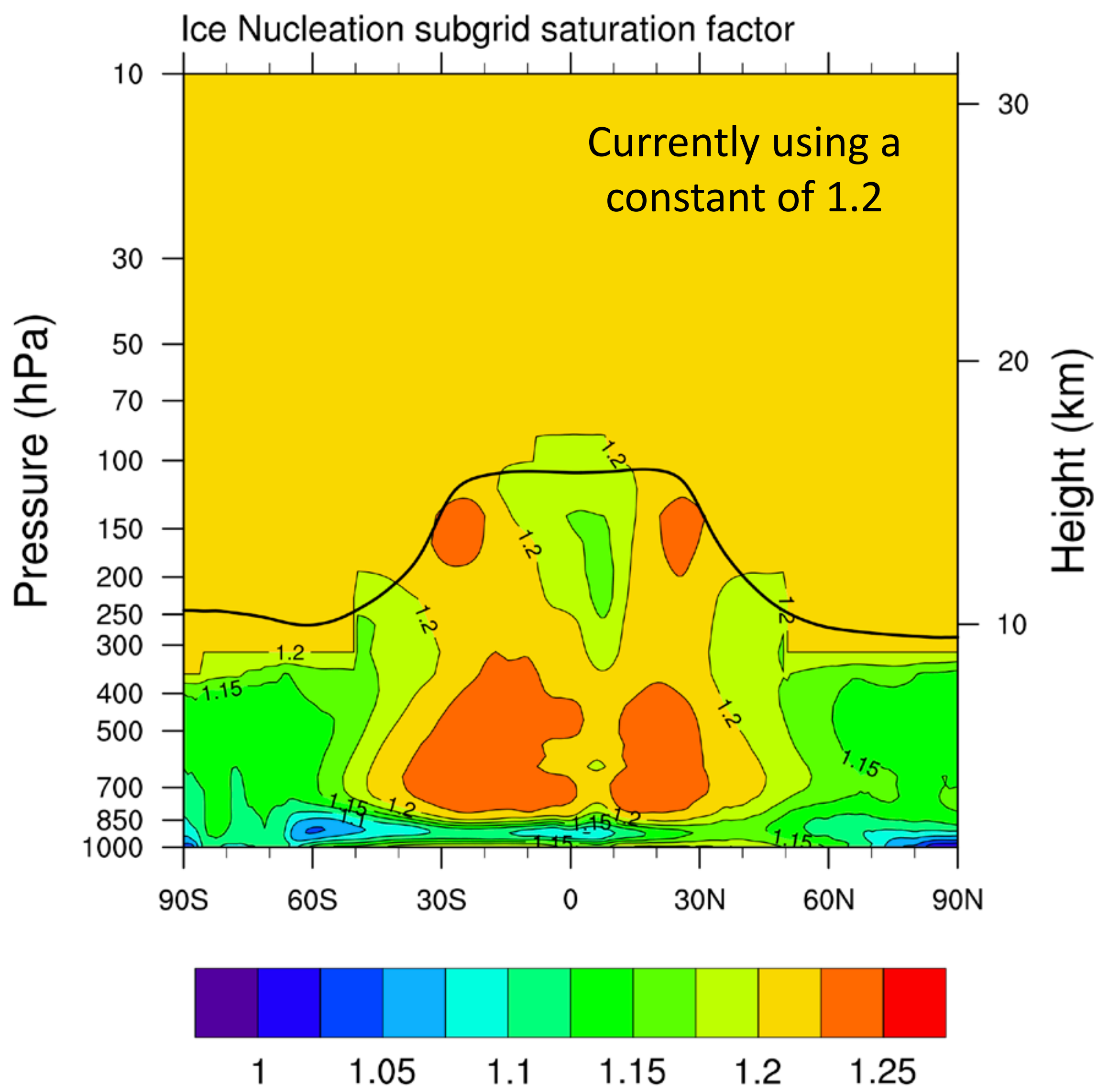
- General
  - Changed ice_macro_tend and micro_do_icesupersat to just remove RHliq > 1, but also disabled it by default and moved the call to inside CLUBB only. [in CLUBB now, disabled]
  - Lowered minimum wsubi back to 0.001 m/s [Tuning]
  - Included snow in SAD_ICE calculation [WACCM-Only]
  - Added calculation of alternate MG_SADICE and MG_SADSNOW from MG size distributions [optional, not used now]
- Ice Microphysics
  - Added subgrid growth of ice clouds starting at rhmini rather than 1.0 [New, Tuning, cldfrc2m_rhmini]
  - Decreased minimum ice size to 1 um from 10 um [Tuning]
  - Changed size of freshly nucleated ice particle to 1 um from 10 um [Tuning]
  - Modified fall velocity for small ice particles (< 20 um) with more appropriate power law expression [New]
  - Added RHMINI and RHMAXI settings for the stratosphere [New, Tuning, cldfrc2m_rhminis, cldfrc2m_rhmaxis]
- Ice Nucleation
  - Fixed bug with how dust fraction of coarse mode was calculated (was ignoring sulfates) [bugfix]
  - Moved coarse dust aerosol from interstitial to cloudbourne upon heterogeneous nucleation [New]
  - Modified dropmixnuc to only move all cloudbourne aerosol back to interstitial if all cloud is gone (not just loss of all liquid cloud) [New]
  - Added transfer of cloudbourne aerosol back to interstitial based upon reduction in ice cloud fraction without regeneration [New]
  - Assumed heterogeneous nucleation can also happen when there is homogeneous freezing [New]
  - Changed ice nucleation from in-cloud to gridbox average, (using gridbox average RH) [New, Tuning, use_incloud_nuc]
  - Added flag to use subgrid growth factor for nucleation supersaturation rather that a fixed 1.2 [optional, not used now, nucleate_ice_subgrid, nucleate_ice_subgrid_strat]
  - Added subgrid supersaturation setting for stratosphere [optional, Tuning, nucleate_ice_subgrid_strat]
  - Included a fraction of accumulation and coarse mode stratospheric sulfates as IN in the stratosphere [New, Tuning, nucleate_ice_strat]

