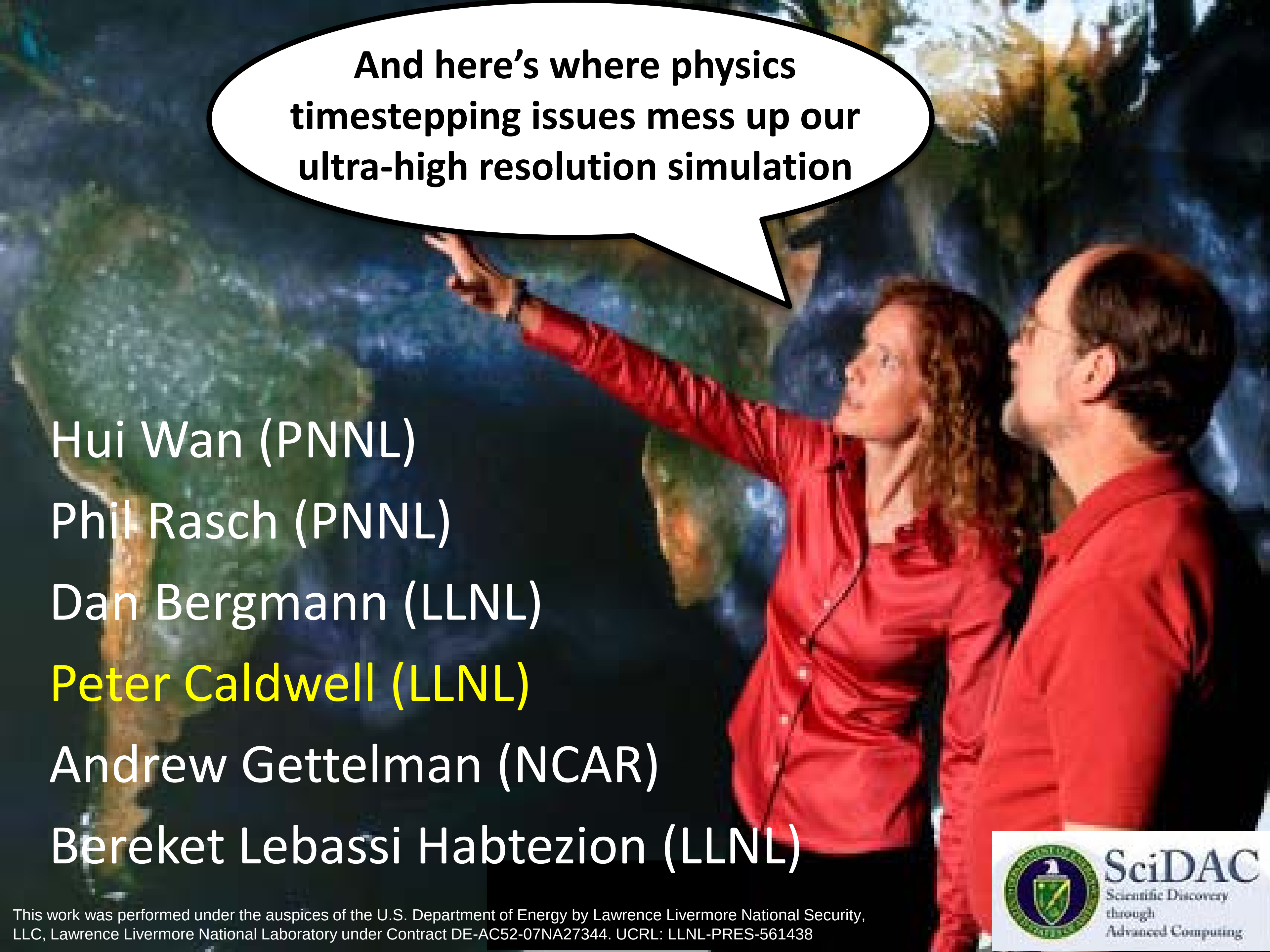

And here's where physics timestepping issues mess up our ultra-high resolution simulation

Hui Wan (PNNL)

Phil Rasch (PNNL)

Dan Bergmann (LLNL)

Peter Caldwell (LLNL)

Andrew Gettelman (NCAR)

Bereket Lebassi Habtezion (LLNL)

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SciDAC
Scientific Discovery through Advanced Computing

Regional climate forecasting requires finer resolution… which often degrades model skill!

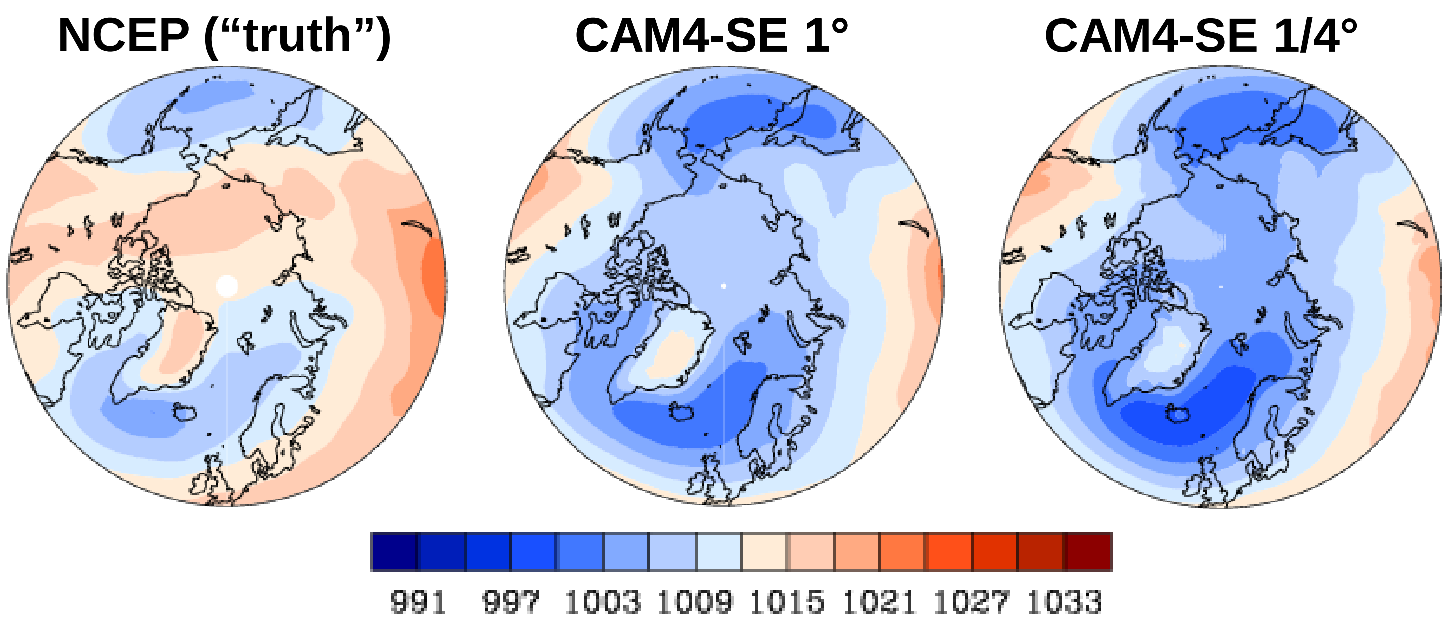


Fig: Sea-level pressure (in mb) from CAM4 runs @ coarser and finer resolution. Courtesy Mark Taylor

Horizontal scale sensitivity of parameterized physics is often demonized… but perhaps the associated timestep decrease is to blame?

