ACME Progress

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AMWG Workshop 2/27/17

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What is ACME?

Accelerated Climate Modeling for Energy

ACME = DOE's new "high-resolution" climate model

- project started in spring 2014
- ACME split off CESM (at CAM5.3.35 tag)
- Uses CLM4.5 for CMIP experiments (though lots of development is going on for nitrogen cycle experiments)
- ACME atm uses same parameterizations as CAM6: CLUBB, MG2, ZM, RRTMG, MAM4
  - code versions and tuning differ

ACME is Pioneering

Accelerated Climate Modeling for Energy

On top of these parameterization changes, ACME:

- Uses 72 vertical layers in the atmosphere
- Always uses the spectral-element (SE) dycore
  - Much faster at high horizontal resolution and allows for regional refinement
- Uses totally new MPAS ocean and sea ice models
  - Faster at higher resolution
  - Includes prognostic ocean thickness important for sea level rise experiments

Big changes like these unbalance compensating errors, inevitably resulting in initially degraded results

Why a "High-Resolution" Model?

- High resolution is needed to capture topographic effects on rainfall (top row)
- and topography has an important effect on rainfall changes (bottom row)!

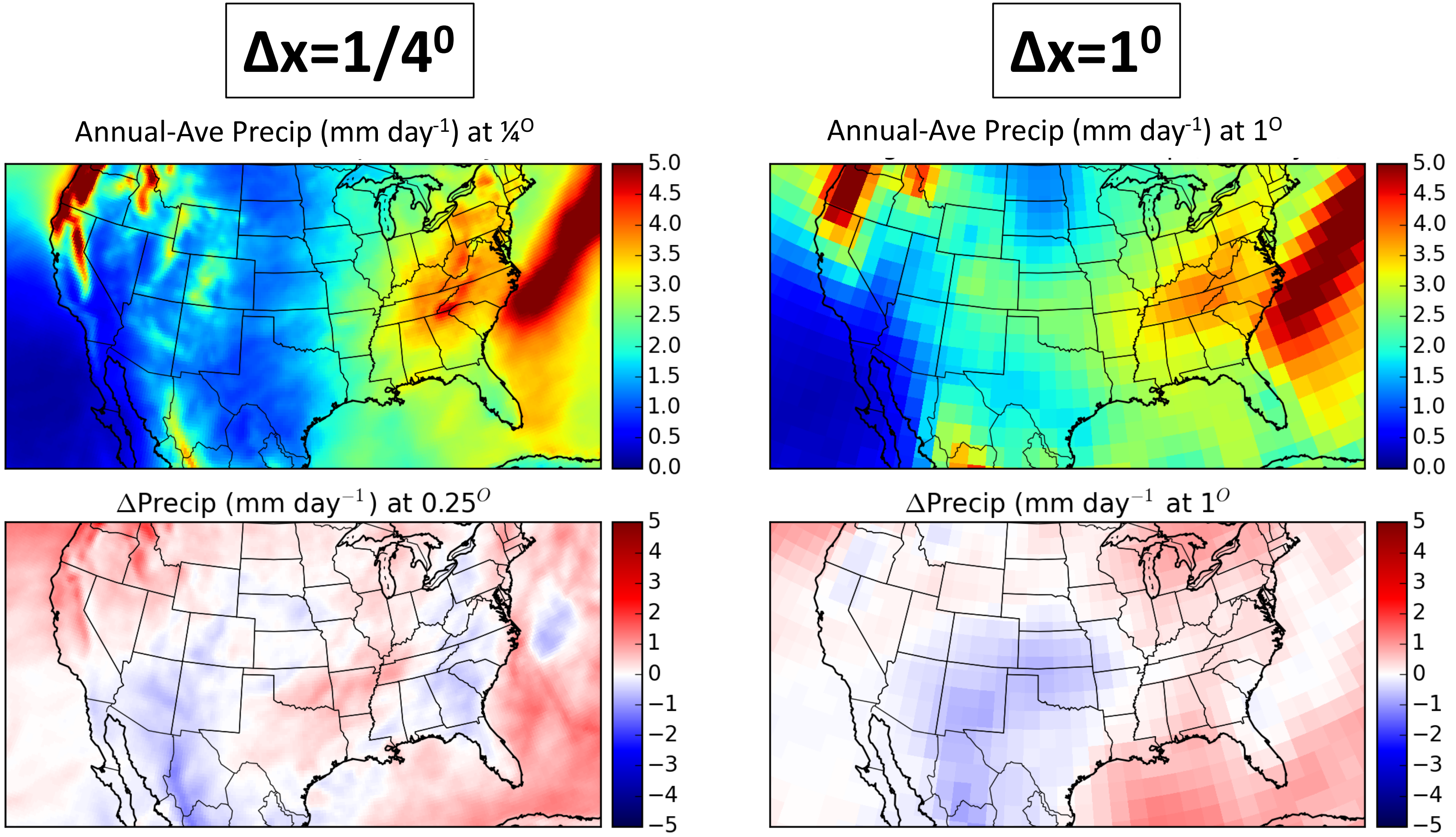
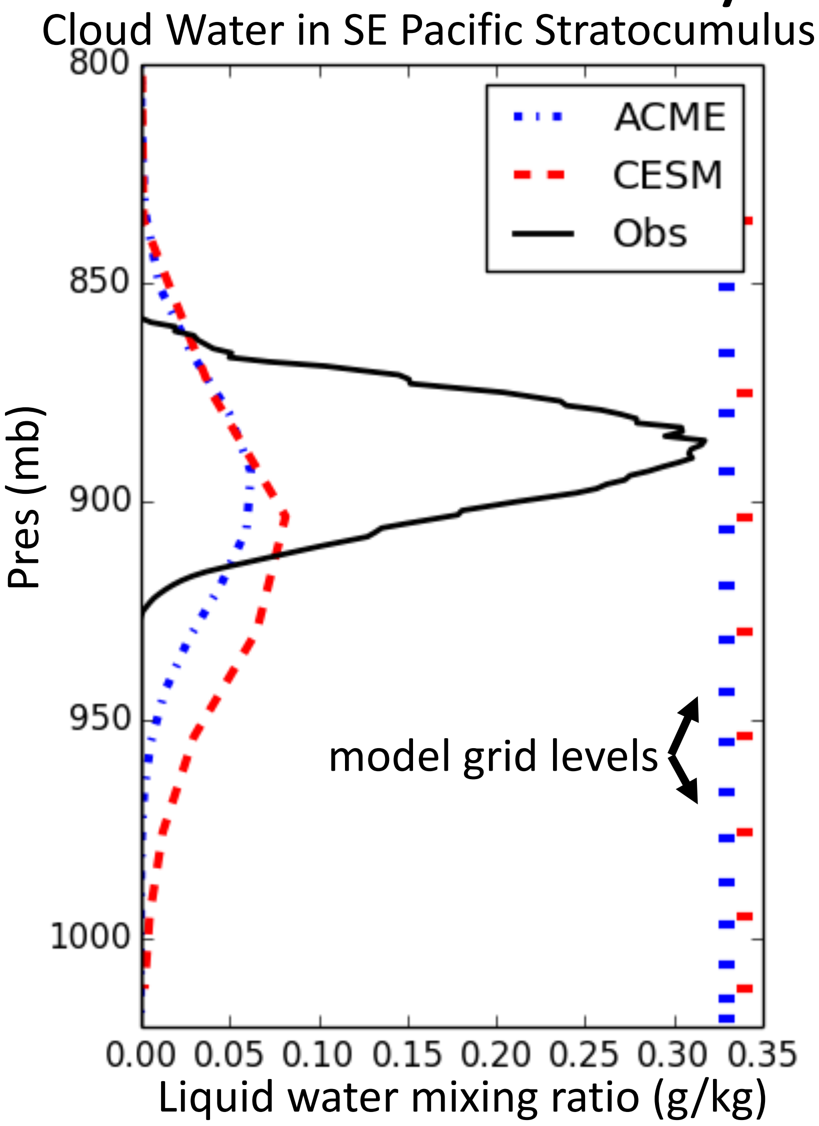


Fig: Precipitation over US from ACME v1 beta0 F1850 simulations at $\Delta x = 1/4^0$ and 1^0 (top row). The bottom row shows the impact of increasing SST uniformly by +4K. Simulations are 5 yrs long and SST is prescribed from pre-industrial conditions.

Why High Vertical Resolution?



- With ~30 model levels, stratocumulus (left) and cirrus are often ≤1 model level thick. This makes capturing associated processes difficult.

- Using more vertical levels seems to raise stratocumulus cloud base in ACME, improving agreement with observations (though cloud mass tends to be smaller/worse... more later)

Fig: Liquid water content for SON average from ACME v2 beta0 years 101-130 and CESM2 run 125 yrs 100-120 for cell closest to 20S, 85W. Obs are from radiosonde data taken during the EPIC campaign (Oct 16-22nd, 2001).

Current Status

- Focus is still primarily on $\Delta x=1^0$, but:
  - Wuyin Lin has been very successful using CAPT to tune at $\Delta x=1/4^0$
  - We have done $1/4^0$ sensitivity studies (shown on previous slide)
  - We will try a $1/4^0$ coupled run next week
- We planned on freezing months ago…
  - because we want to make significant progress on the CMIP deck before our 3 yr review this June
  - but we're still finding/fixing problems:
    - Problems in ocean mixing (excessive 2dz mixing)
    - River runoff issues due to problems with mapping files
    - land spinup was insufficient
    - Energy and water conservation needed help (See Kai's talk)
    - coupled model crashes every 75 yrs or so (negative layer thickness in SE vertical remap or forcing height below plant canopy height)
    - and so on

Coupled Model Performance

- CESM2 run 125 is among the best CMIP5 models
- ACMEv1 is middle of the road – like CESM from a year ago?
- Both models struggle with 850 mb T
  - related to cold SST?

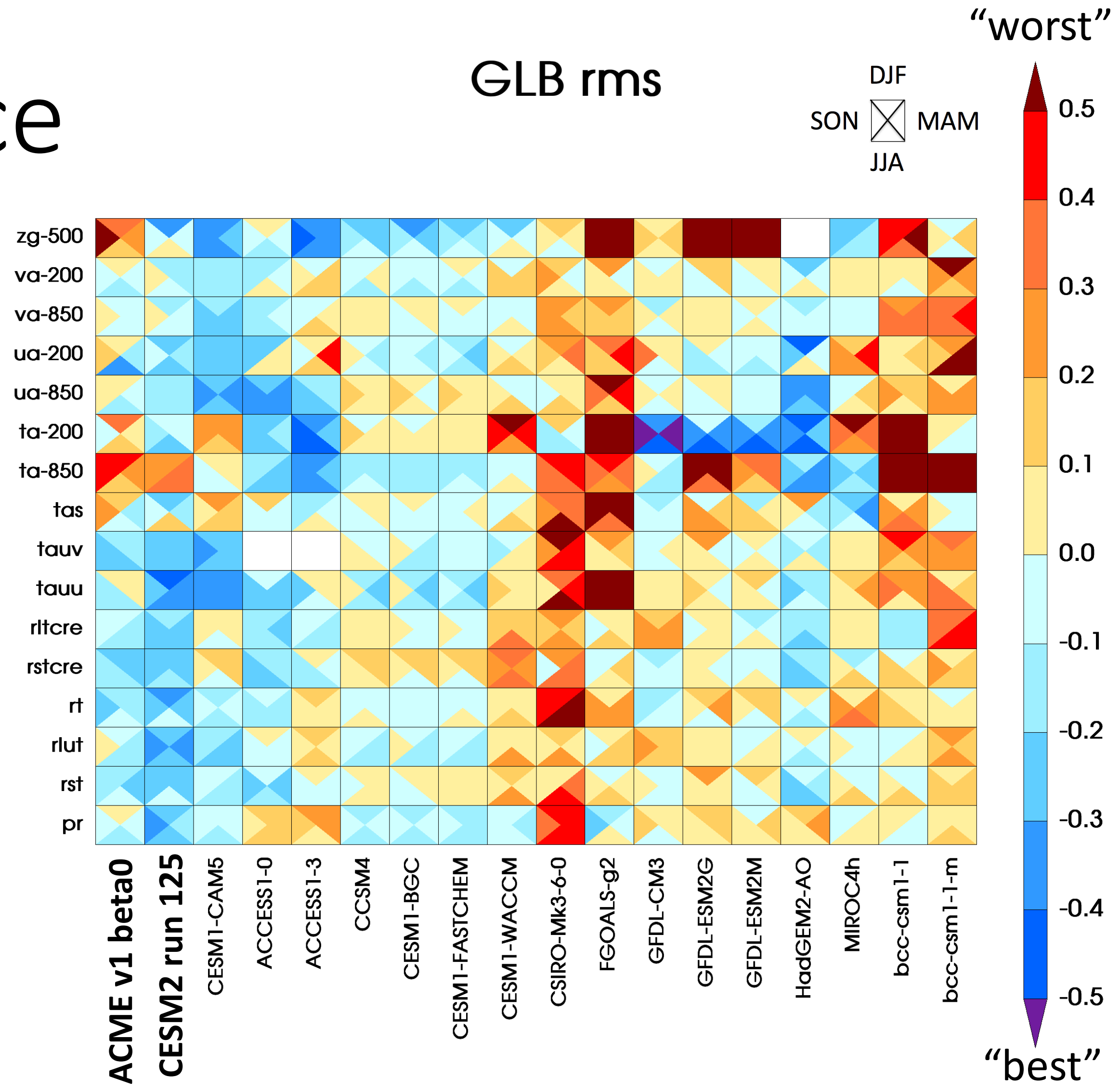
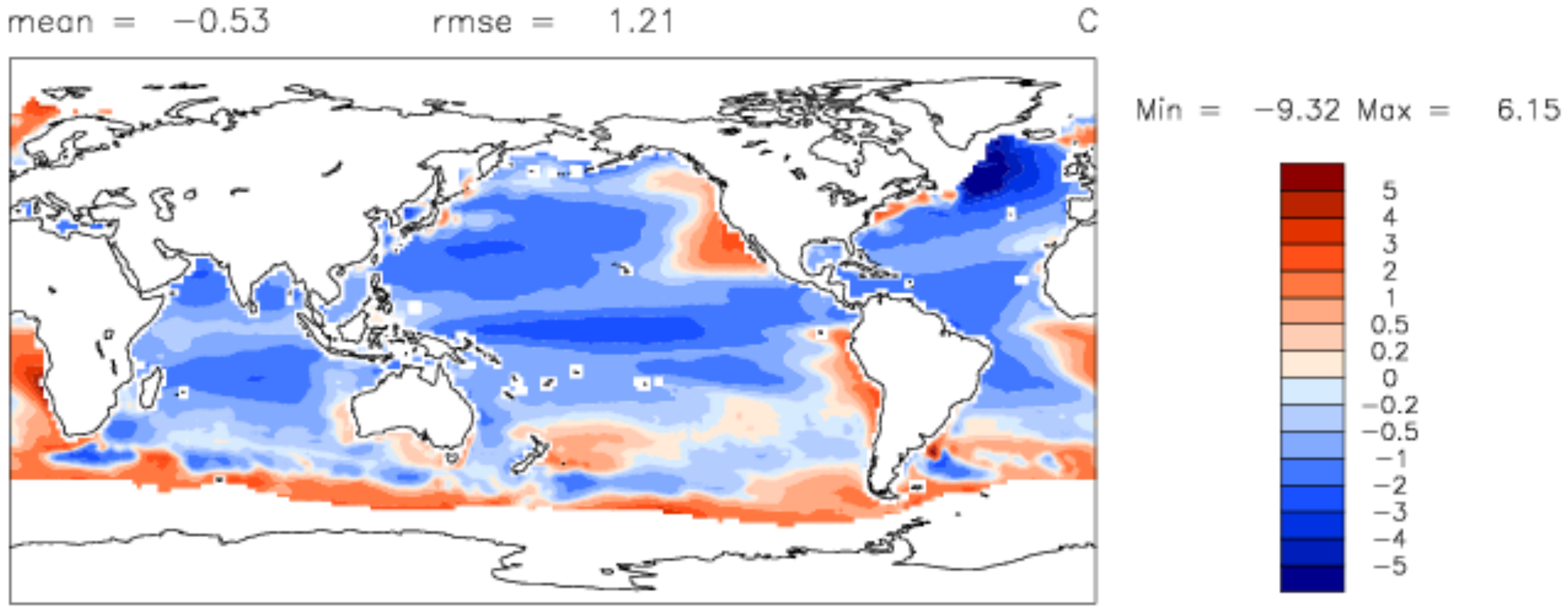