Backup Slides

Issues Identified, But Not Resolved

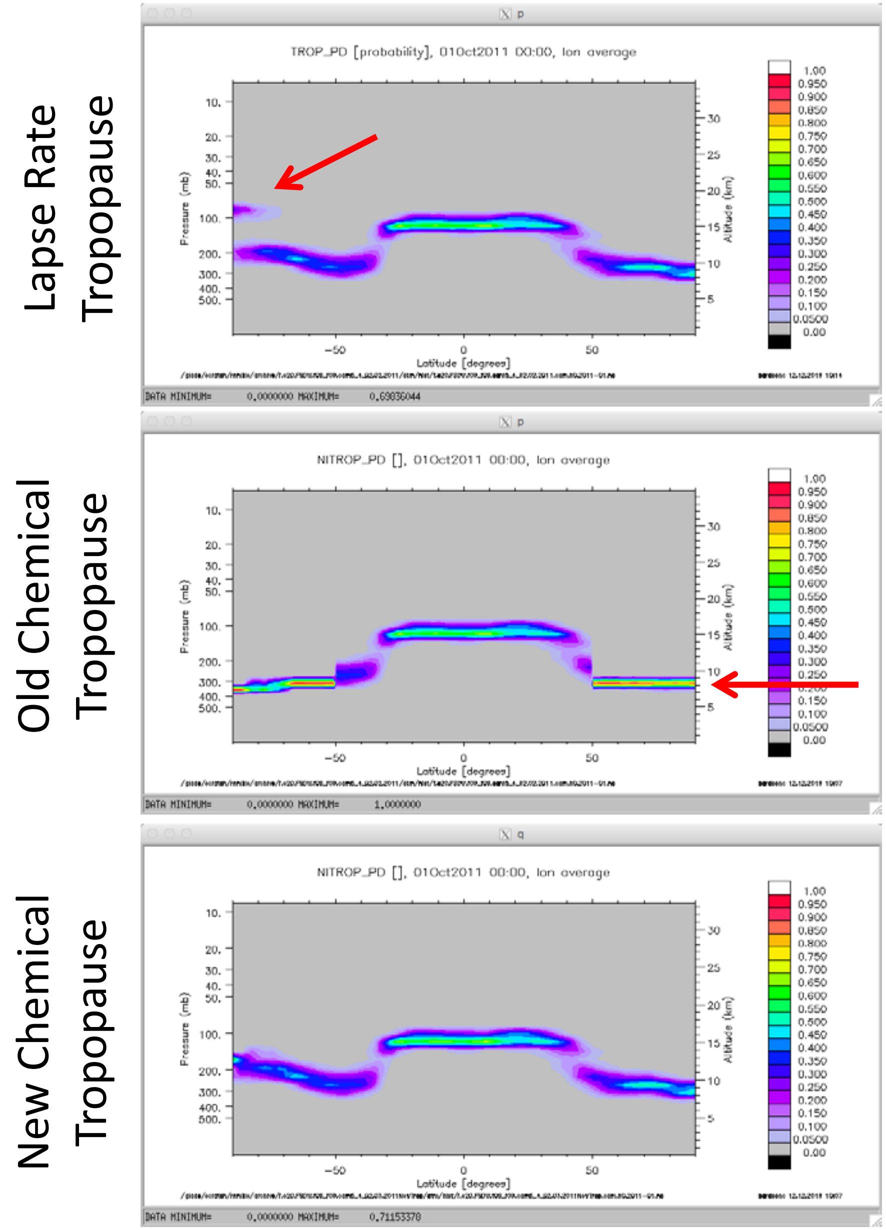
- Homogeneous freezing needs to become aware of aerosol modes
  - nucleates from Aitken mode only
  - sulfate aerosols are not moved to cloudbourne after nucleation
- Need improved nucleation parameterization for Type II (ice) PSCs (e.g. learn from CARMA PSC model by Zhu)
- Need ammoniated sulfates rather than using the diagnosed “chemical” tropopause to differentiate stratospheric and tropospheric aerosols
- Nucleation assumes constant subgrid saturation factor of 1.2, and is not linked to supersaturation assumed in growth (coded, but disabled).
- Size distributions of small particles might be better represented if the shape parameter (μ) were not 0 for ice.
  - $N(D) = N_0 D^{\mu} e^{-\lambda D}$ D=diameter, N_0=intercept parameter, λ=slope parameter
- Could shift to a PDF based or other more sophisticated approach for determining and/or implementing subgrid variability of ice in the future.