Evidence of Timestep Sensitivity

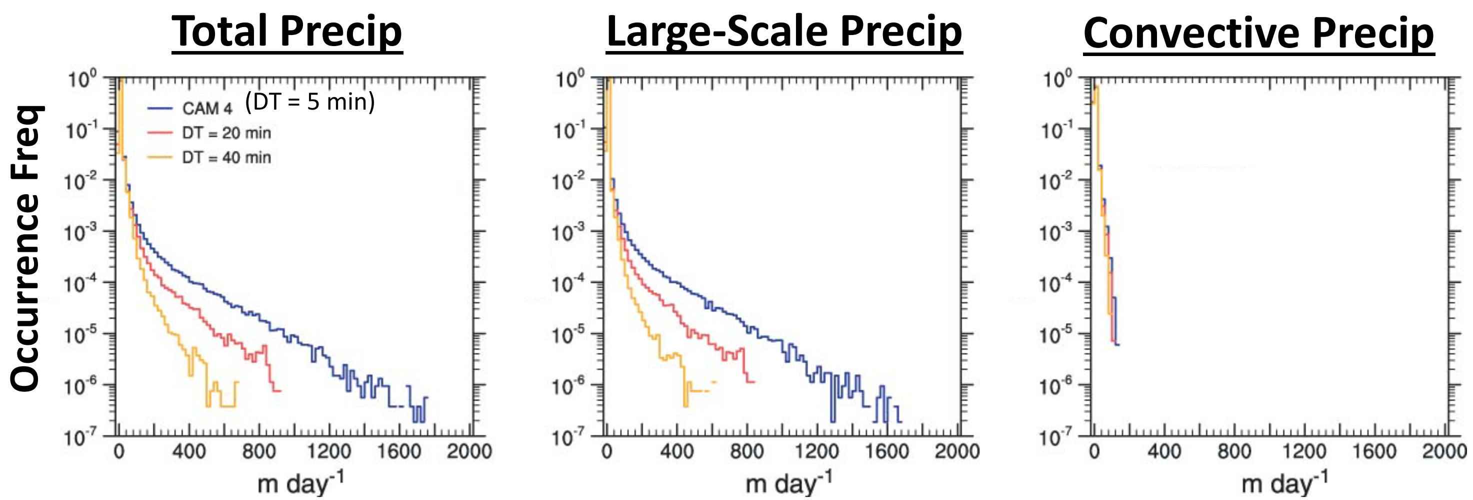
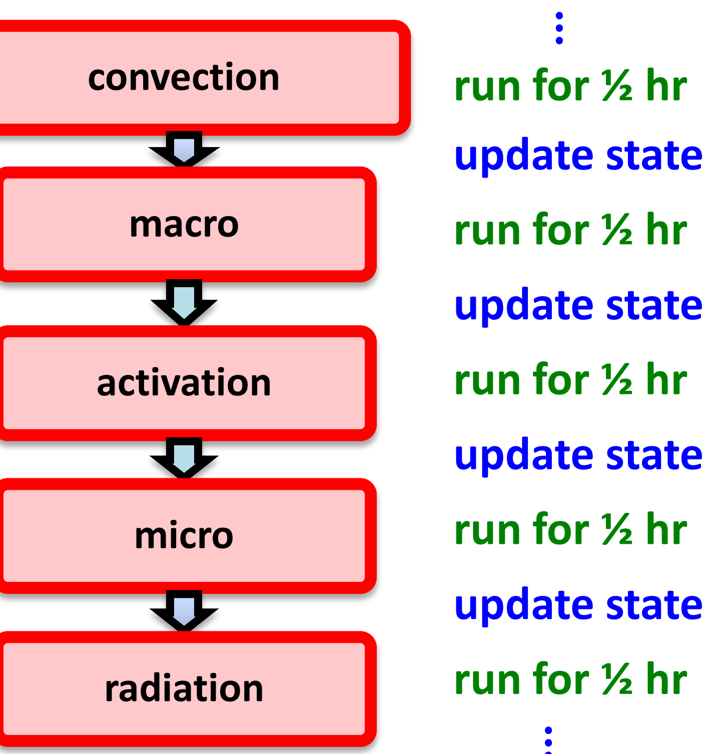


Fig: Impact of increasing time step on precipitation strength in gridpoint-storm regime. Adapted from Fig 11 of Williamson (2012 QJRMS)

Williamson showed that convection turns off as dt/τ gets large, forcing resolved-scale precip to take over

Splitting & Numerics Issues

Physics is *Sequentially Split*:



- Splitting can ruin balance between tendencies
  - e.g. condensation vs precipitation

And Numerics may be Insufficient:

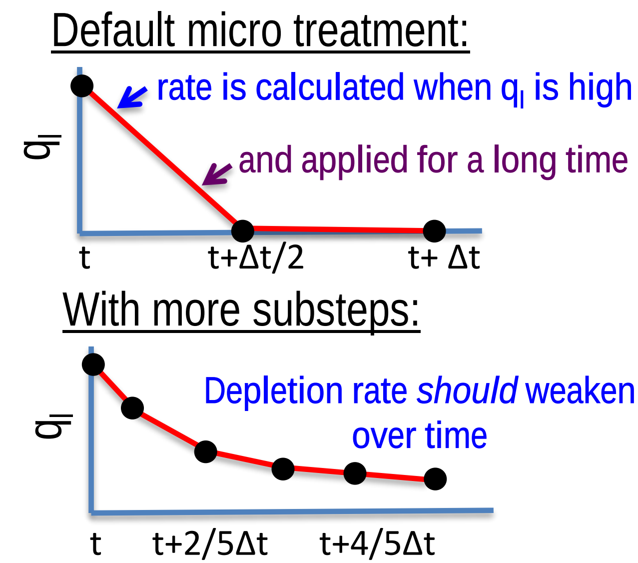
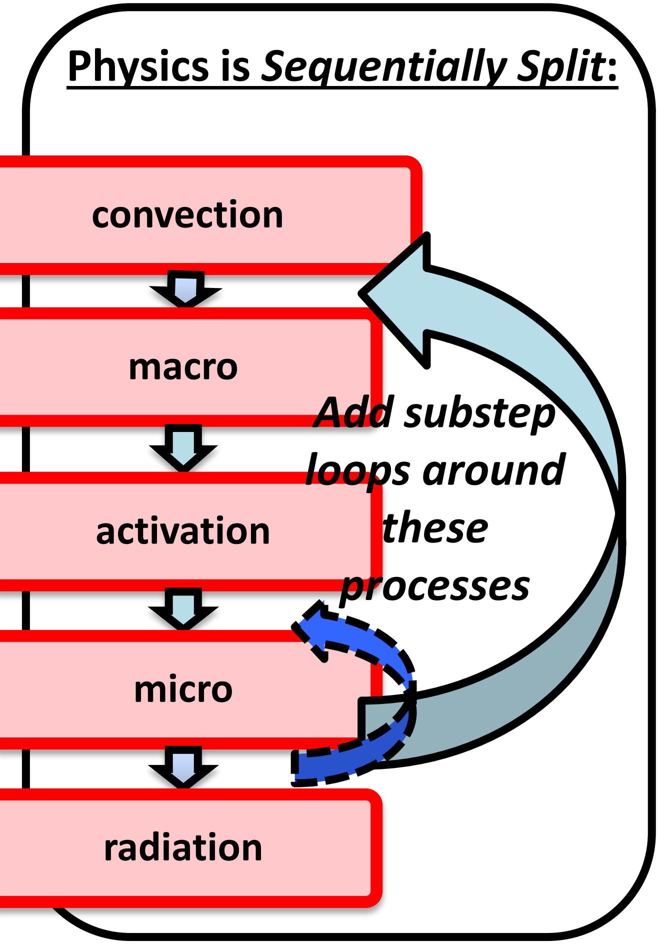


Fig: Time integration scheme in CAM5 microphysics

- And removal of numerical artifacts @ fine Δt may show up as resolution sensitivity
  - microphysics shown here

Splitting & Numerics Issues



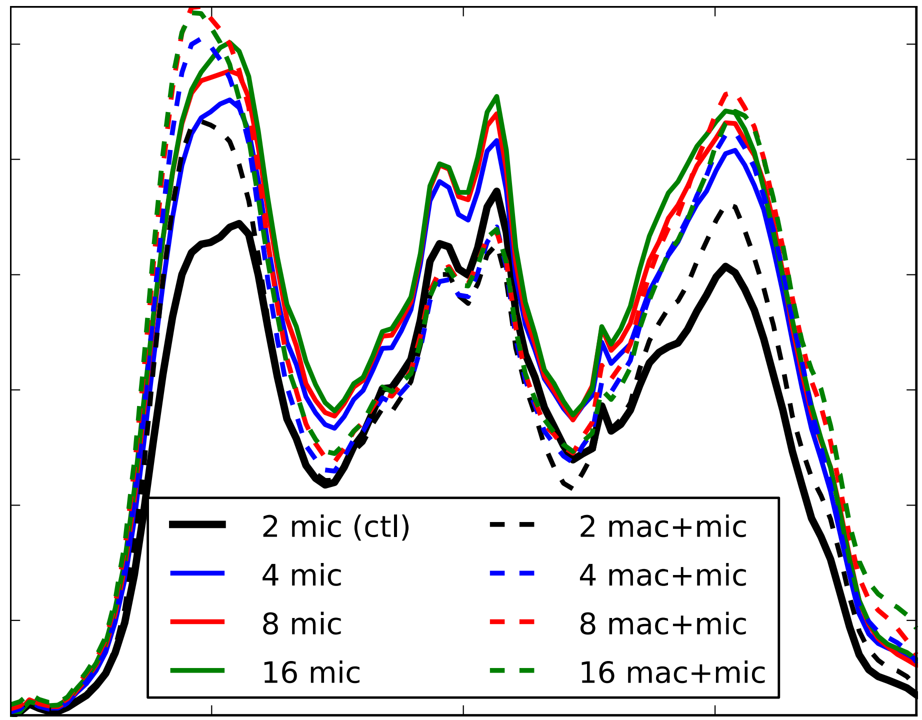


Fig: Effect of increasing the number of macro (mac) and/or microphysical (mic) substeps. Values are zonal and time-averages from the last 4 yrs of 5 yr current-climate AGCM runs.

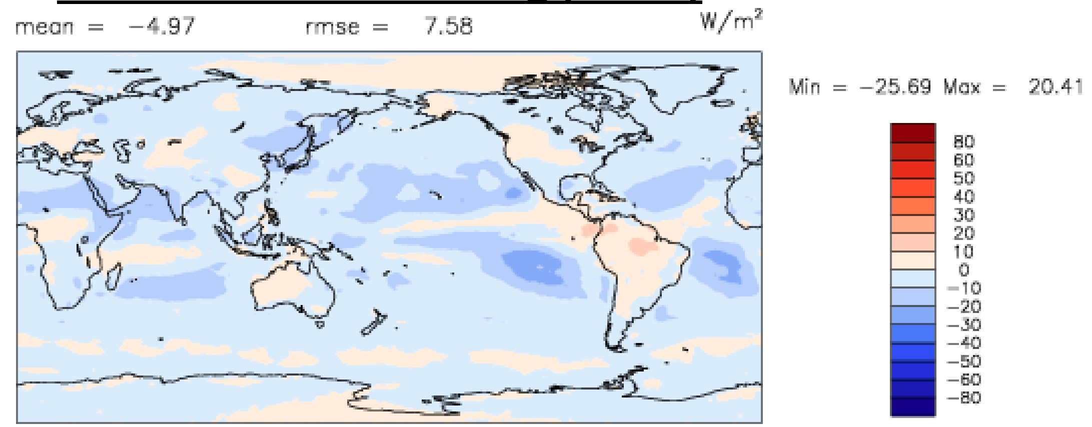
- **Process interaction & numerics make huge difference!**
- **Hui Wan will note other splitting problems tomorrow**

So is CAM5 Sensitive to All-Physics Δt?