Fig: "Gleckler" et al (2008; JGR) diagram evaluating ACME beta0 and CESM2 run 125 coupled pre-industrial runs against CMIP5 models. Fig from Qi Tang.

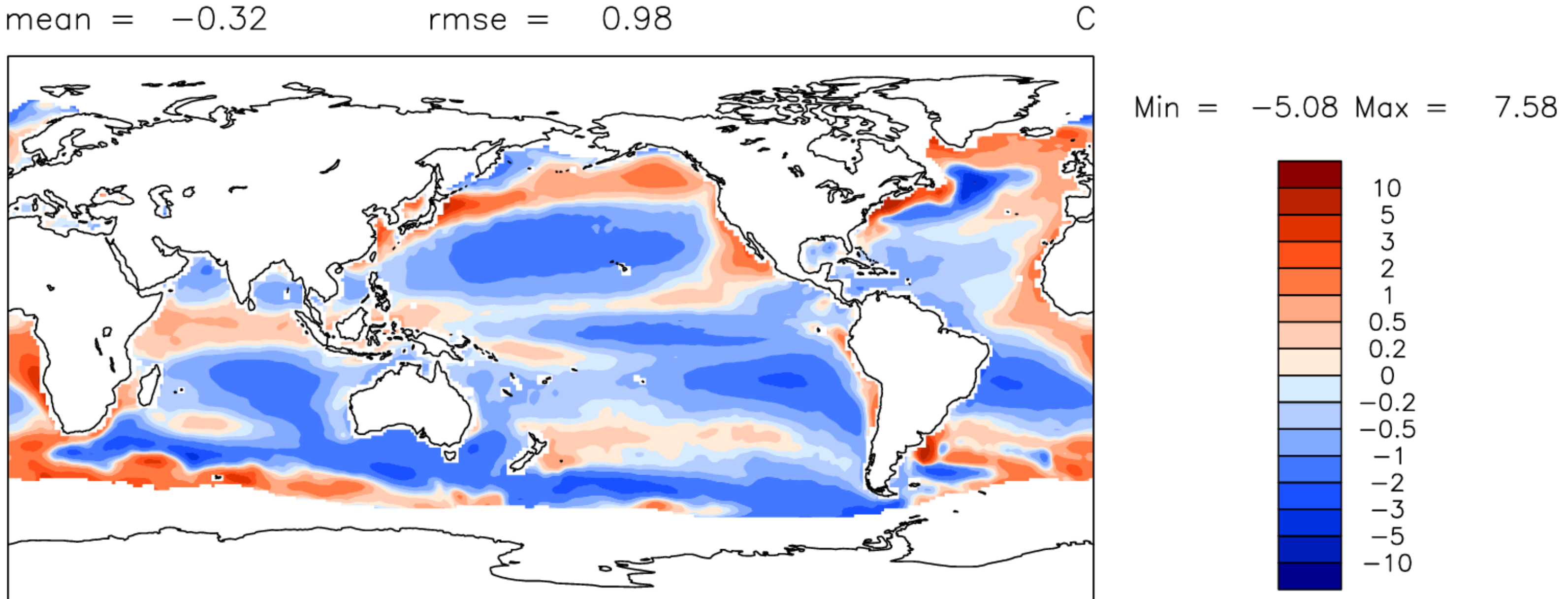
SST

- ACME and CESM generally share similar biases
  - generally too cold
  - warm bias off west coasts
  - too warm over S Ocean
- ACME is colder in general
  - particularly in N Atlantic

ACME v1 beta0 1850 Coupled (yrs 101-130)



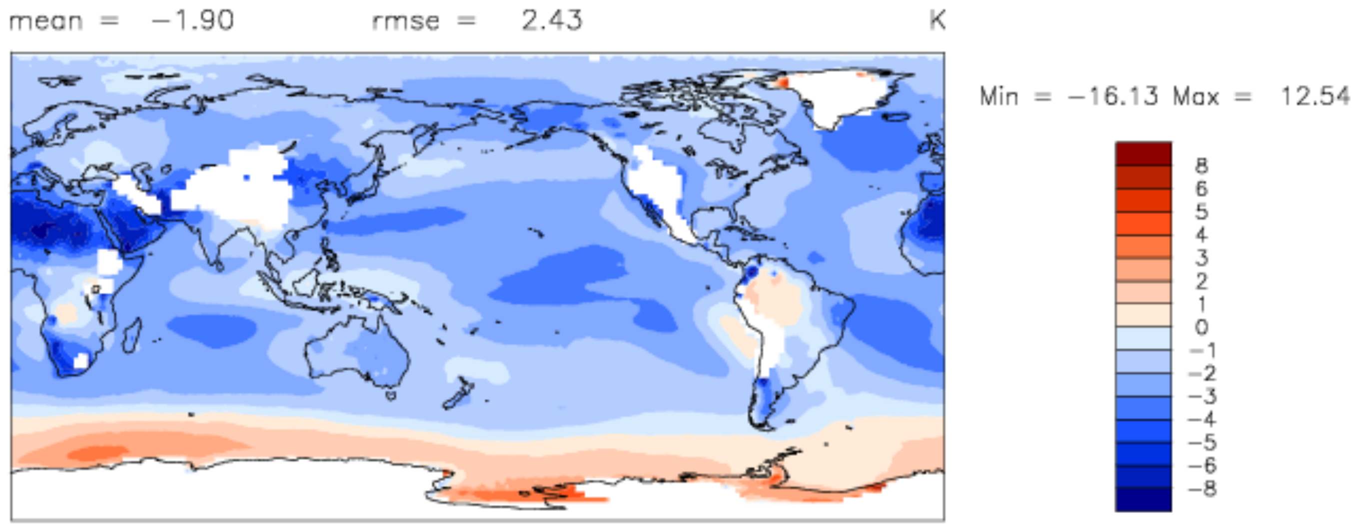
CESM2 run 125 1850 Coupled (yrs 100-119)



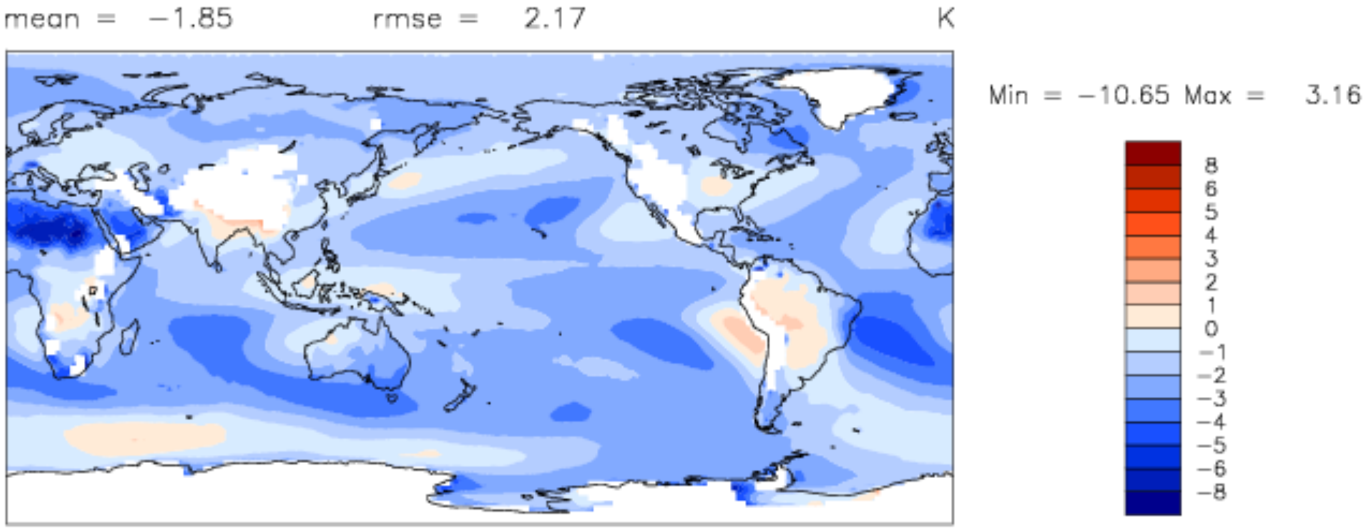
850 mb T

- Both ACME and CESM are generally too cold (shown vs AIRS here, but true for all reanalyses as well)
- ACME is too warm over S Ocean, consistent with its greater SST bias there

ACME v1 beta0 1850 Coupled (yrs 101-130)



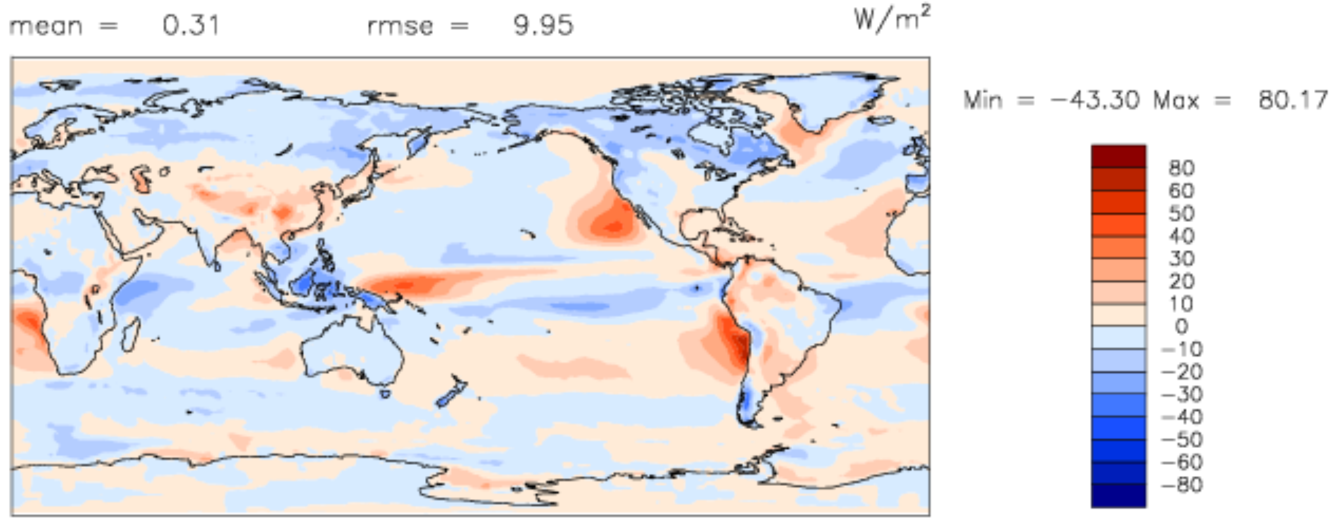
CESM2 run 125 1850 Coupled (yrs 100-119)



