A CAM5 Configuration with Improved Cloud Physics Consistency

Peter Caldwell, Dan Bergmann, Steve Klein, Sungsu Park, Hugh Morrison, Phil Rasch, Xiaohong Liu, et al.

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Issue #1: Cldfrac/Condensate Coupling

In CAM5:

1. Liq cloud fraction A_l from triangular PDF with width mimicking Rh_{crit} from CAM4
2. Liq condensate q_l is computed to satisfy:

$$RH_{in-cld} = 1 = f(q_t, q_l, q_i, T_c, A_l) \Rightarrow \frac{dq_{l,in-cld}}{dt} \approx \alpha \frac{dq_t}{dt} + \beta \frac{dq_l}{dt} + \chi \frac{dq_i}{dt} + \delta \frac{dT_c}{dt} + \varepsilon \frac{dA_l}{dt}$$

(given: $\frac{dq_t}{dt}$, $\frac{dq_i}{dt}$, $\frac{dT_c}{dt}$)

- *Condensational heating changes cloud fraction, handled via iteration.*
- *Consistency between A_l and q_l ensured via "if" statements*

constraint: $$\frac{dq_l}{dt} = A_l \frac{dq_{l,in-cld}}{dt} + q_{l,new} \frac{dA_l}{dt}$$

$$\frac{dA_l}{dt} \approx \frac{A_{l,new} - A_{l,old}}{\Delta t}$$

In New Scheme:

- Cloud fraction and condensate *both* computed assuming a truncated Gaussian PDF
- PDF width and ice are treated ~ as in default model

$$\text{Cloud Fraction} = \int_0^\infty PDF(s)\,ds \qquad \text{Cloud Mass} = \int_0^\infty s \cdot PDF(s)\,ds$$

saturation excess $s = q_t - q_i - q_s(T,p)$

Benefit:

- Single parameterization for q_l & A_l improves consistency, simplicity, and efficiency

Issue 1.5: Infinite Tails

- Infinite tail of Gaussian PDF ⇒ $q_l > 0$ everywhere
- Where q_v is small this can reduce RH and hence ice cloud fraction
- Truncating PDF fixes this issue

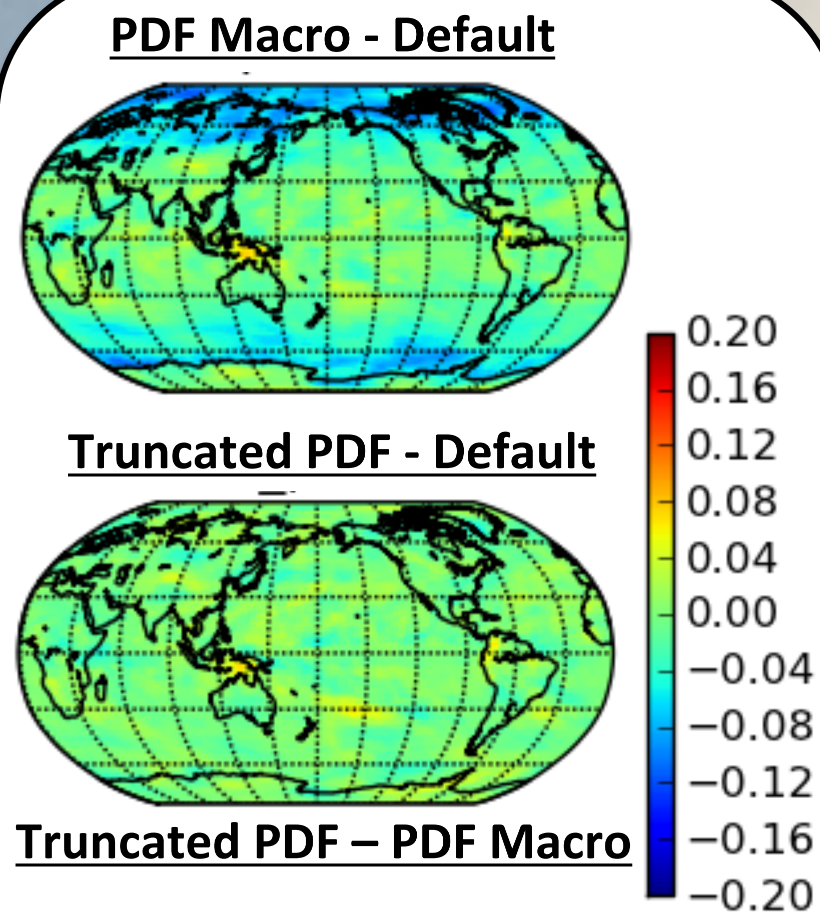


Fig: 5 yr ave ICECLDF differences @ ~300 mb for PDF and PDF truncated at μ±2σ (versus default)