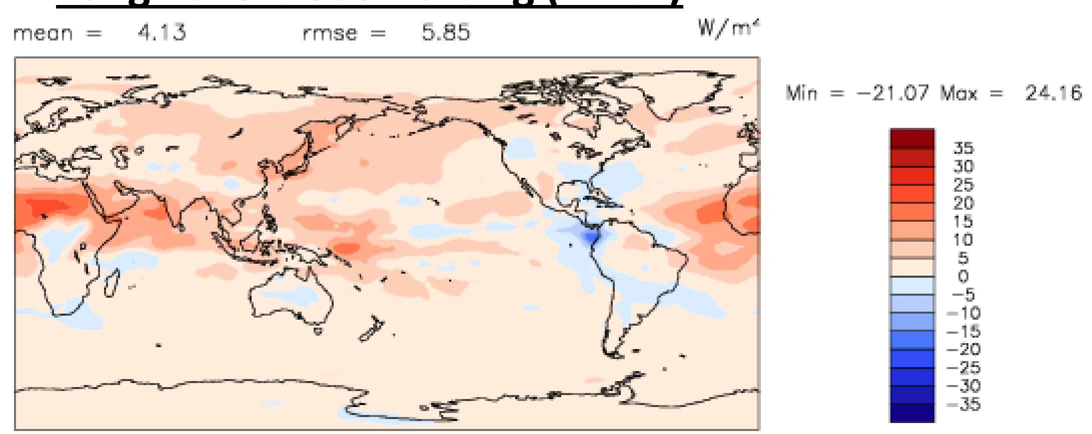
What we did: 6 yr Y2K Climo SST runs @ 30 min (default) & 7.5 min physics Δt. Dynamics Δt @ 7.5 min for both simulations.

- SWCF decreases by ~10% globally
  - decrease is global, but centered on shallow convection regions
- LWCF compensates somewhat
  - mainly in deep convective regions
- @ 7.5 min Δt, TOA energy loss is 1 W/m2 (default run gains energy @ 2 W/m2)

Shortwave Cloud Forcing (SWCF)

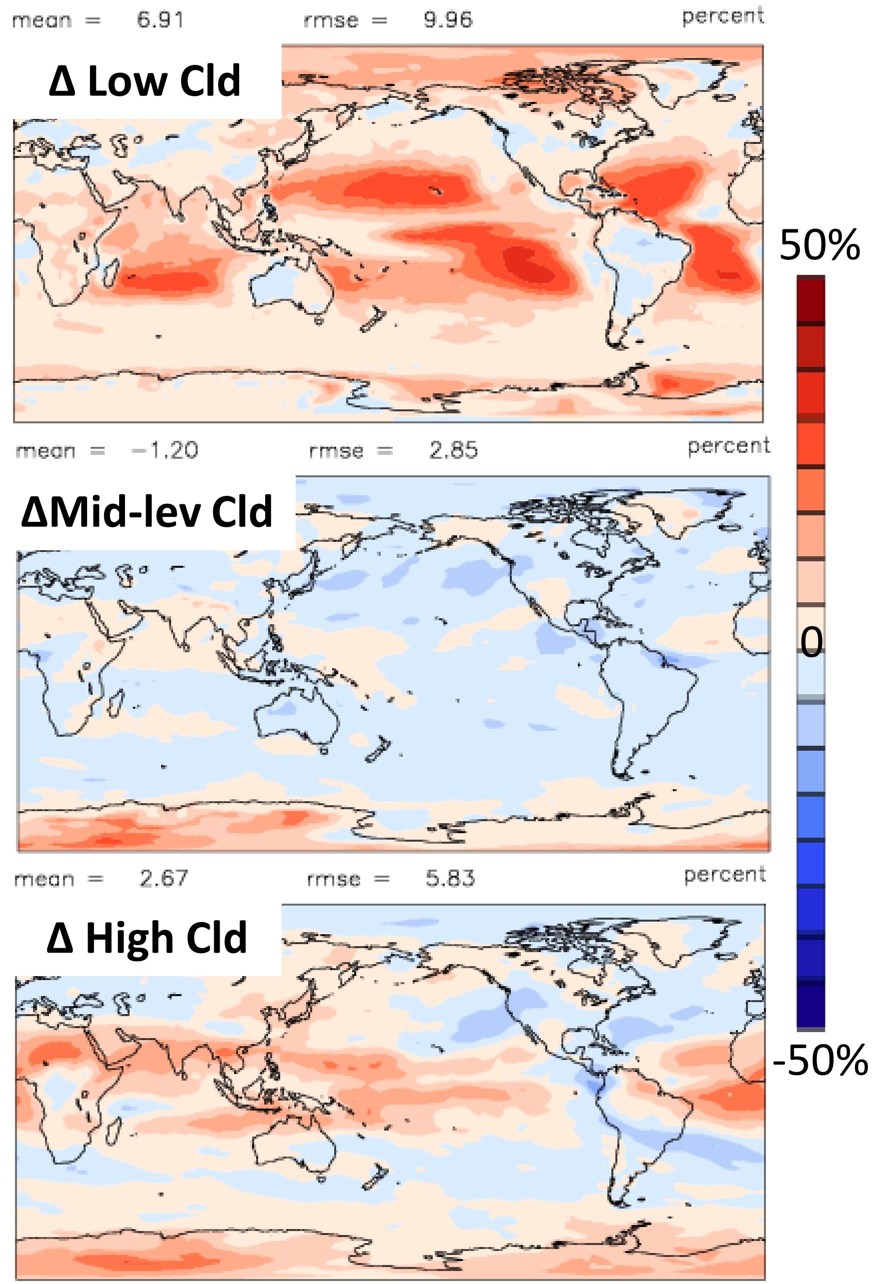


Longwave Cloud Forcing (LWCF)

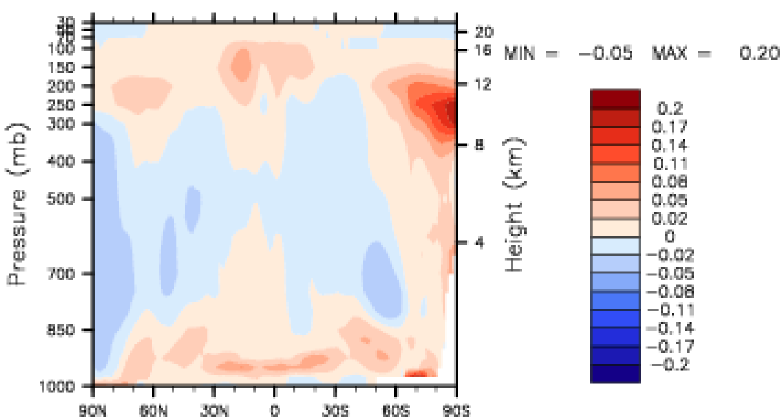


So is CAM5 Sensitive to All-Physics Δt?