Stratocumulus

- SWCF bias (relative to CERES-EBAF)
  - Much worse in ACME in Sc regions
- We are working on this

ACME v1 beta0 1850 Coupled (yrs 101-130)



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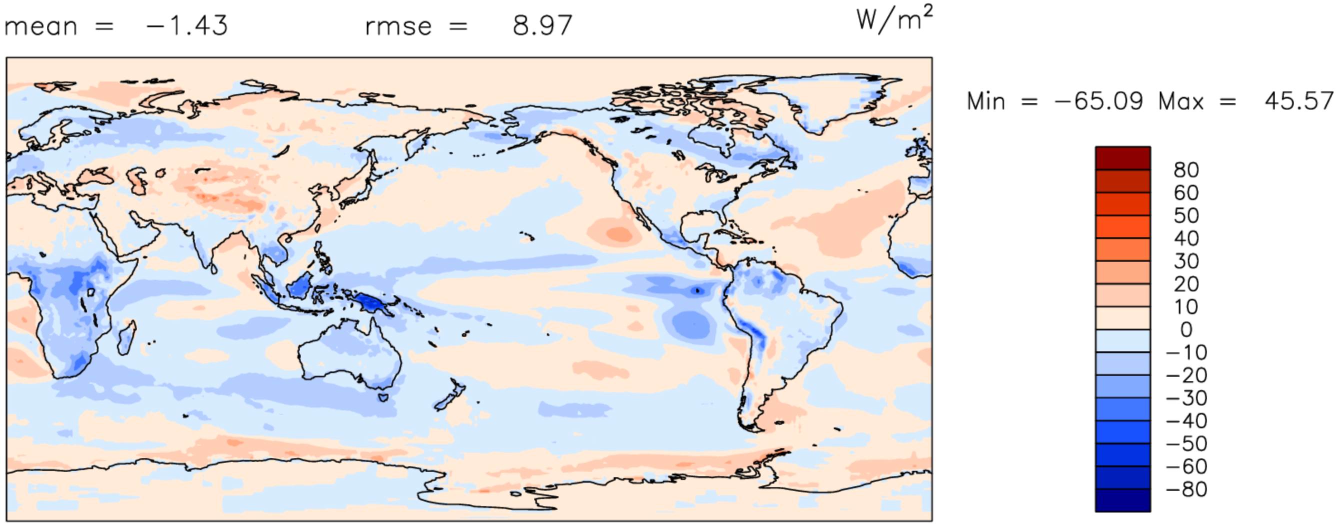
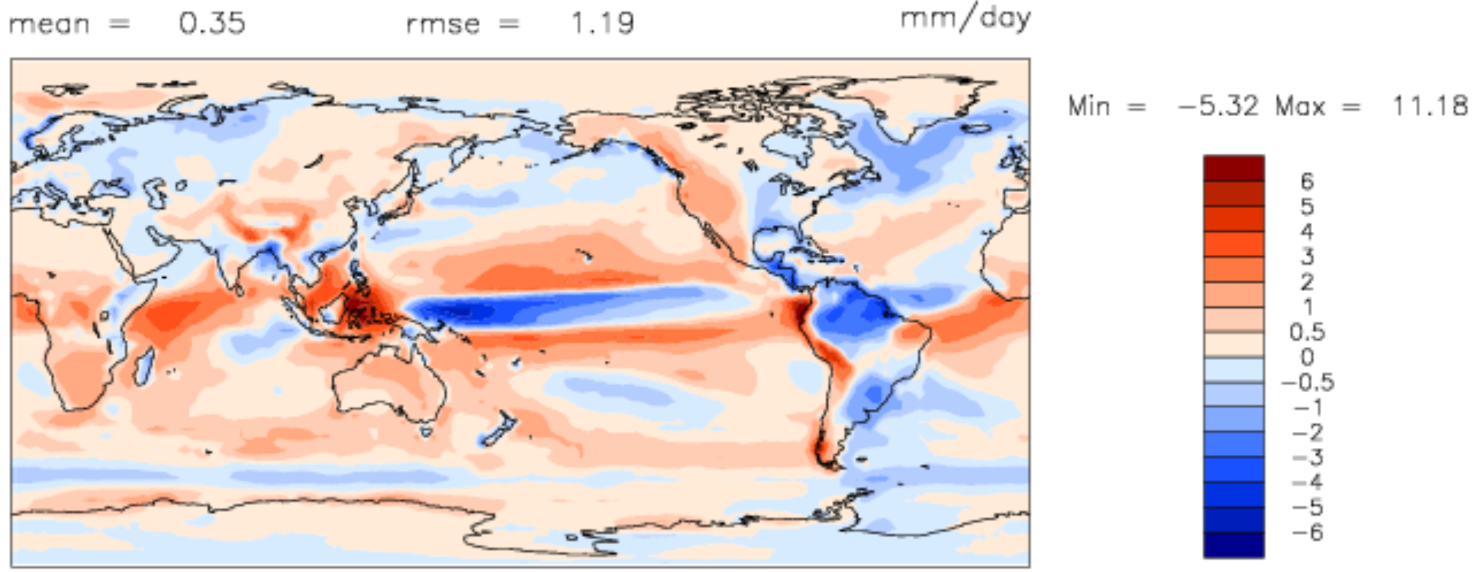


Precipitation

- PRECT bias (using GPCP obs)
- Similar biases:
  - double ITCZ (though CESM is much better)
  - dry Amazon/wet Andes
  - Too strong over Maritime Continent/Indian Ocean
- ACME generally worse
  - also wet over W Coast N America

ACME v1 beta0 1850 Coupled (yrs 101-130)



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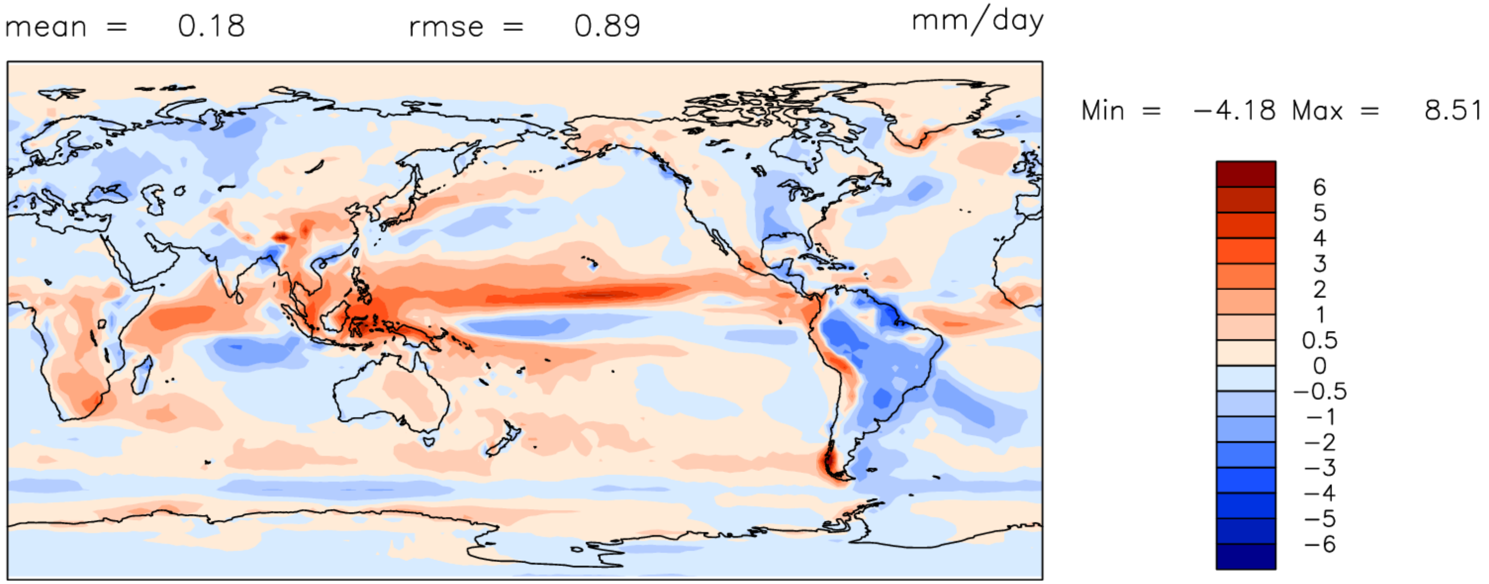
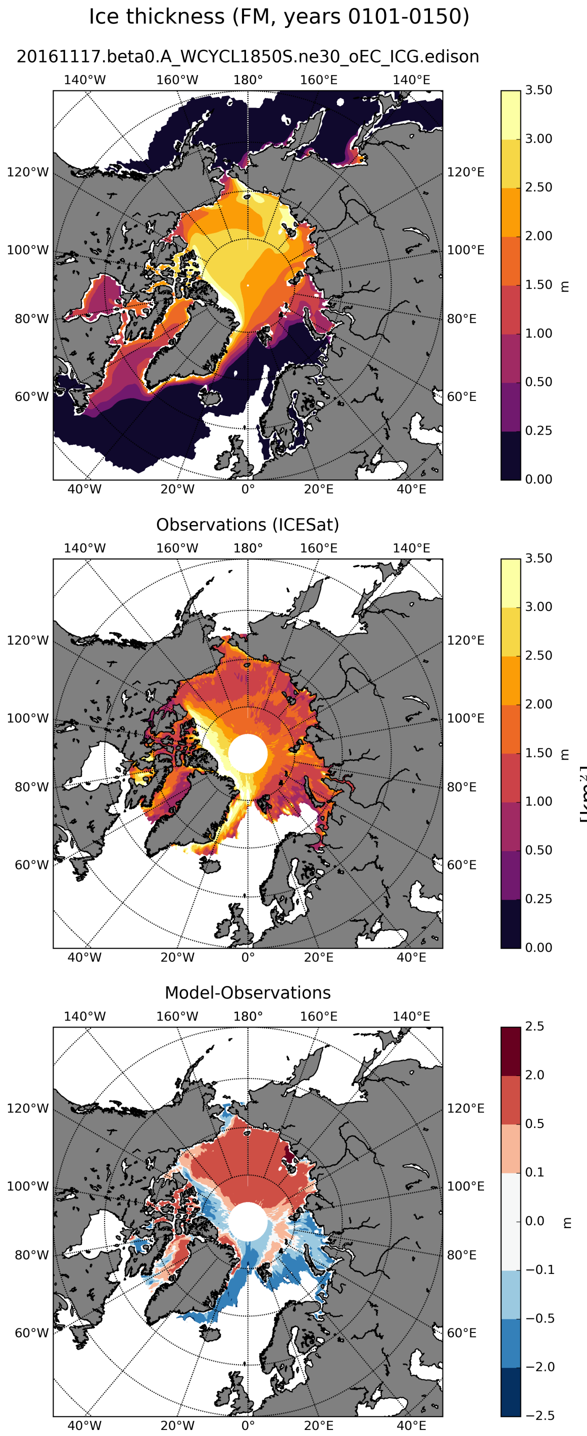


Sea Ice

- Sea ice is stable and not outlandish

- There's a bit too much ice in the Labrador Sea, but it is too thin to cause instability



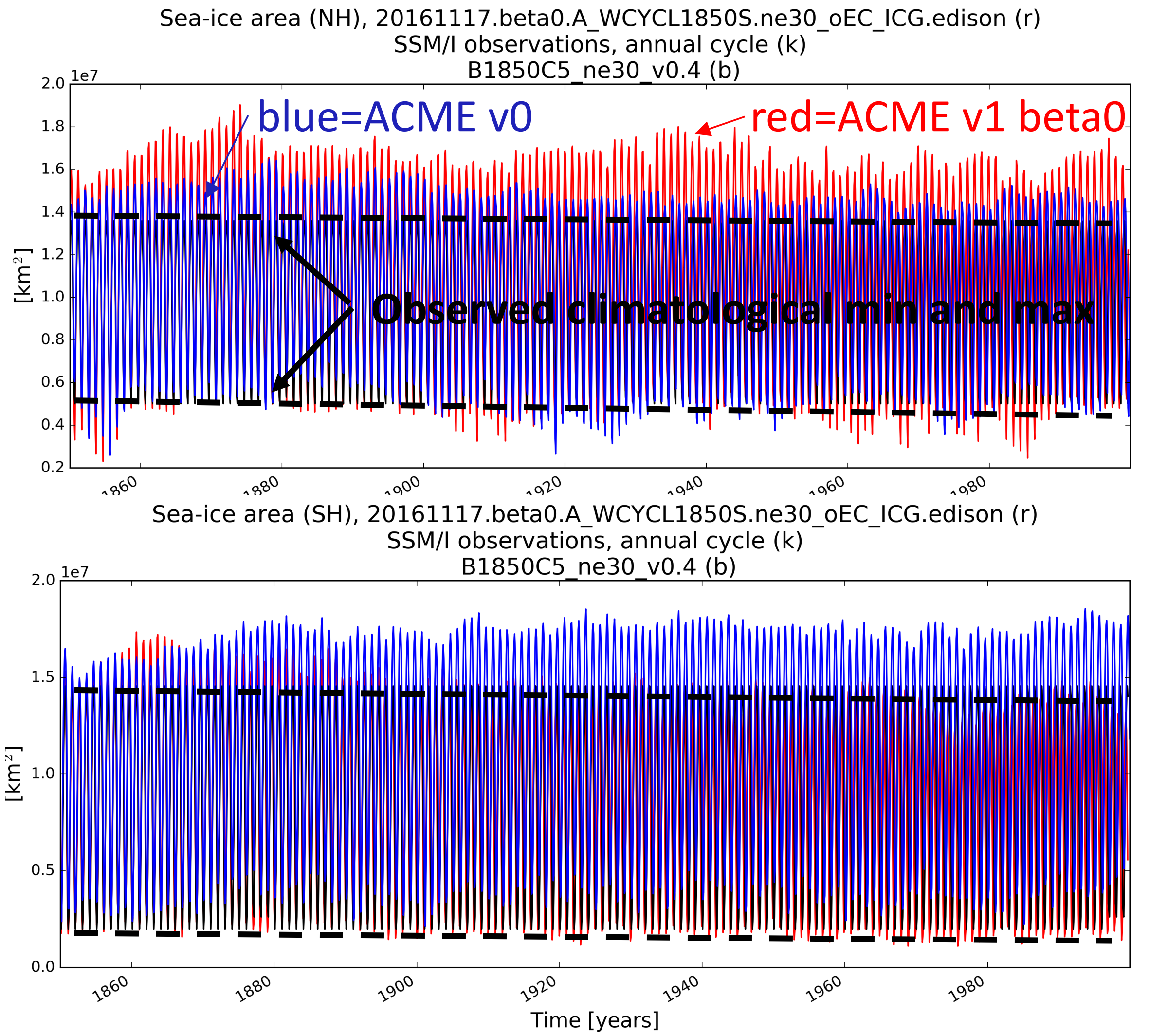


Fig: Left: Northern hemisphere ice thickness. Top: northern-hemisphere-averaged ice area. Bottom: southern-hemisphere-averaged ice area. All plots from ACME v1 beta0 PI control simulation. From Milena Veneziani.