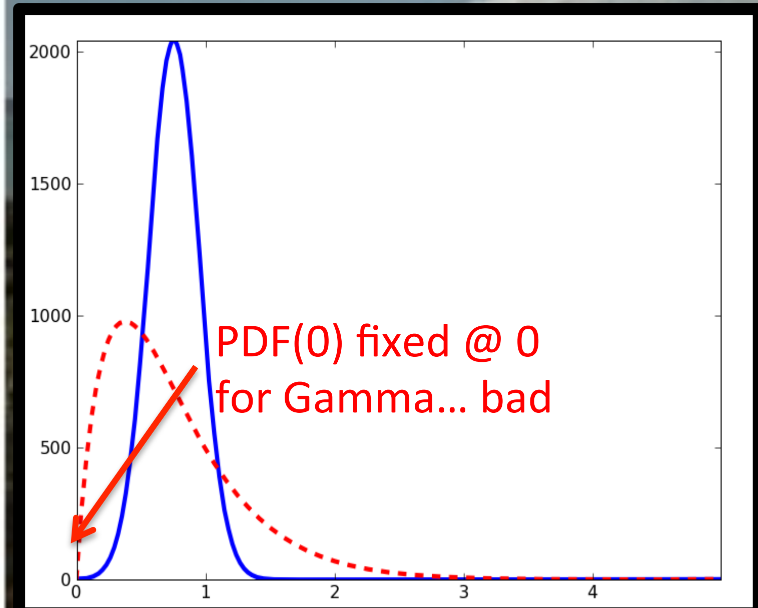
Issue #2: Inconsistent SGS Assumptions btwn Macro/Microphysics

In CAM5:

- Subgrid-scale (SGS) variability in q_l is assumed to follow a **gamma** distribution for **autoconversion**, **accretion**, and **droplet freezing** calculations which is inconsistent with the Gaussian or triangular PDF assumed in macrophysics

In New Scheme:

- The Gaussian PDF used for macrophysics is truncated at s=0 and used for these processes. Implemented as table-lookup⇒efficient



Impact:

- +skewness & PDF(0)=0 make Gamma tails larger ⇒ new scheme should have generally weaker process rates

Fig: Gaussian (blue) vs Gamma (red) PDF for same atmospheric state.

Issue #3: LWC/Droplet # Inconsistency

In CAM5:

Macro creates q_l, Activ creates n_l → Micro procs → ½ of new n_l added → sed, rad, etc

2 substeps

New q_l applied ***but not n_l***

In New Scheme:

q_l AND n_l are updated before microphysics

Impact:

ARSCL Obs Cloud Frac | CAM5 Cloud Frac | Cloud Frac w/ this Fix

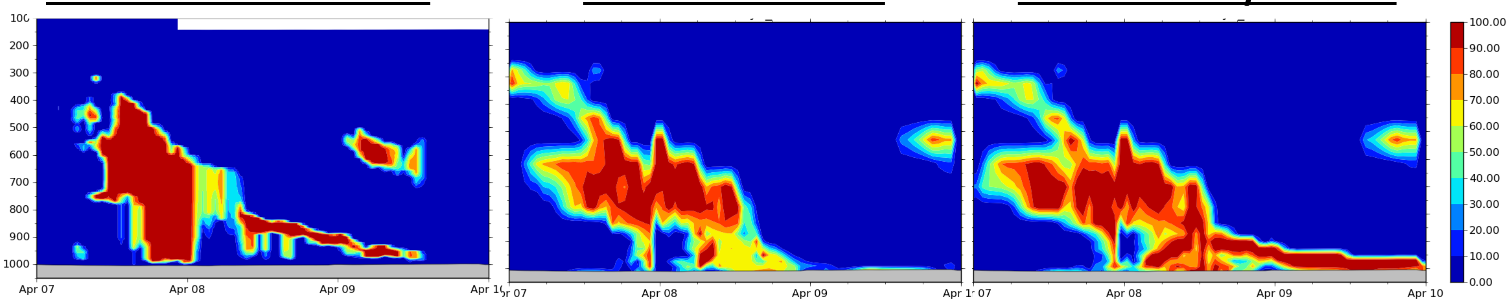


Fig: MERRA-driven 24-48 hr CAPT forecasts for ISDAC “Golden Day” (Courtesy J. Boyle)