- Low clds increase, especially in **shallow convective regions**
- High clds increase in deep convective & S Polar regions, decrease @ midlats
- Mid-lev clds decrease except in Antarctic



Zonal Ave Lat vs. Ht Cld Change

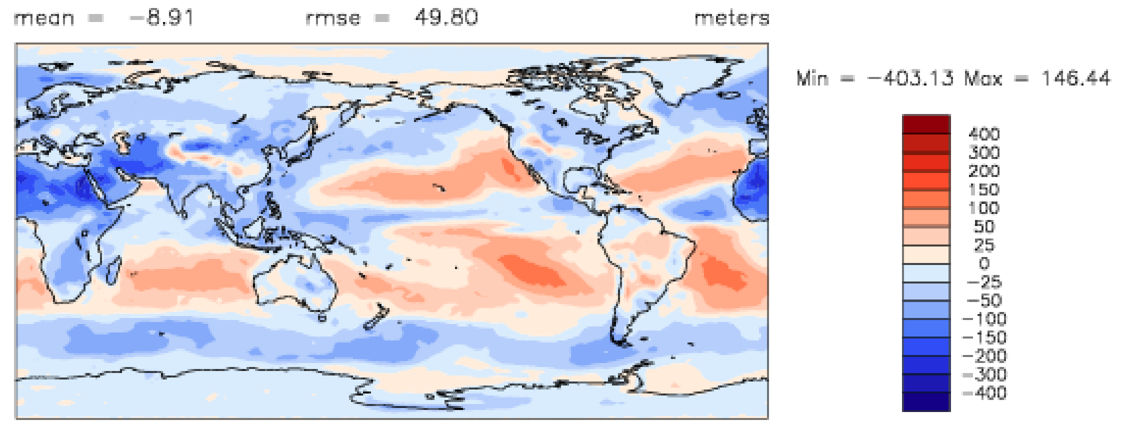


Possible Connection to PBL Scheme?

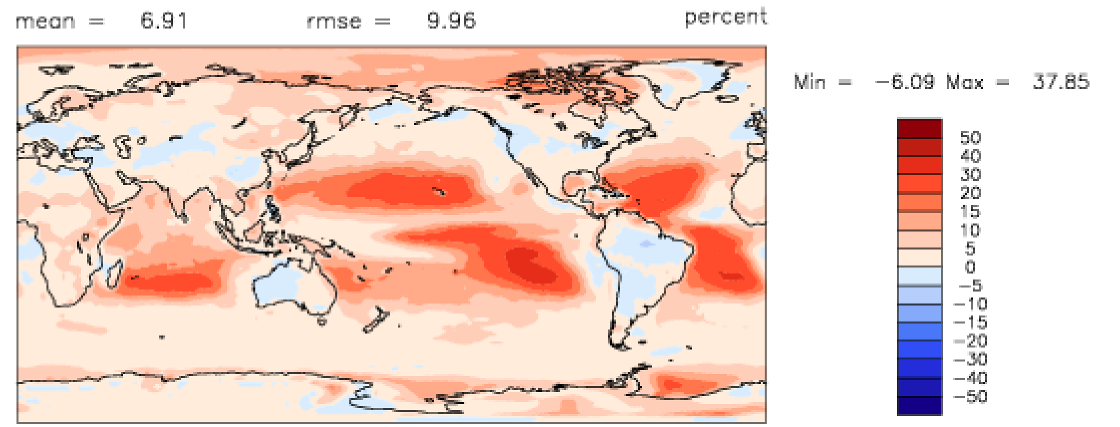
- Large boundary Layer (PBL) height increases where low clouds increase

- PBL shallower elsewhere

Δ PBL Height



Δ Low Cld

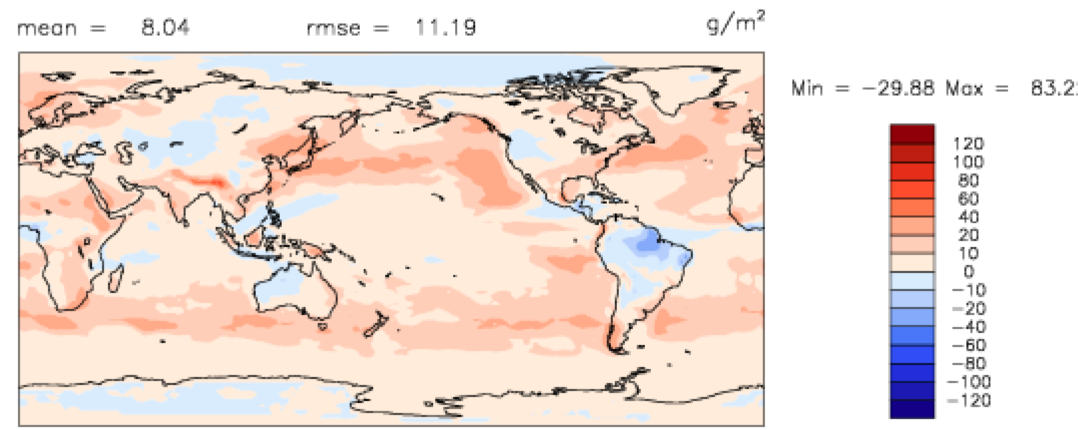


All-Physics Δt Sensitivity to CWP

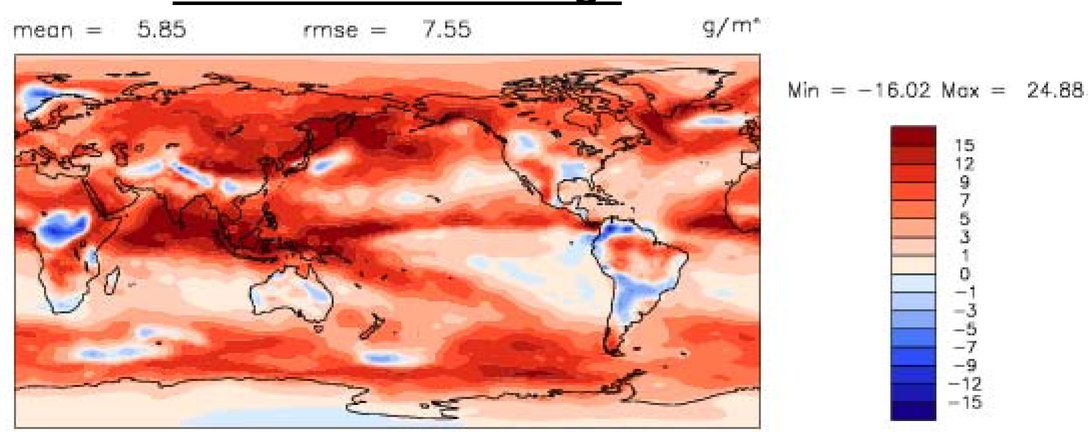
- LWP increases by ~20% globally

- IWP increases by ~25% globally

Liquid Water Path Change



Ice Water Path Change



Due to Macro/Micro Splitting Error?

- Splitting/numerics effect from slide 5 (green dots) captures the sense but not magnitude of physics Δt sensitivity

- Fixing macro/micro coupling is NOT sufficient!