High Frequency Variability

- ACME does pretty well with MJO and other high-frequency modes

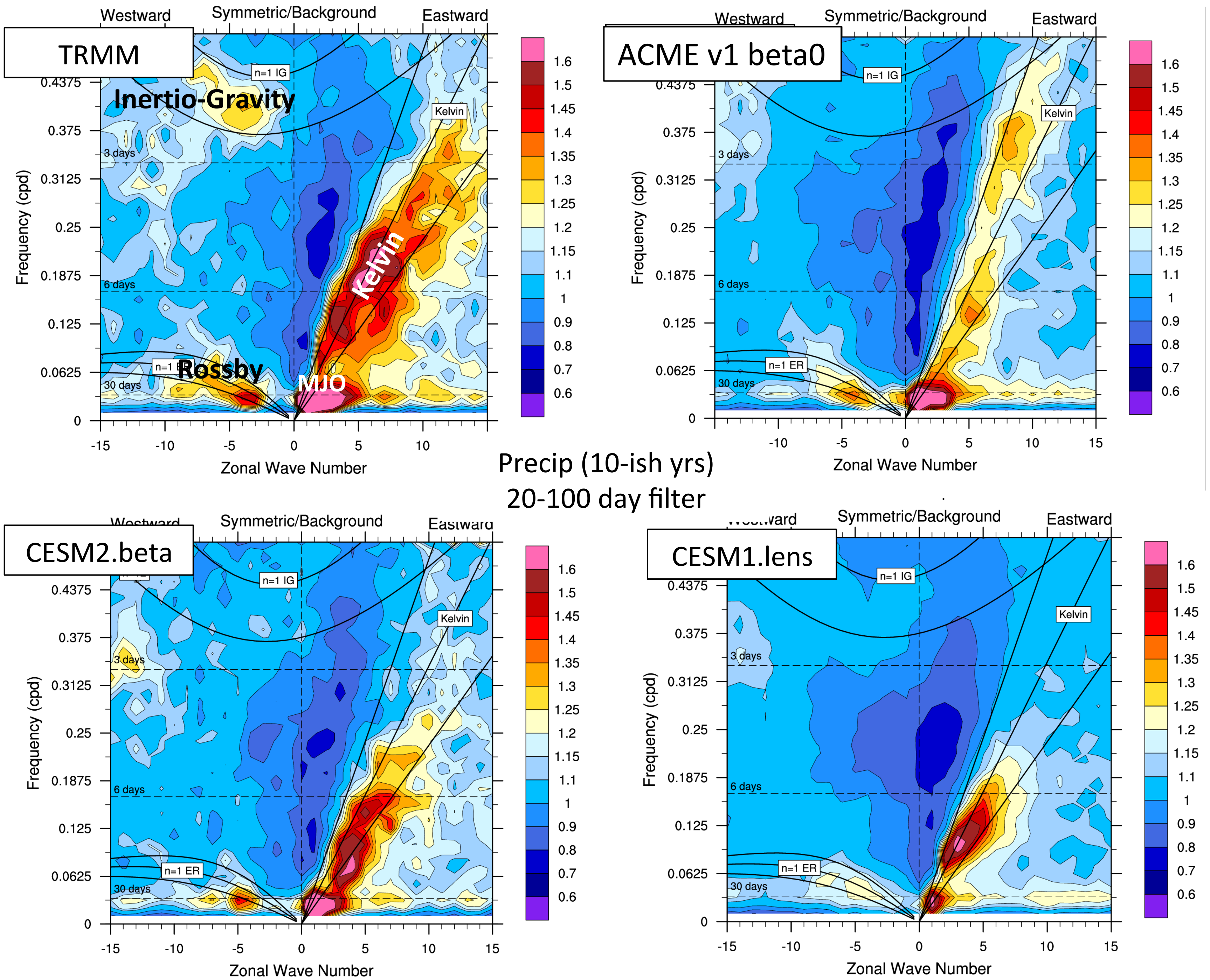


Fig: Time/space power spectra showing equatorially-trapped wave modes in CESM and ACME coupled runs. From Rich Neale.

Equilibration in ACME

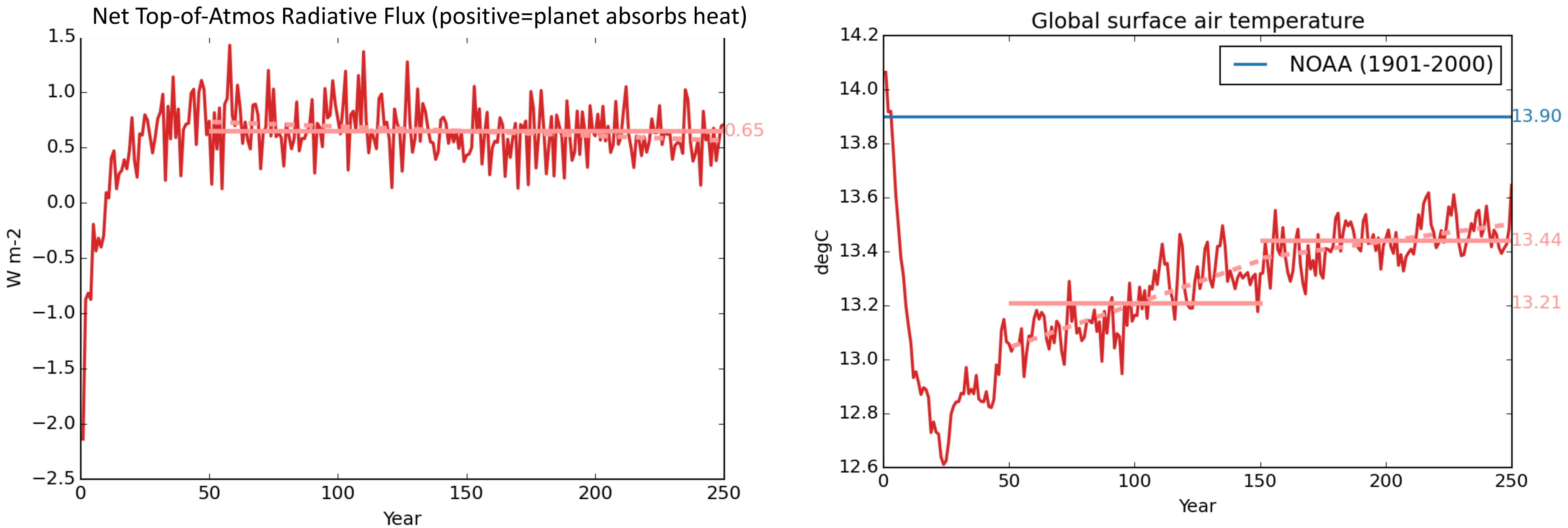
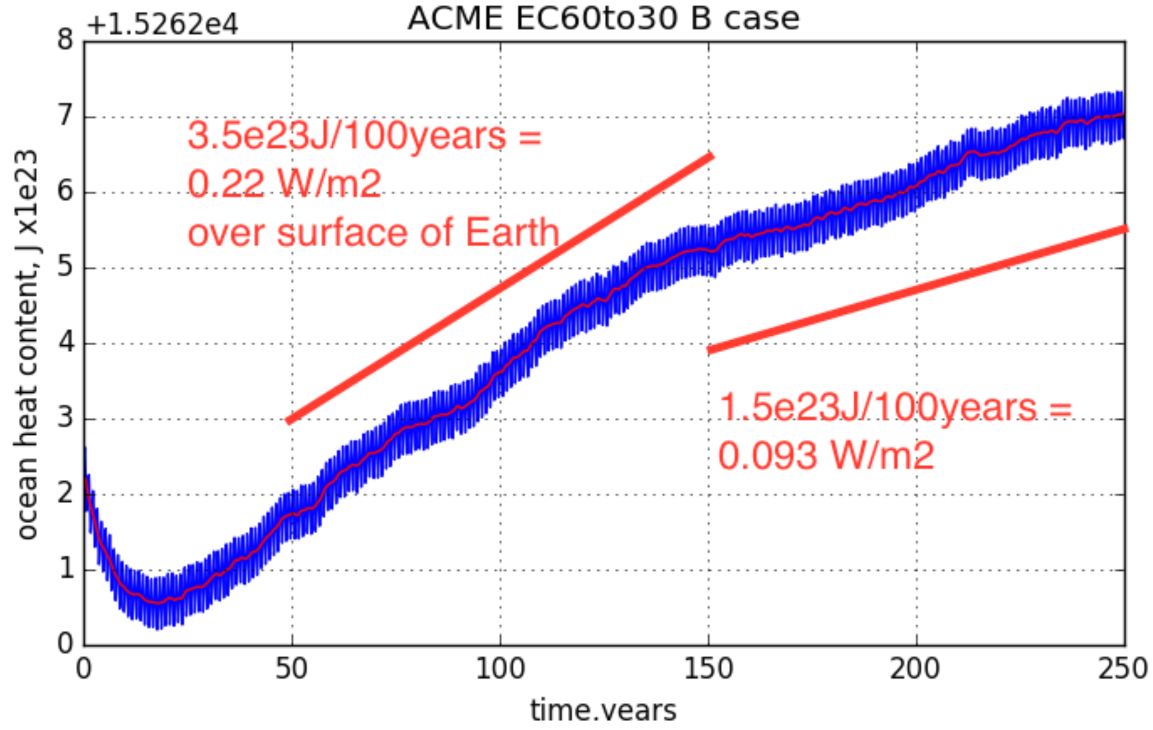


Fig: global-average TOA net radiation ("RESTOM") (left) and global-average surface temperature ("TS") (right) from ACME v1 beta0 run

- The climate system *seems* happy to stay out of energy balance indefinitely
- This energy input doesn't have much effect on surface temperature
  - This looks *similar* to CESM's experience with CAM5-SE (due to wind stress changes in S Ocn)

but the main reason for this behavior in ACME is different!

ACME Coupled Energy Balance



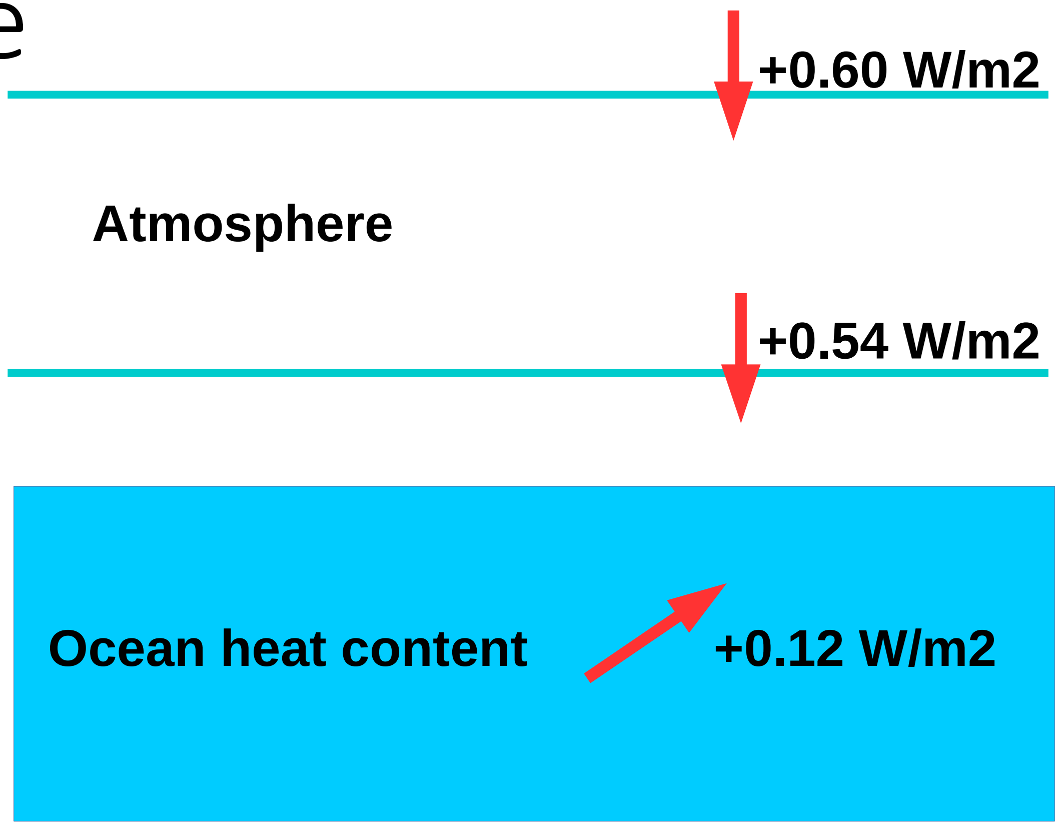


Fig: Left: ACME v1 beta0 ocean heat content from Mark Peterson. Right: Corresponding energy discrepancies from Chris Golaz