Subgrid Saturation Using QSATFAC

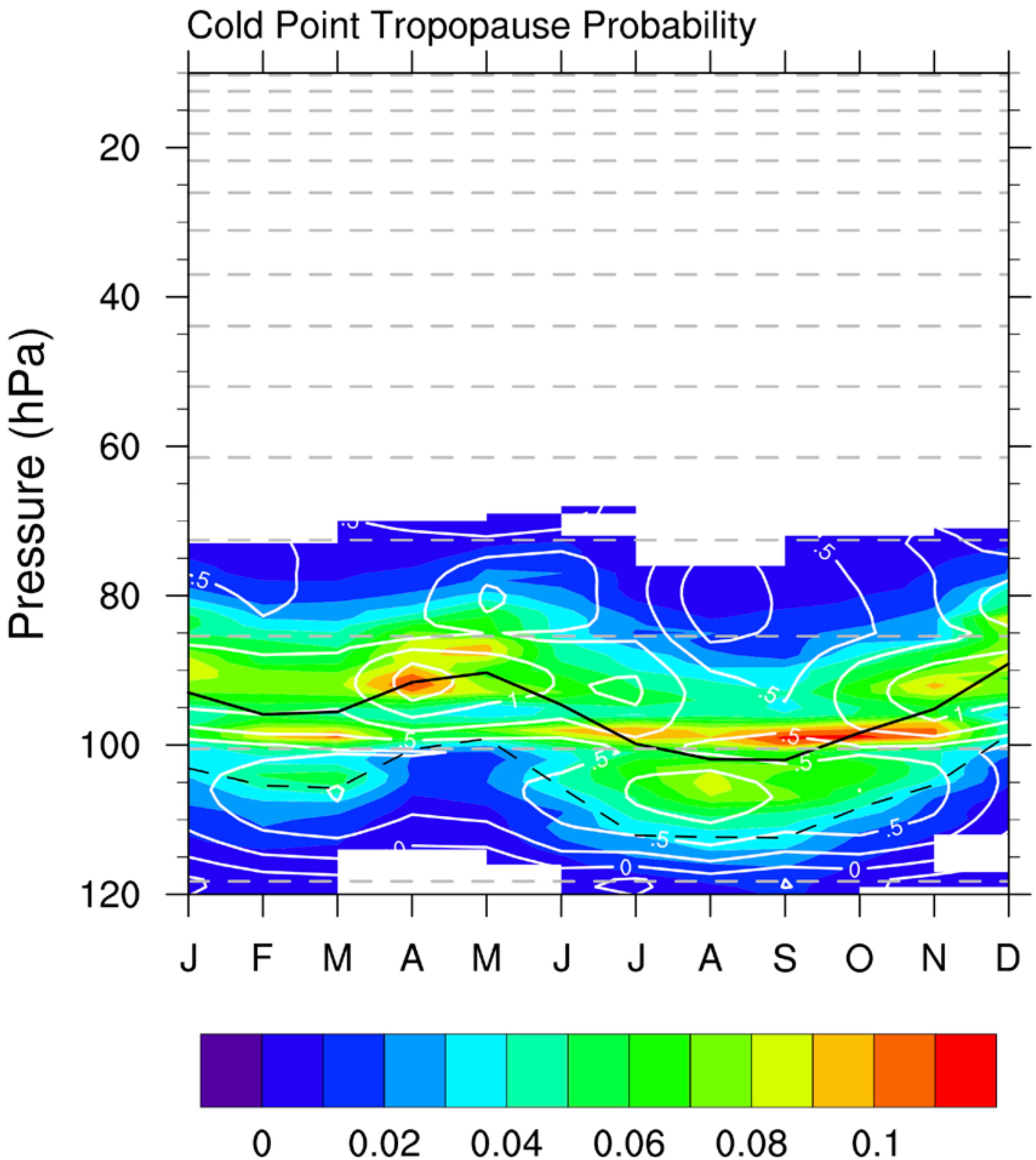


Change in Chemical Tropopause

- Determines when in the stratosphere for aerosols, heterogeneous chemistry, and clouds
- Was 300 hPa, lat > 50˚
- Now use climatology if P < 125 hPa, lat > 50˚
- More physical definition
- Still improves ozone compared to lapse rate
- Can respond somewhat to climate change



Not enough models levels for CPT



- CPT often near 100 hPa model level
- Shifts +½ model level in April, May, November, December and January leading to low RH
- Shifts -½ model level in August leading to high H_2O
- Causes ~1 K error at CPT