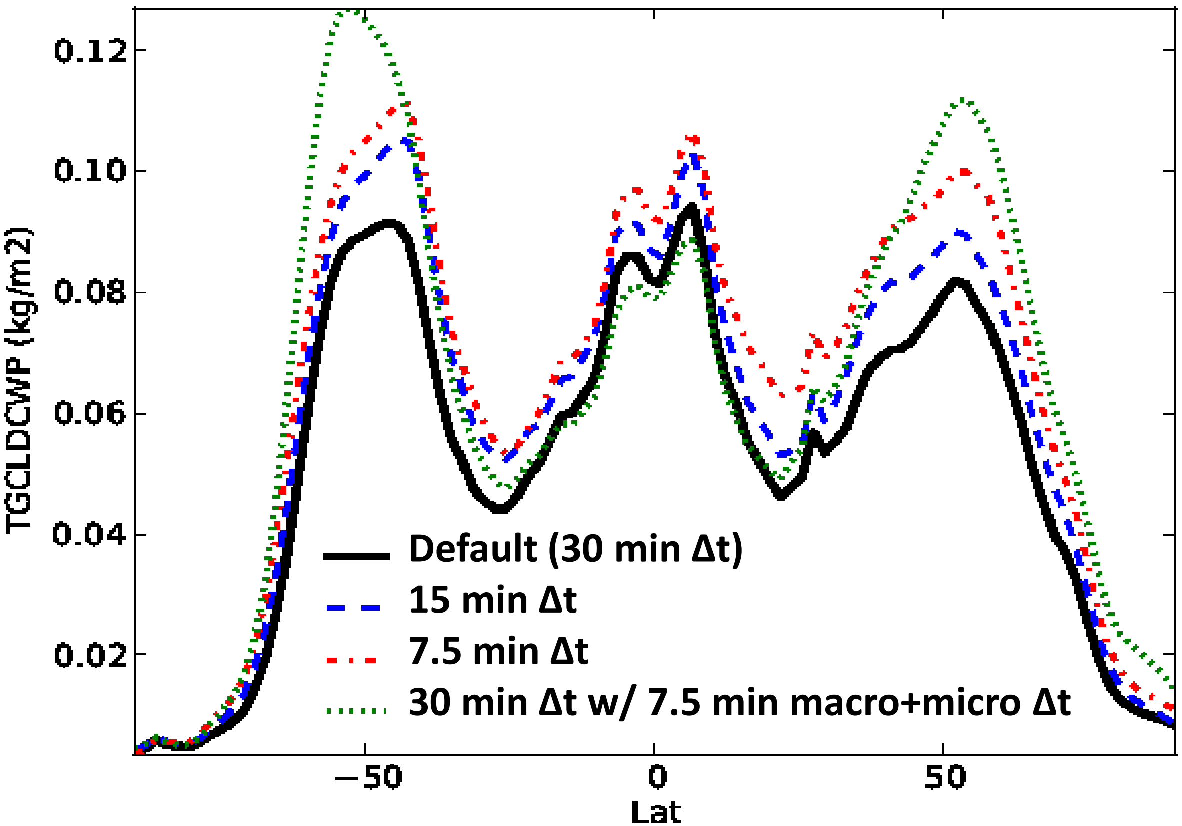
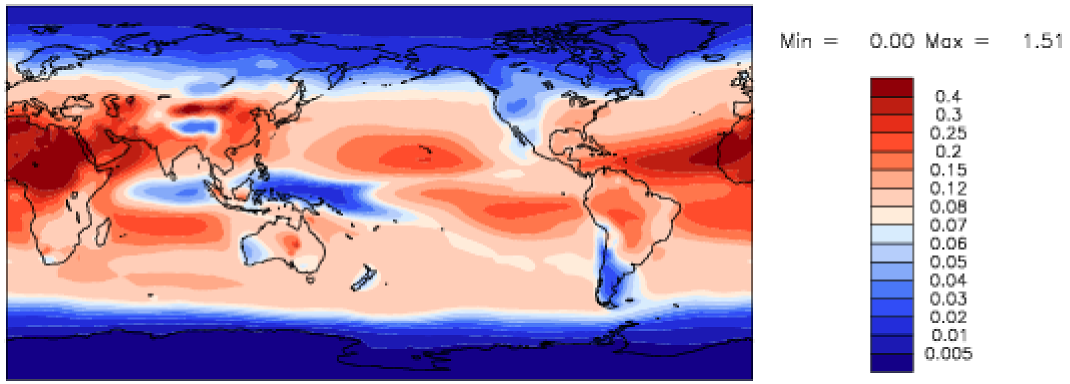


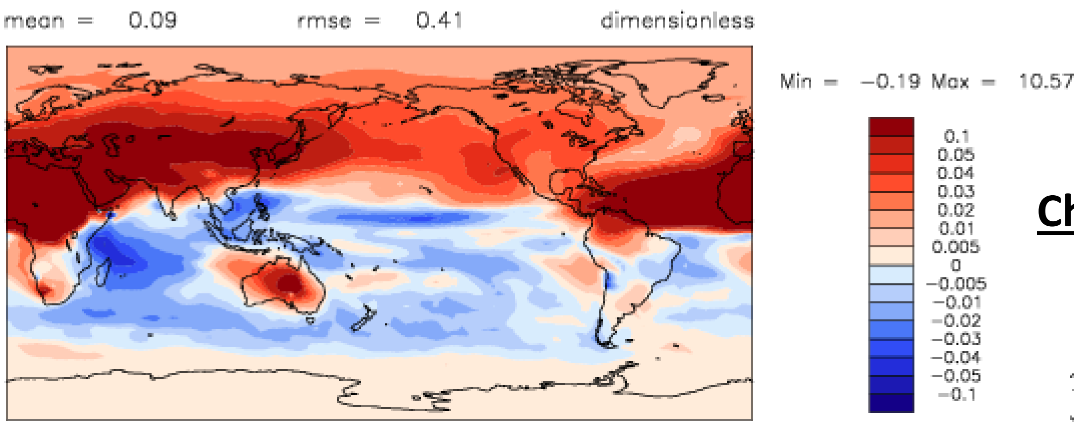
Fig: Zonal average cloud water path from ~5 yr Y2K climo SST simulations @ 2^{O} resolution with changing Δt or increased macro+micro substepping.