- Uh-oh! Energy transfer from the atmosphere to the ocean aren't consistent!
  - hypothesis: water rains back onto the ocean at a colder temperature than it evaporates

$$\mathbf{c_p \left(evap * T_{evap} - precip * T_{precip} \right) = 0.33\ W/m2}$$

⇒ much of this discrepancy comes from the atmosphere not keeping track of the internal energy of condensate

Sensitivity

- Equilibrium climate sensitivity (ECS) from a 150 yr abrupt4xCO2 run is **4.5 K**
  - the net feedback parameter from 5 yr F2000 and F2000+4K Cess runs is **-1.4 W/m2/K**
    - The range of CMIP5 net feedback values is -1.05 to -1.95 W/m2/K, so ACME is fairly typical
  - At ¼^0, the net feedback parameter is **-1.2 W/m2/K** (suggesting increased ECS at high resolution)
- The Total Adjusted Forcing (TAF, the TOA net radiation difference between F1850 and an F2000 run with 1850 SST) is **1.2 W/m2**
  - The the CMIP5 mean TAF was 1.7 W/m2 with σ = 0.9 W/m2, so ACME is on the low side of average (due to strong aerosol indirect effect)
  - At ¼^0, TAF is **1.9 W/m2** suggesting aerosol effects weaken at higher resolution, as found for CAM5 by Ma et al. (GRL 2015)

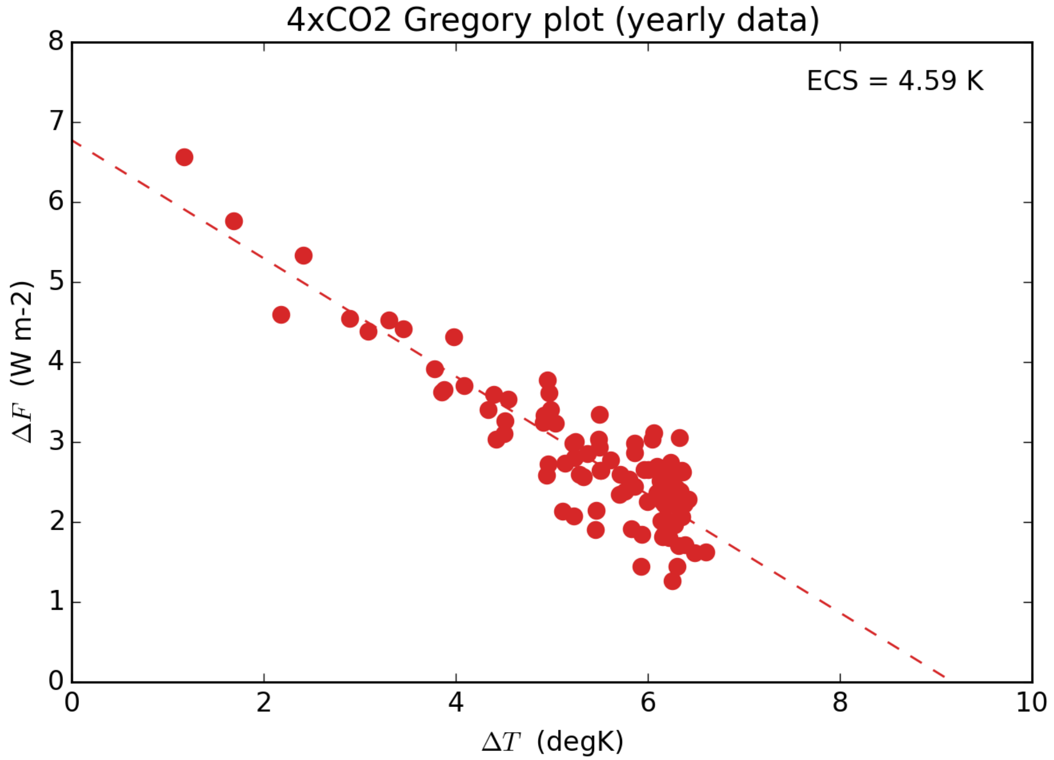
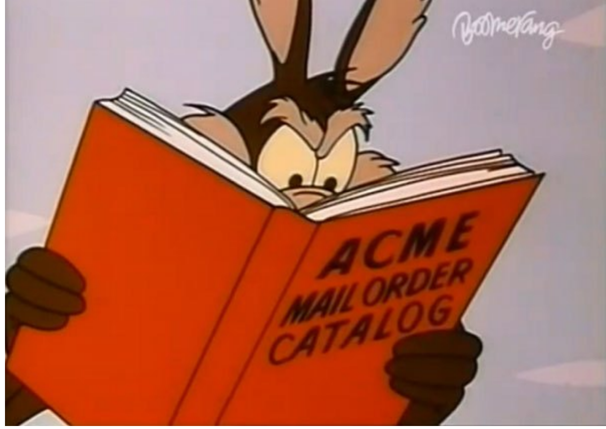


Fig: scatter plot of global-average TOA radiative and surface temperature changes (relative to 1850 control) after abruptly quadrupling CO2 in ACME v1 beta0 simulation. From Chris Golaz.

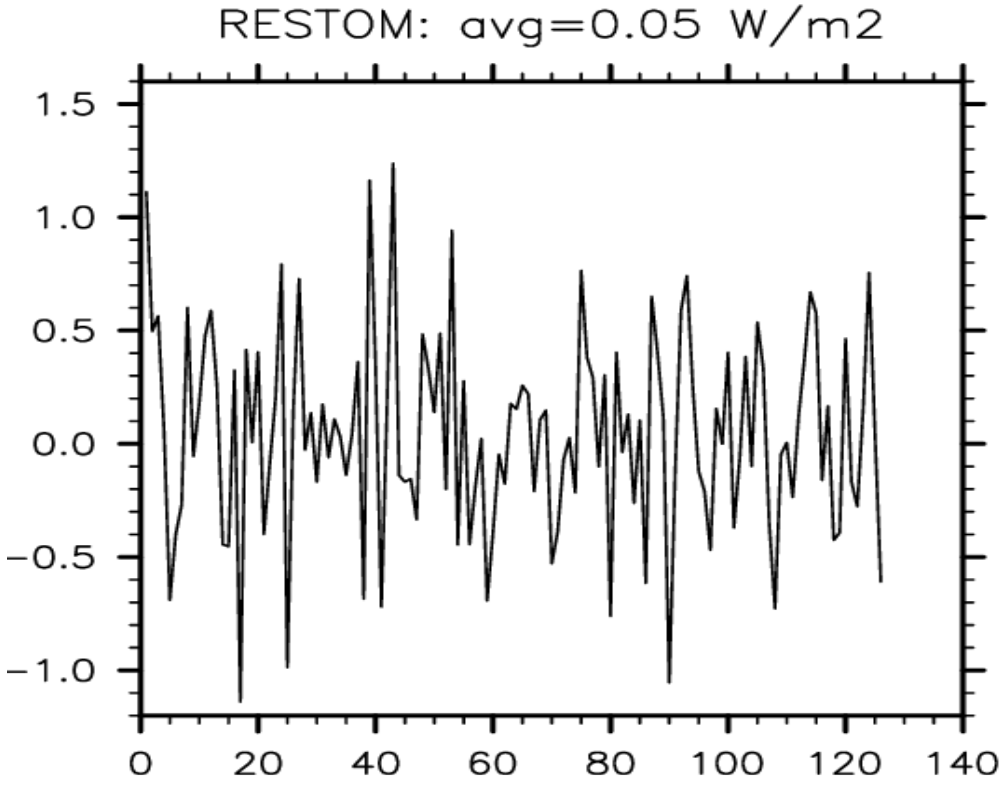
Conclusions:

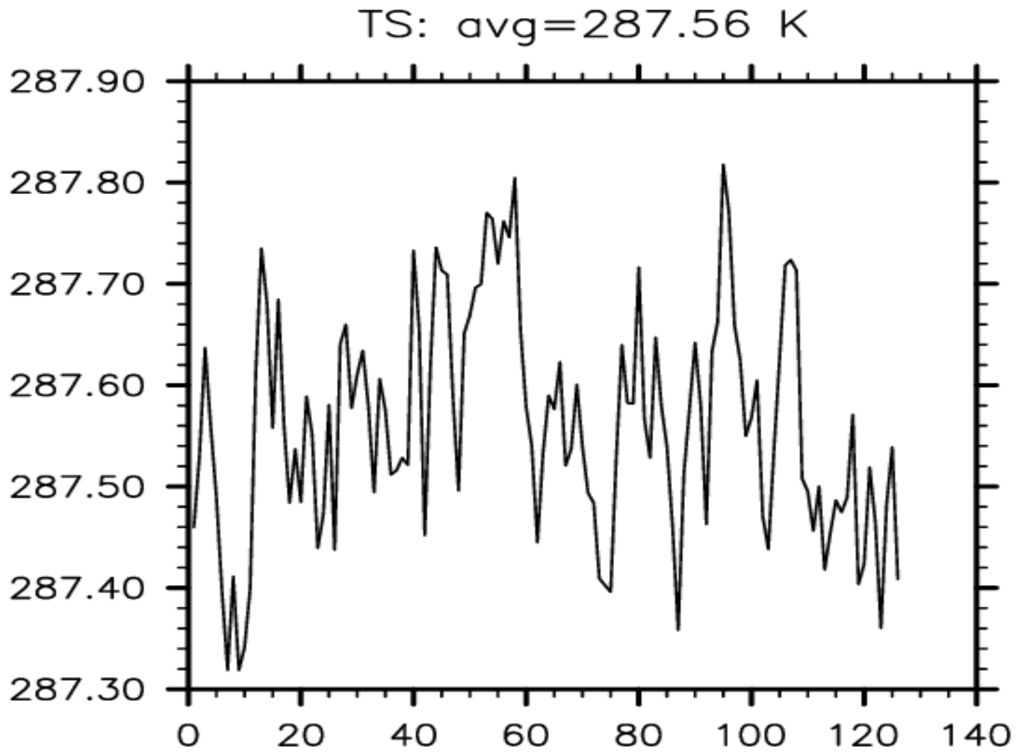


- ACME has made some bold changes (increased vertical resolution, SE dycore, MPAS ocean and ice) and working out the resulting kinks will take some time
- ACME only matured to the point where we can do coupled runs a few months ago, which puts us about a year behind CESM… and it shows
  - but ACME is already a middle-of-the-road CMIP5 model
  - we are still working through bugs and issues (so improvement is likely)
- Most biases are shared by both ACME and CESM, indicating that problems are *structural* rather than related to *tuning*

Extra Slides

Equilibration in CESM2 run 125





- CESM starts at RESTOM near zero and stays there.

ENSO

- ACME currently lacks ENSO
    - we are working to fix this

CESM 2.beta

V1. beta

Obs.
Had (20th C)

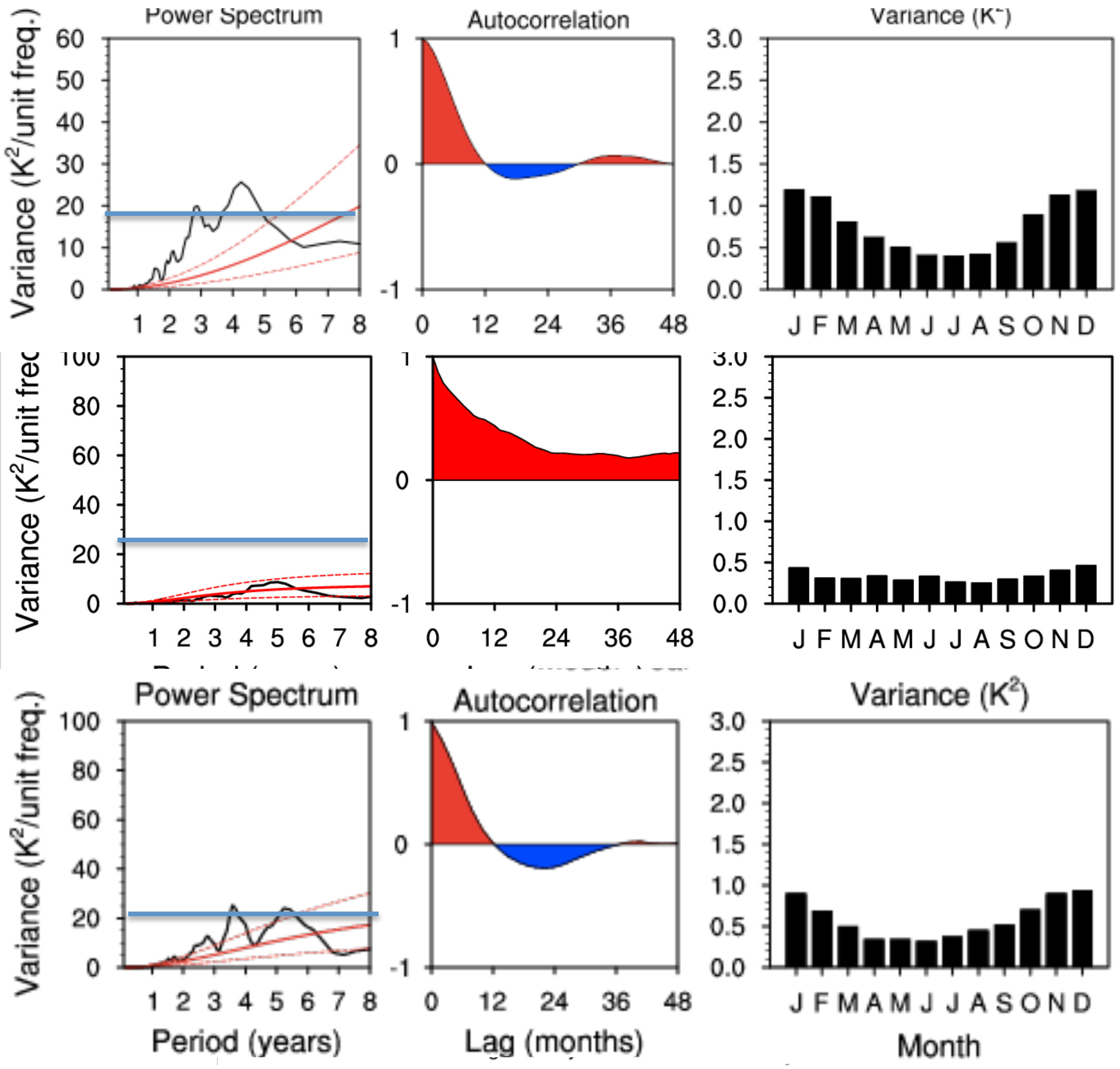
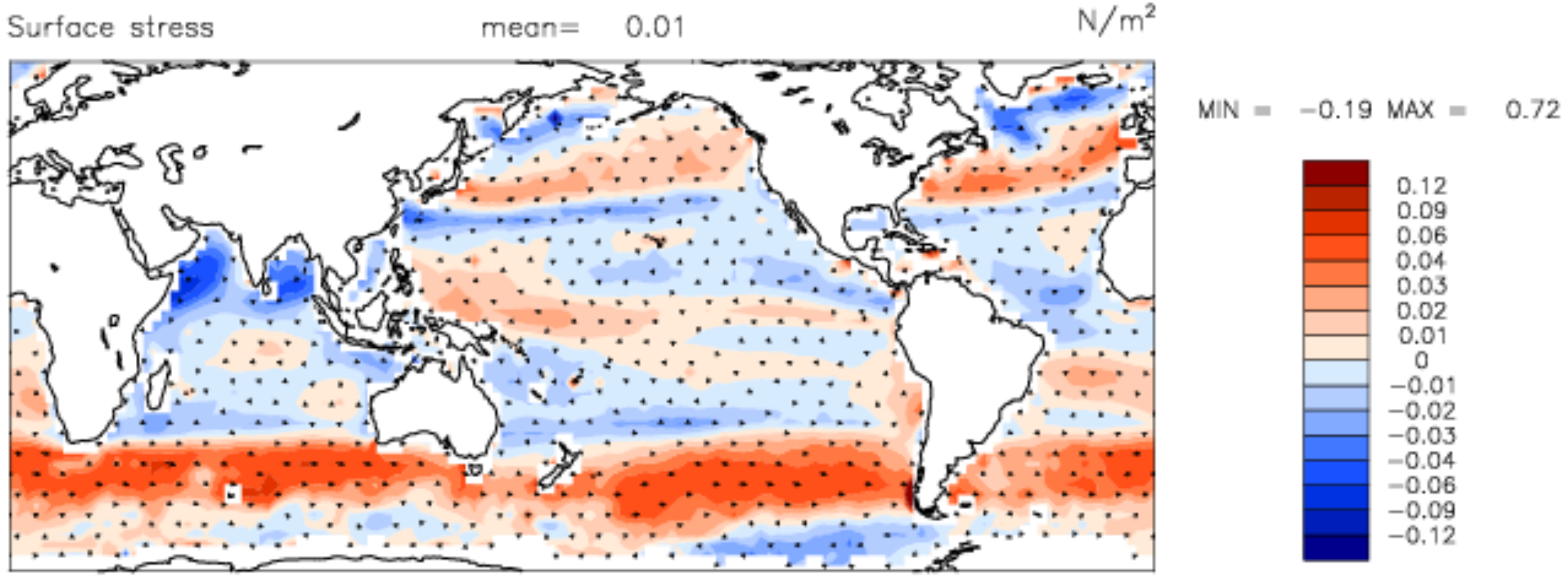


Fig: Nino3.4 power spectrum (left column), autocorrelation (middle column), and seasonality (right column). From Rich Neale.

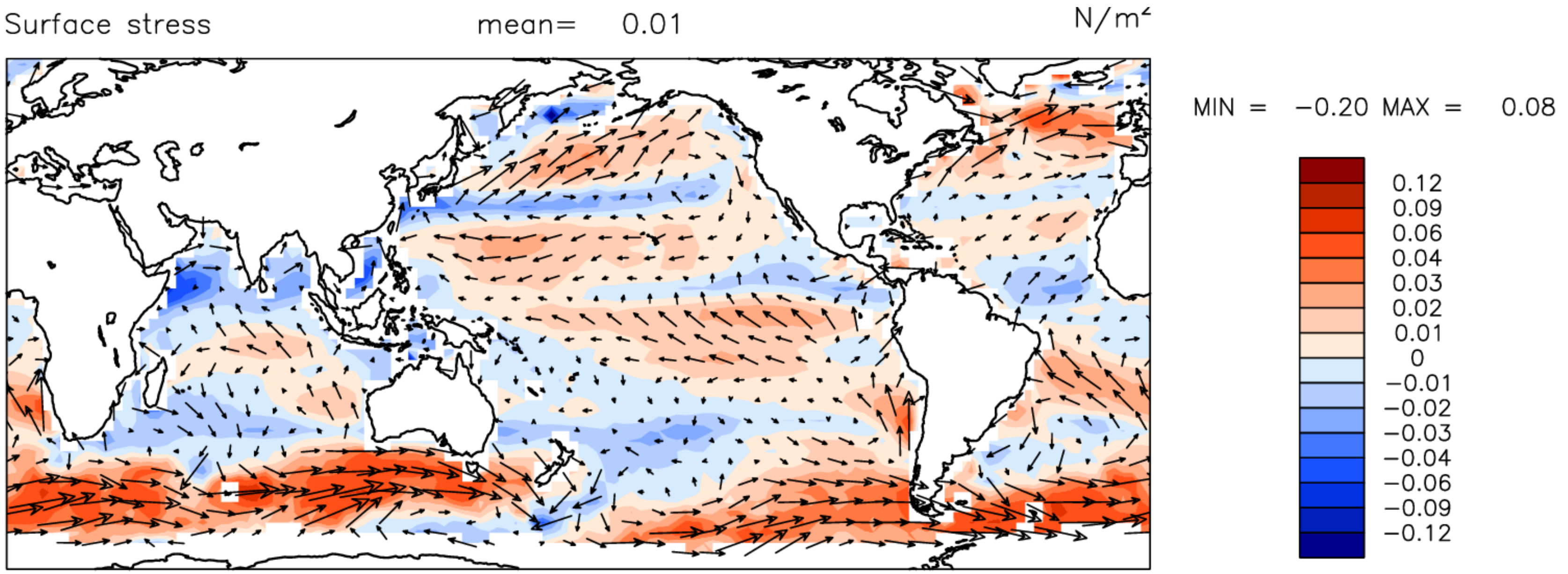
Wind Stress

- Wind stress bias is fairly similar in both models

ACME v1 beta0 1850 Coupled (yrs 101-130)



CESM2 run 125 1850 Coupled (yrs 100-119)



Ocean Heat Content

- CESM found that persistent imbalance when using the SE dycore came from wind stress differences over the Southern Ocean
- ACME was hoping that switching ocean models would solve the problem…
- We're working on it...

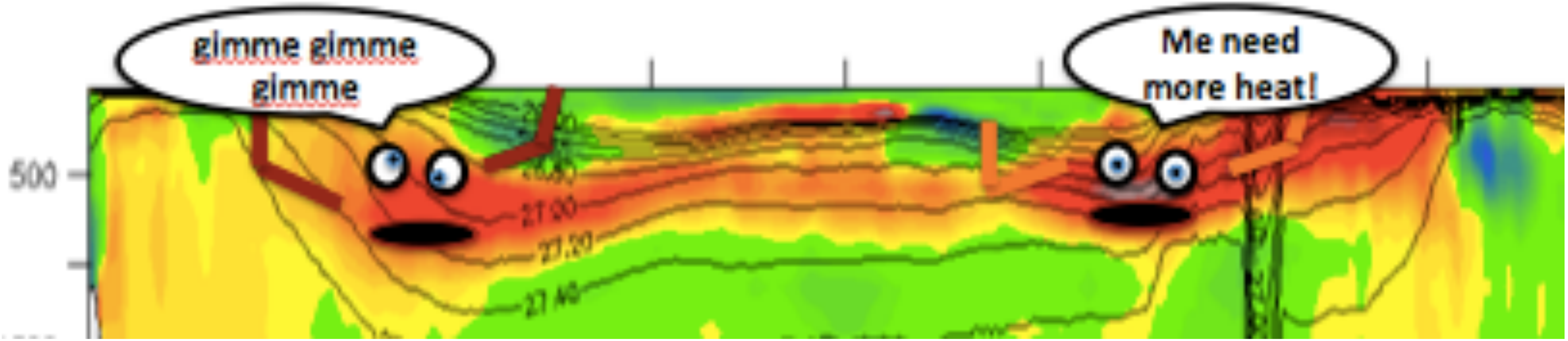
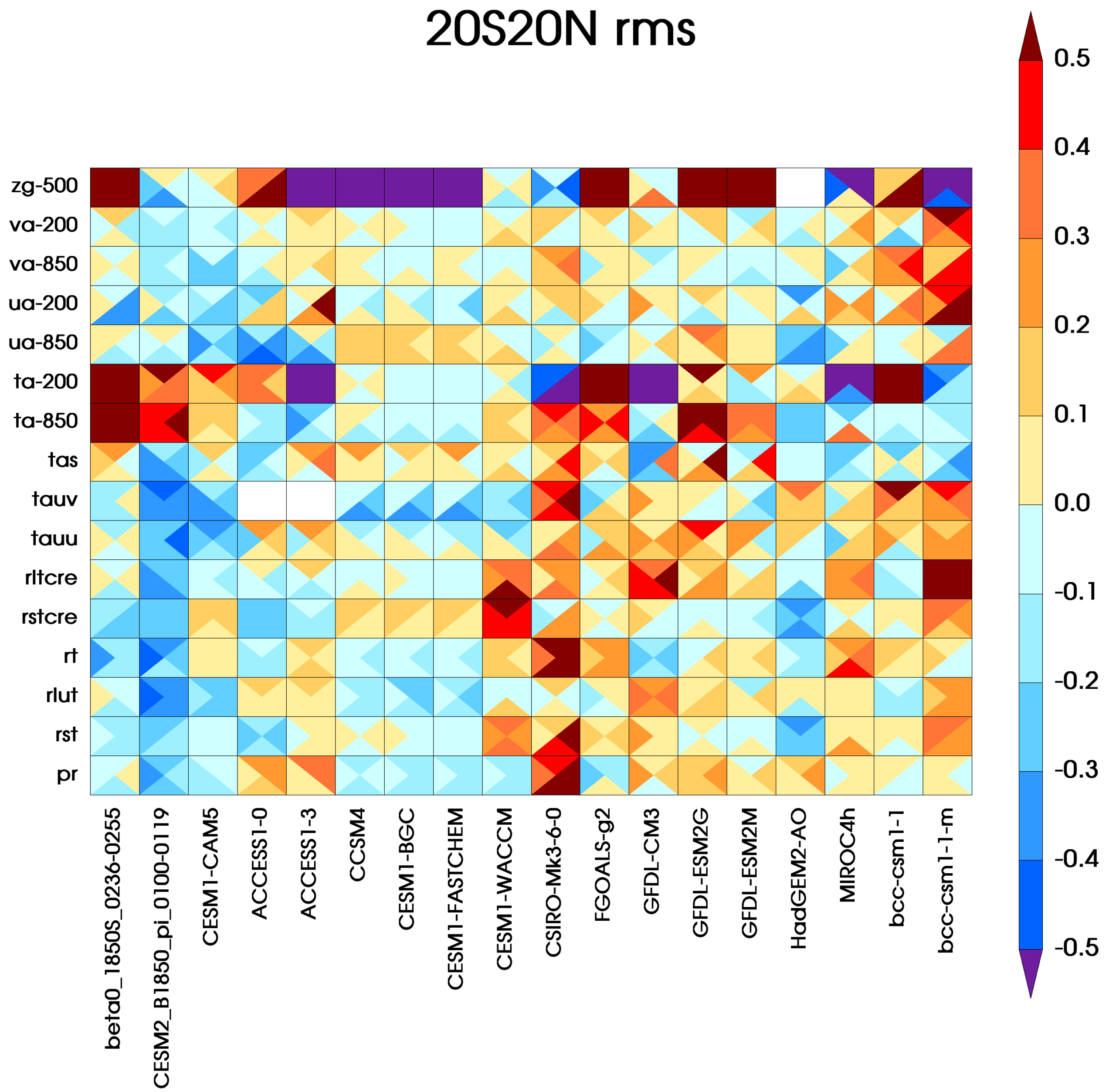


Fig: an atmospheric scientist's understanding of why the ocean is taking up heat. Ocean warming lat-height plot from an early (CESM1-like) version of ACME.