Aerosol Sensitivity to Timestep

Default Run Aerosol Optical Depth (AOD) @ 550nm

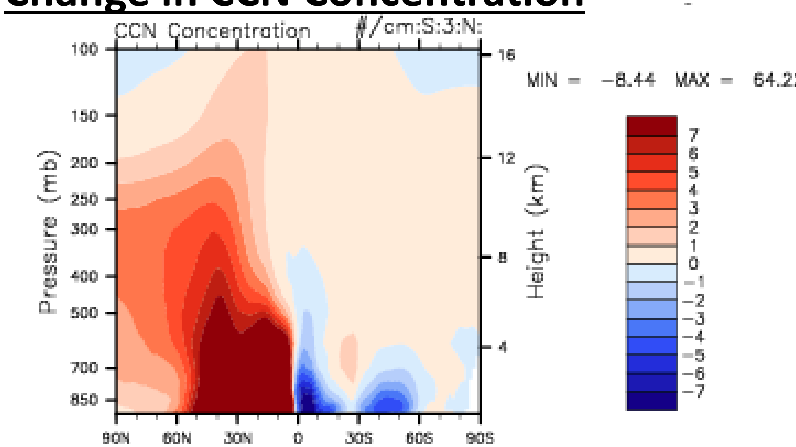


Change in AOD @ 550nm (7.5 min Δt – Default)



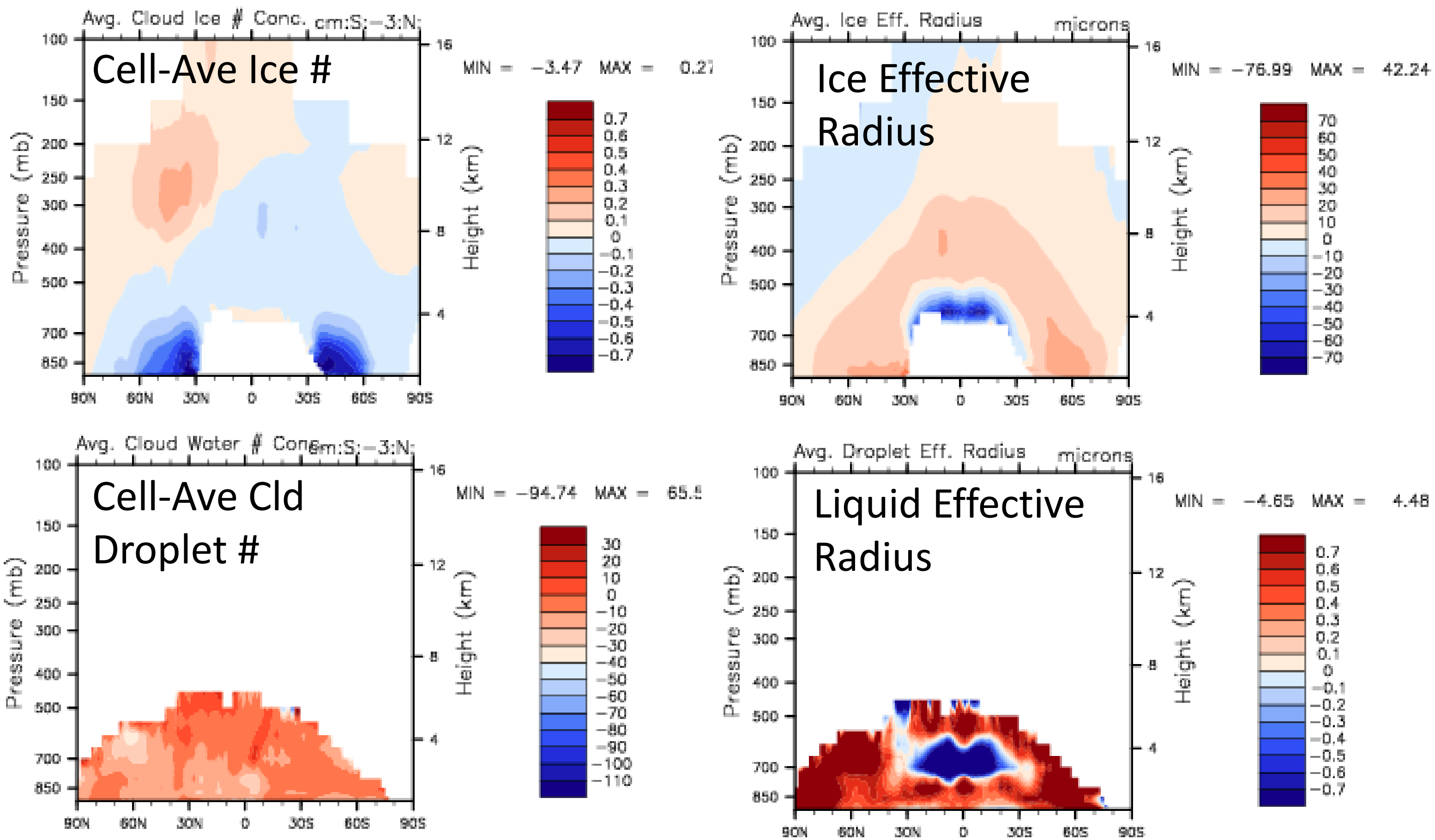
- AOD in N Hemisphere increases by 100%!
- CCN # behaves similarly

Change in CCN Concentration



- MISR plot in Sungsu's talk suggests high-res better?

How Does Aerosol Change Affect Cloud?



- Hemispheric asymmetry in AOD not found in drop # and size!
- Liquid droplet # increases + LWP increases = *in*creased effective radius

Conclusions

Identified 3 Kinds of Timestep Error (any more?):

- Conceptual (convective timescale)
- Splitting (push/pull between macro and micro)
- Integration Method (use of Fwd Euler time in micro)

When Physics Timestep Decreases:

- Low cloud fraction, LWP, and IWP increase by 10-25%
- High cloud increases in deep convective regions and over Antarctica
- N hemisphere AOD jumps by 100%

the Path Forward:

Clues:

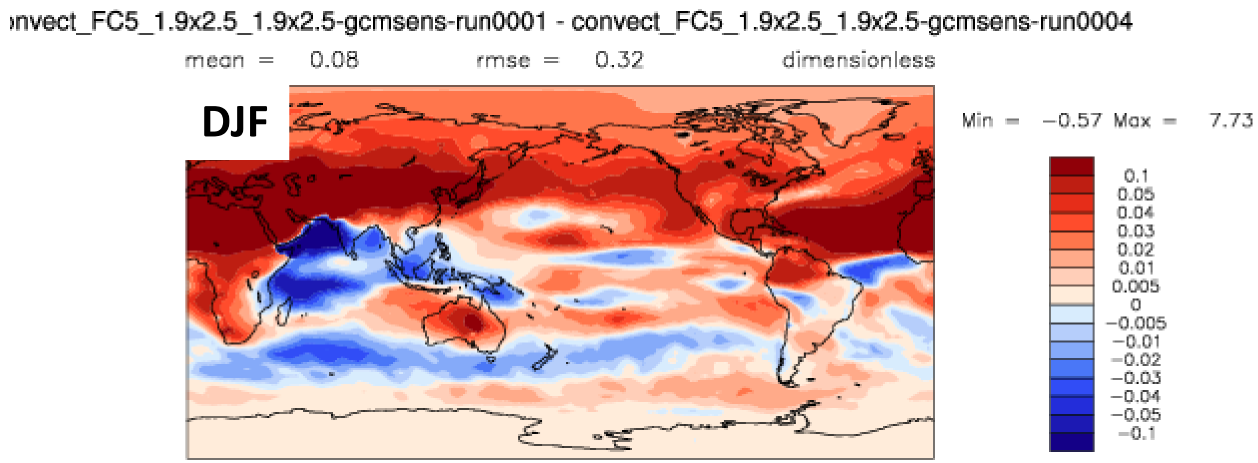
- Peak low cloud increases occur in shallow convective regions and are associated with PBL rise
- Macro+micro substepping explains some but not all of this sensitivity
- Aerosol loading seems to be very sensitive to timestep