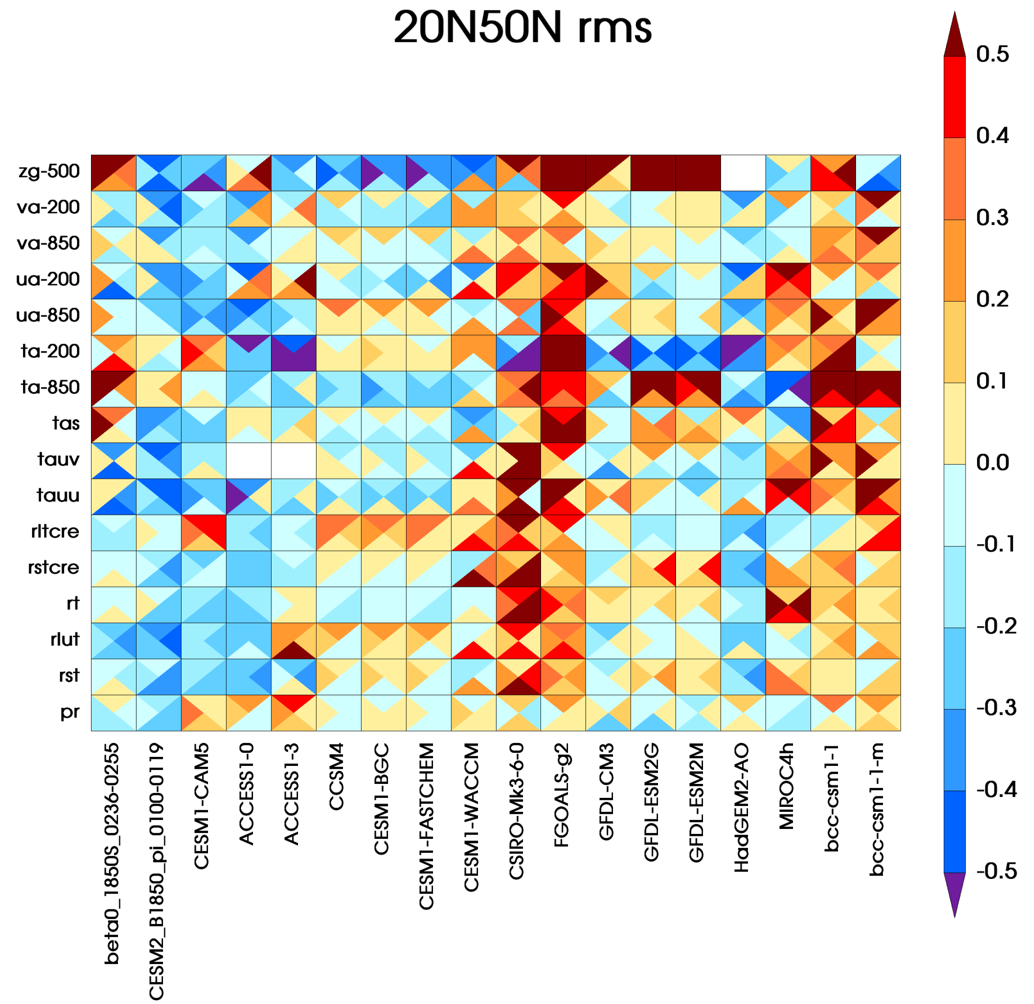
Tropical PMP

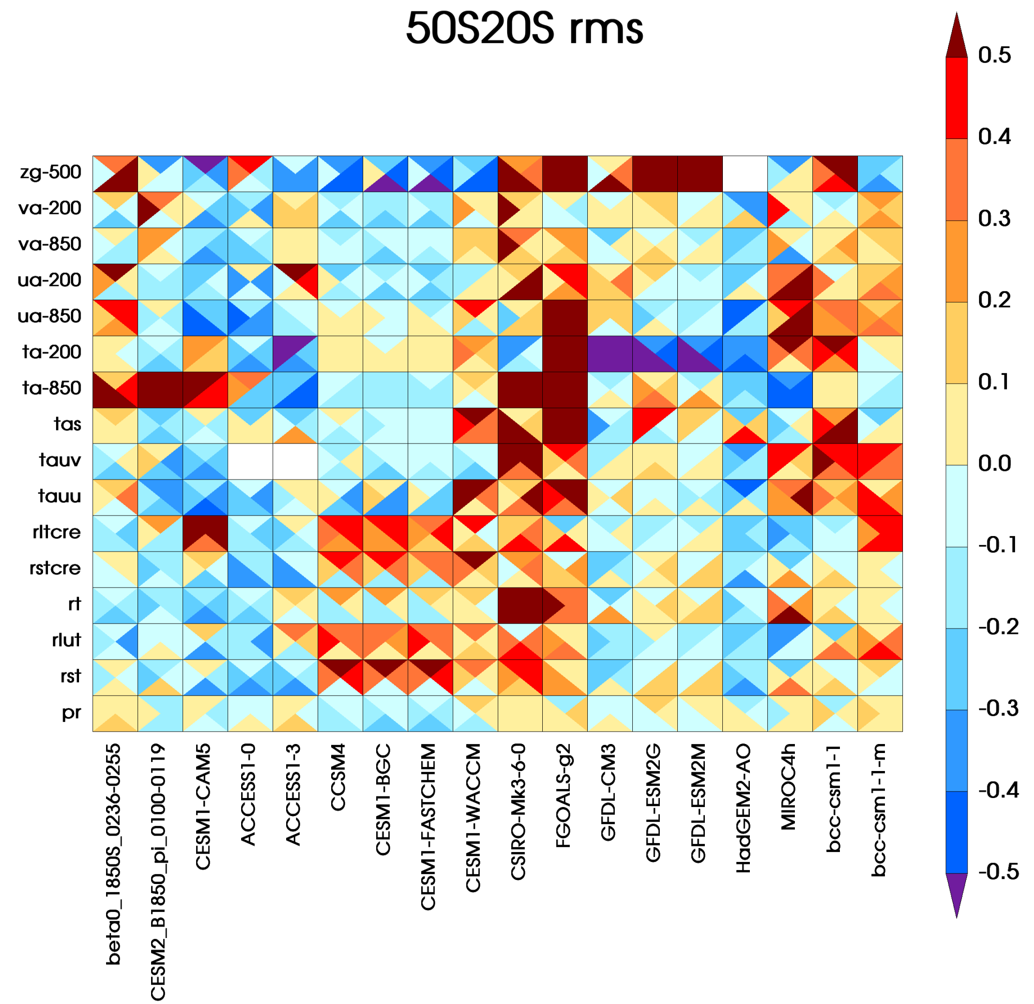
- adsf



20-50 Lat

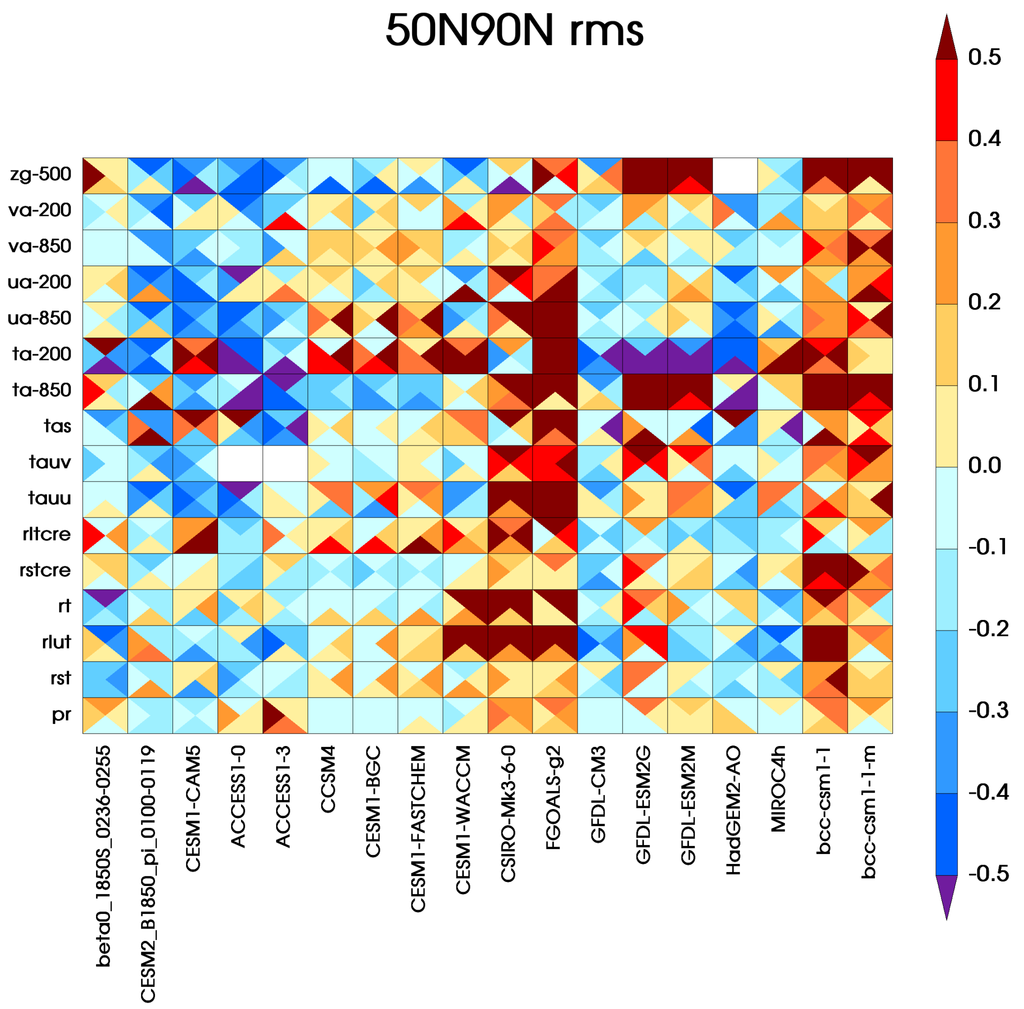
- asdf

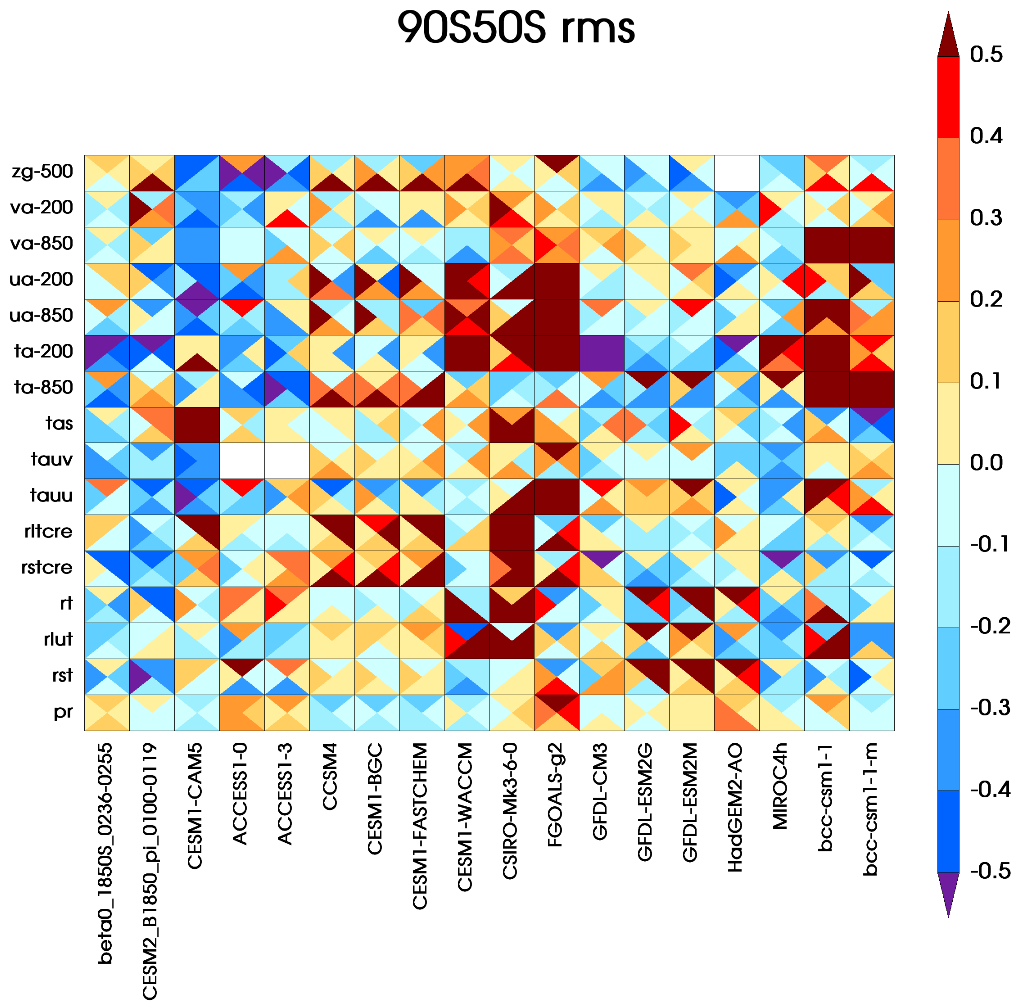




High Lats

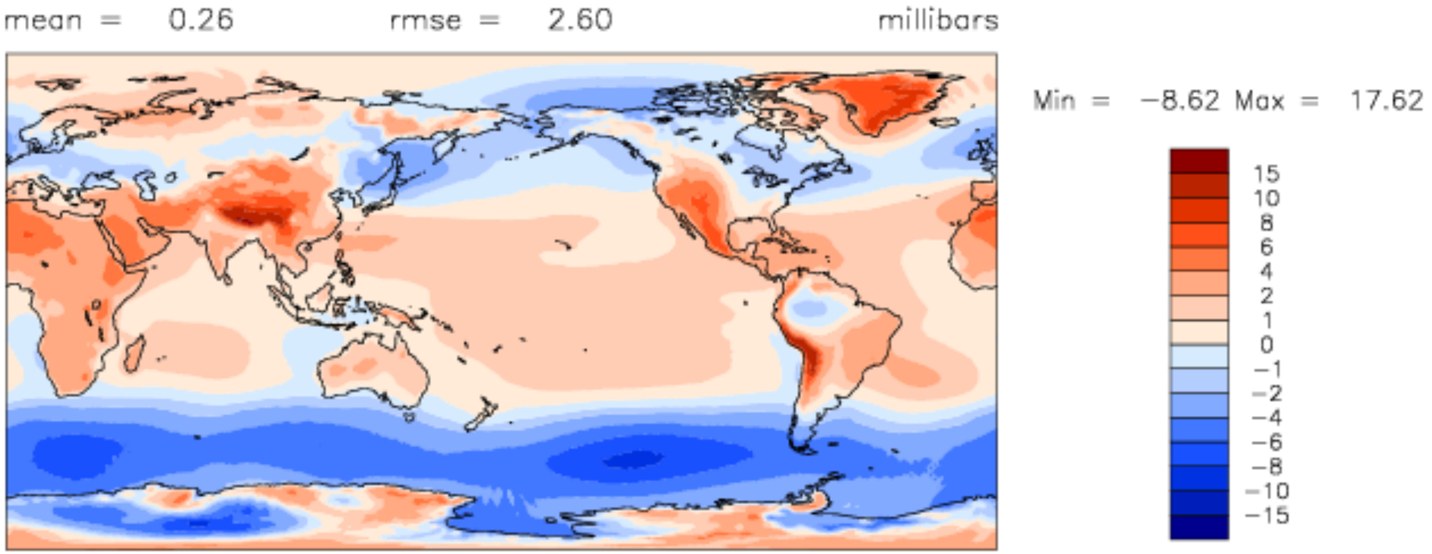
- adsf

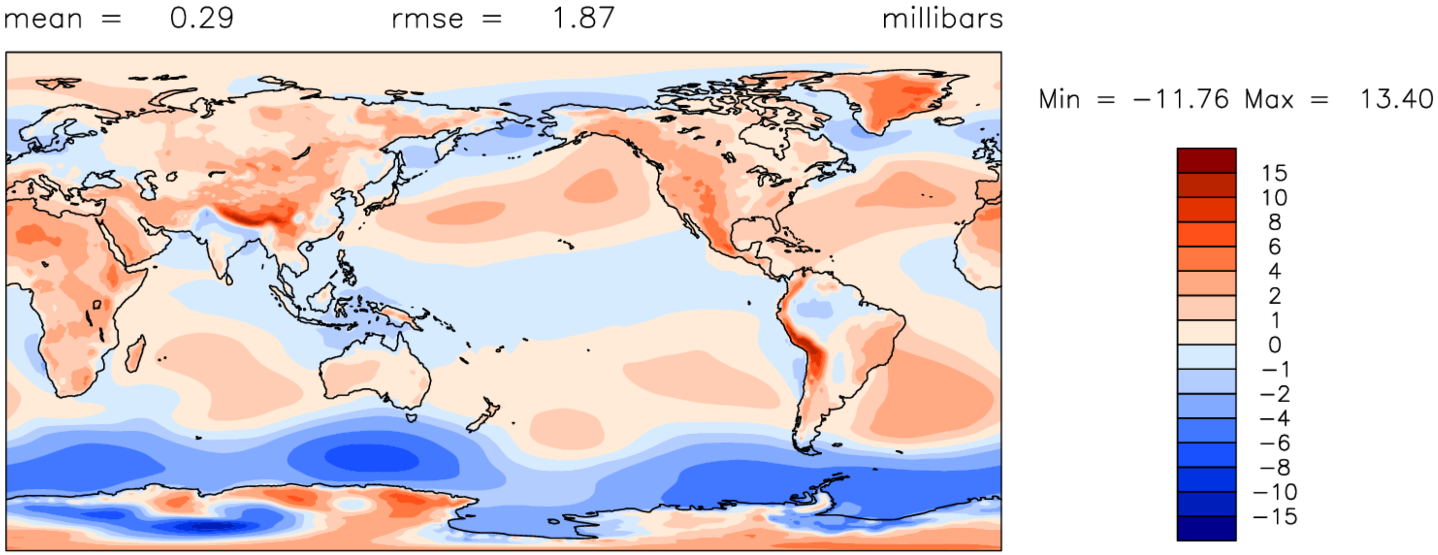




Sea Level Pressure

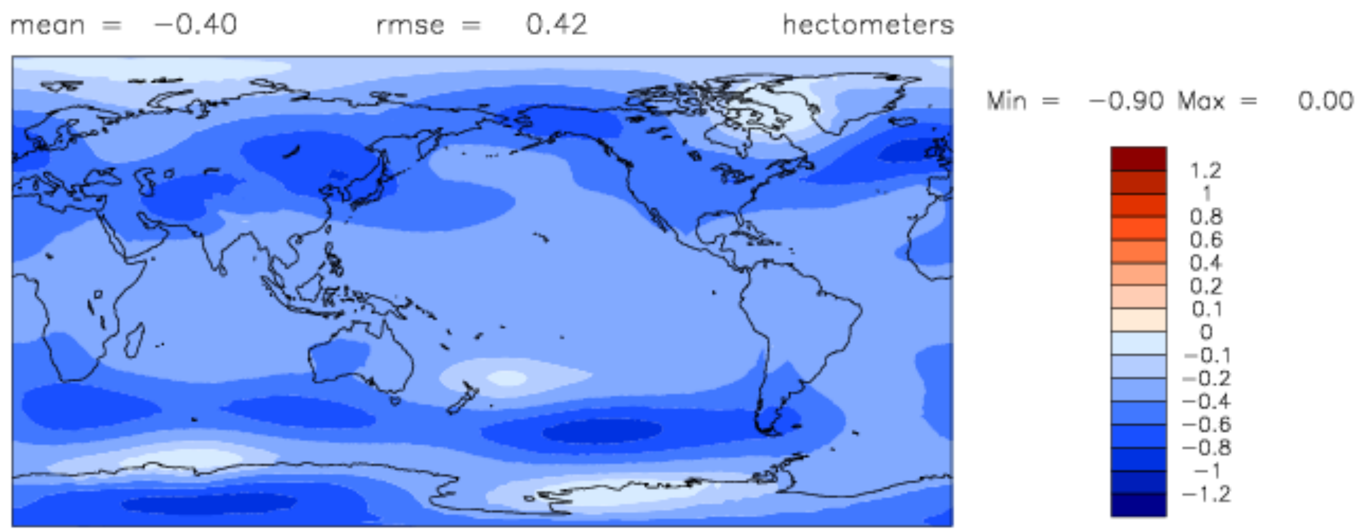
- S Ocn bias consistent with 850 mb T?