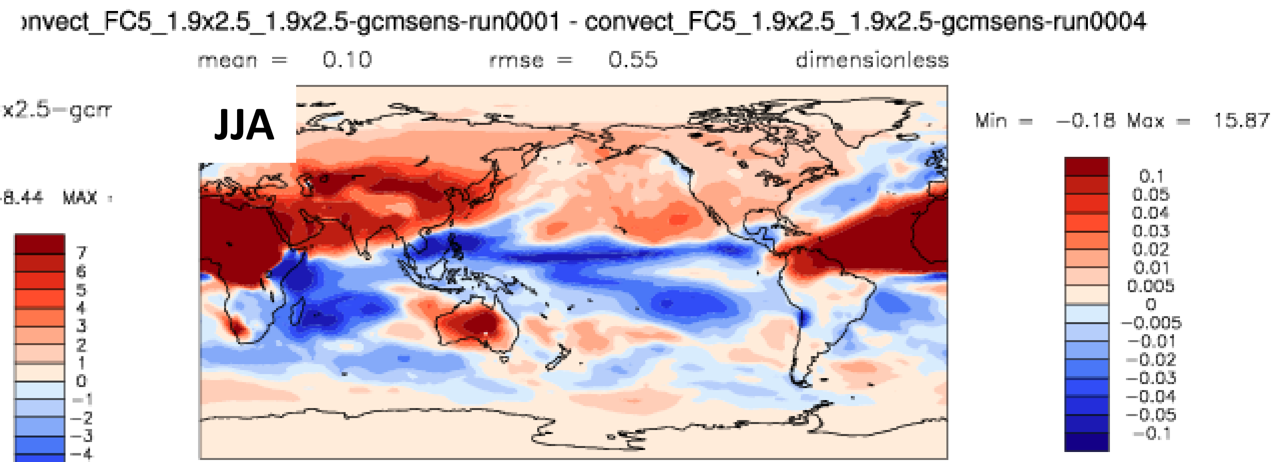
Future Work:

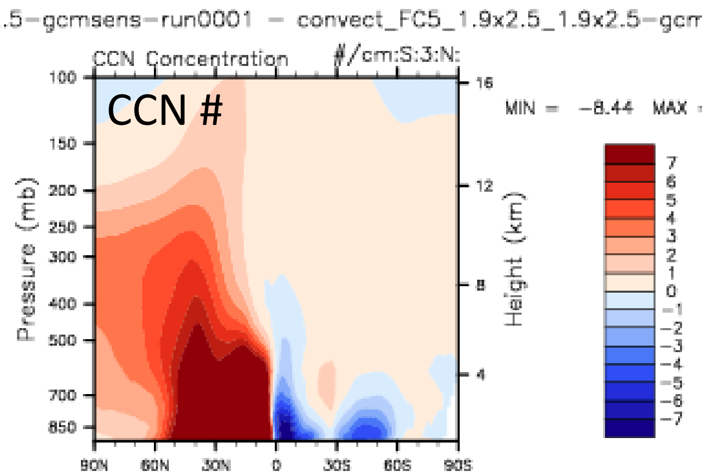
- Substep other processes/combinations of processes
- Use simple model to explore splitting/numerics effects

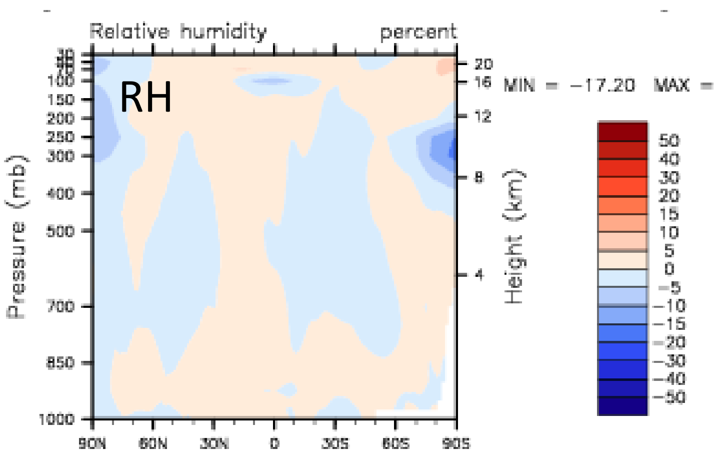
Extra Slides

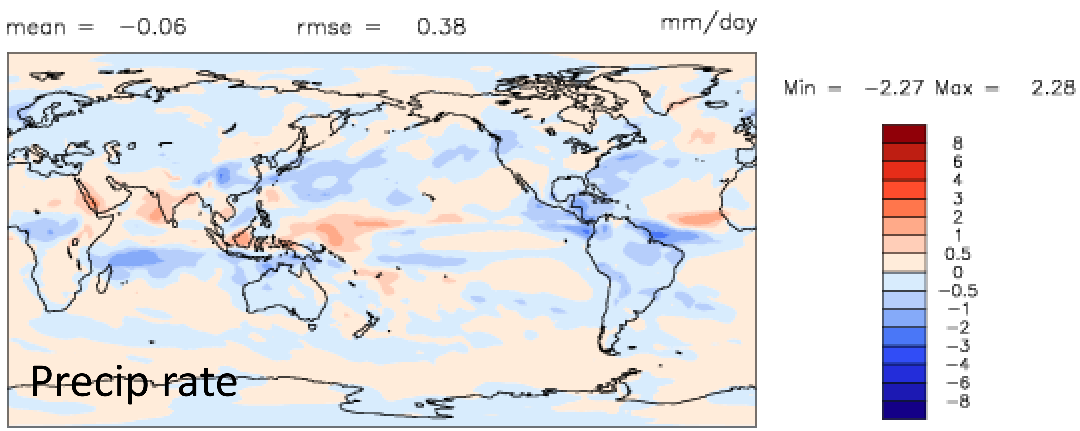
AOD Change @ 550 nm








Relative humidity
percent
RH
MIN = −17.20 MAX =
Pressure (mb)
Height (km)
30
50
70
100
150
200
250
300
400
500
700
850
1000
20
16
12
8
4
90N
60N
30N
0
30S
60S
90S
50
40
30
20
15
10
5
0
−5
−10
−15
−20
−30
−40
−50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rmse = 0.38
mm/day
Min = −2.27 Max = 2.28
Precip rate
8
6
4
3
2
1
0.5
0
−0.5
−1
−2
−3
−4
−6
−8