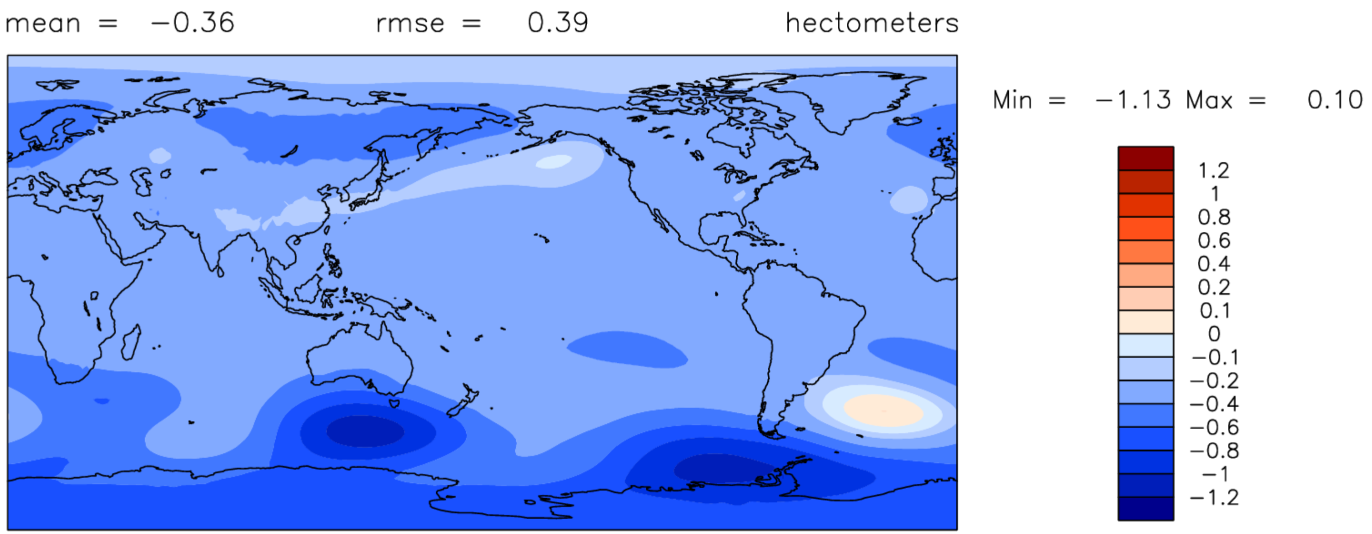




500 mb Geopotential Height

- Using ERAI as obs
- not sure what to say





Impact of Vertical Resolution on Stratocumulus

- Experience in CESM is that vertical resolution does not explain Sc differences

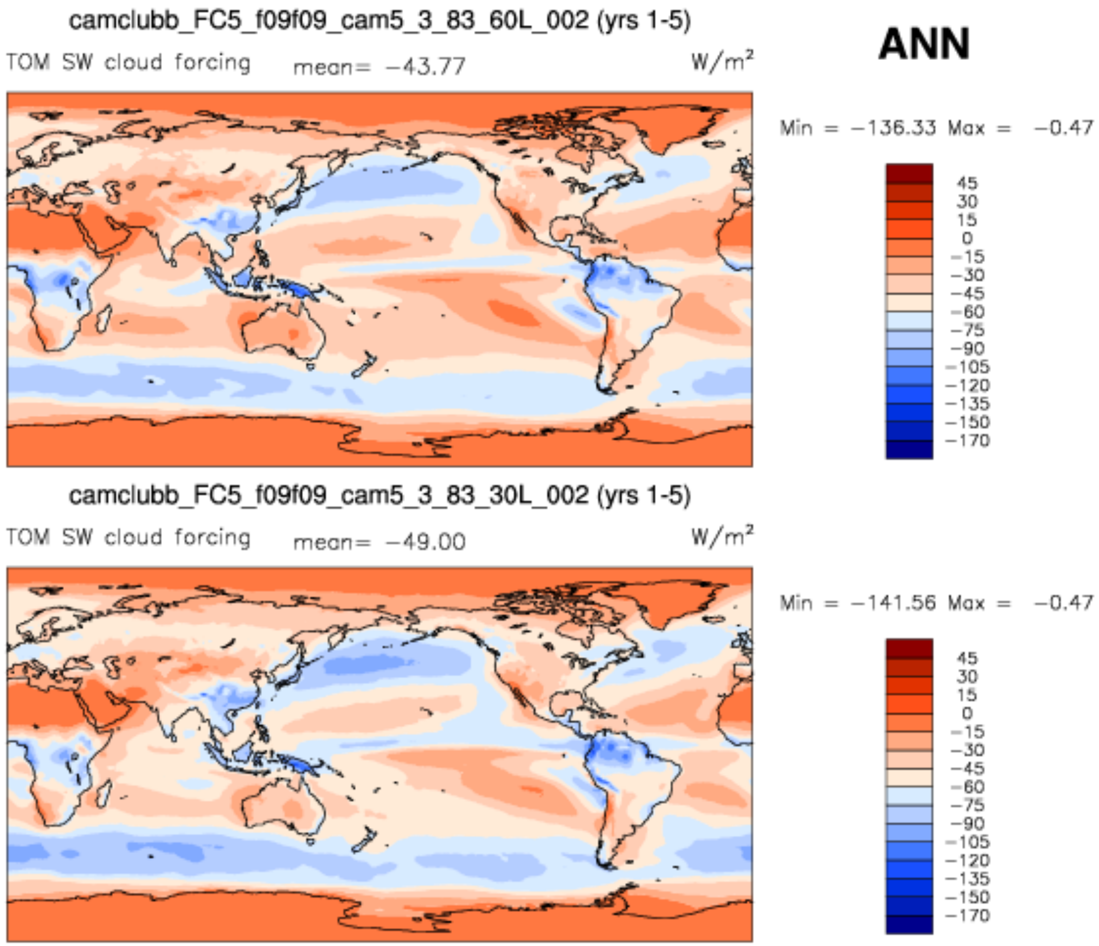


Fig: SWCF from CAM5.5 with 60 layers (top) and 30 layers (bottom) don't show much difference. Plots from Pete Bogenschutz.