Issue #4: Macro/Micro Decoupling

In CAM5:

Macro creates q_l → Micro depletes q_l (2 substeps) → Radiation sees depleted q_l

In New Code:

Macro creates q_l → Micro depletes q_l (2 substeps)

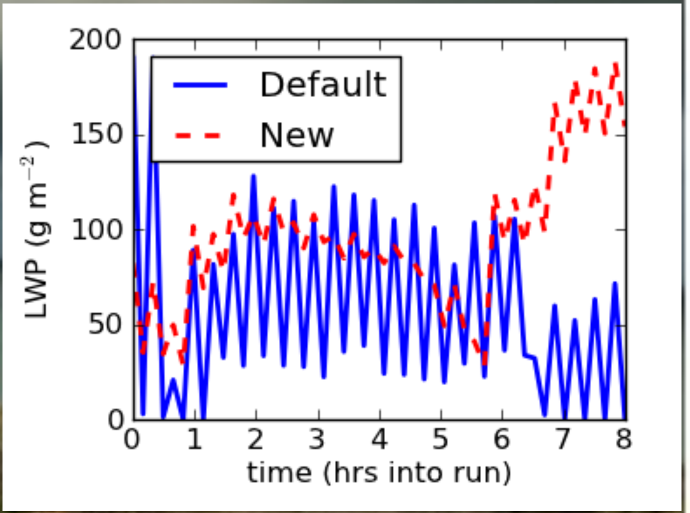


Fig: LWP sampled before and after microphysics for MPACE-B single column run with default and all fixes.

Issue: Schemes are acting independently for too long!

Results:

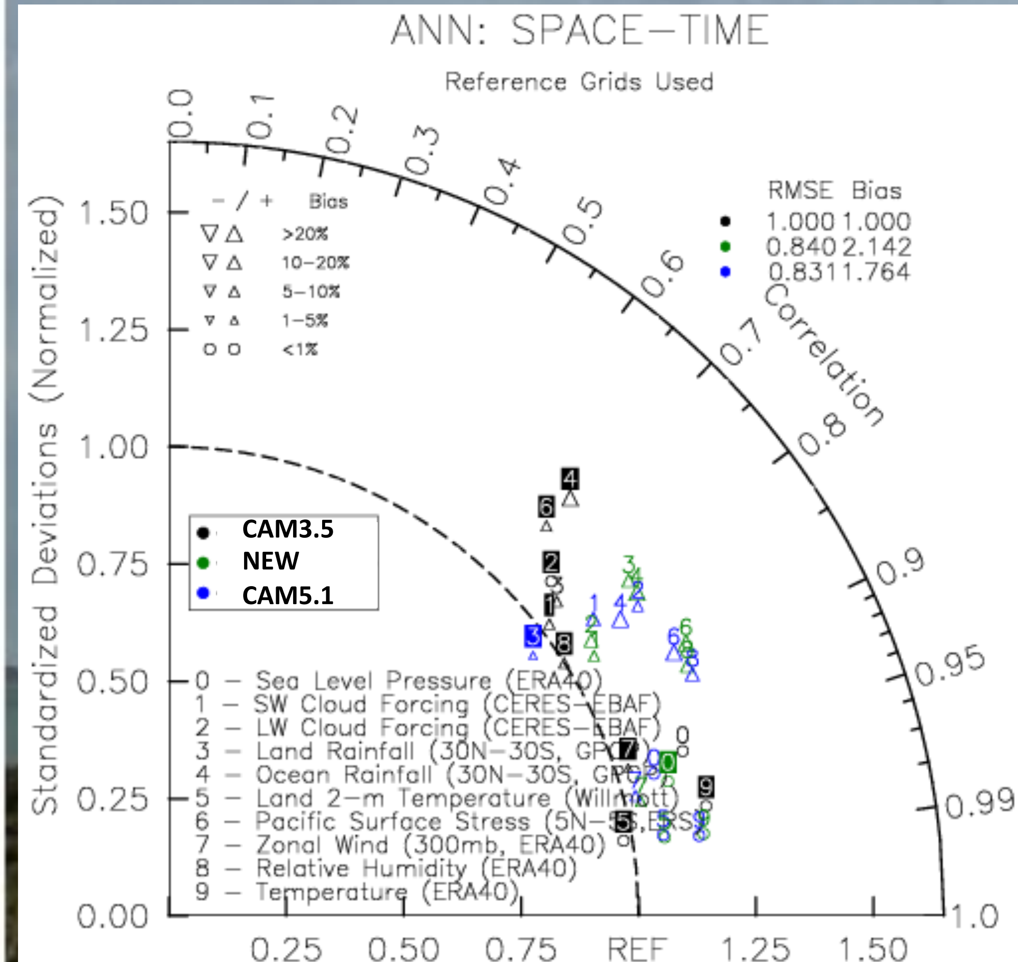


Fig: Taylor plot summary of old and new runs (10 yr climatological Y2K SST, no tuning done).

- Overall RMS is ~unchanged
- PDF macro runs ~8% faster than default (but sub-stepping macro undoes gain?)

Shortwave Cloud Forcing

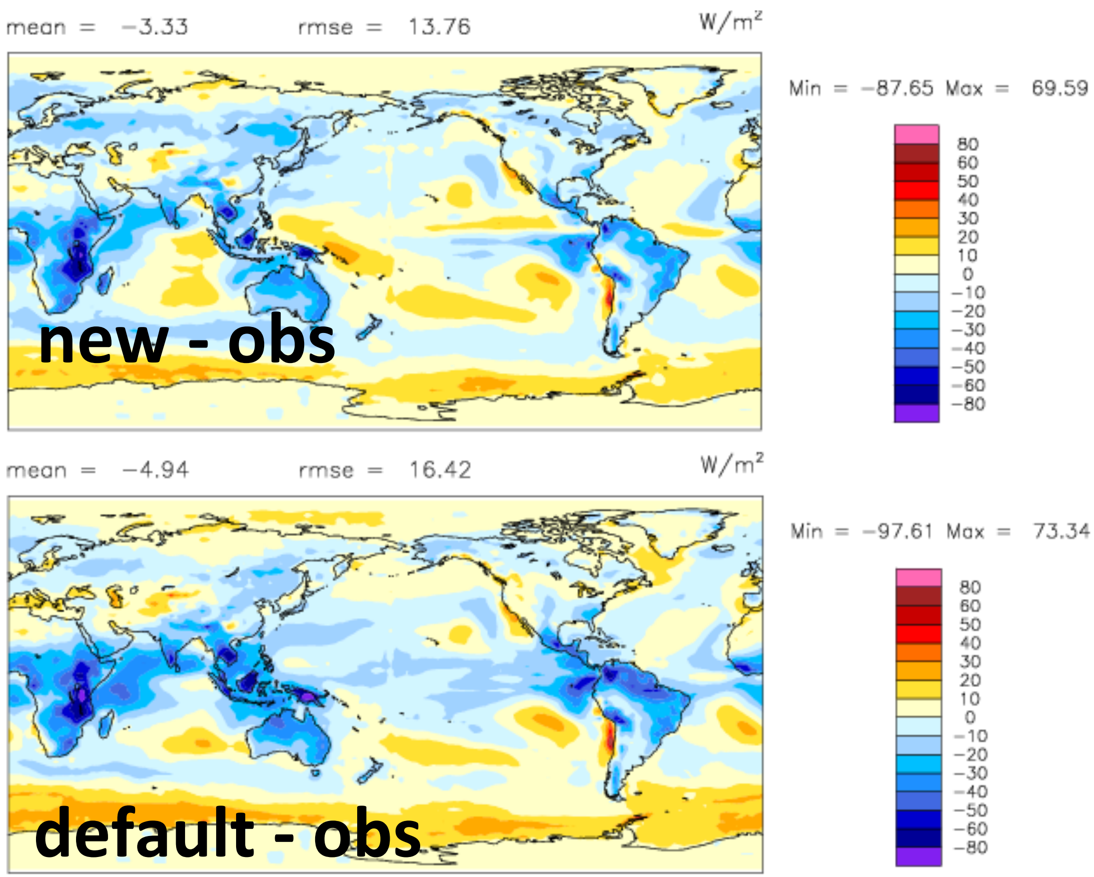
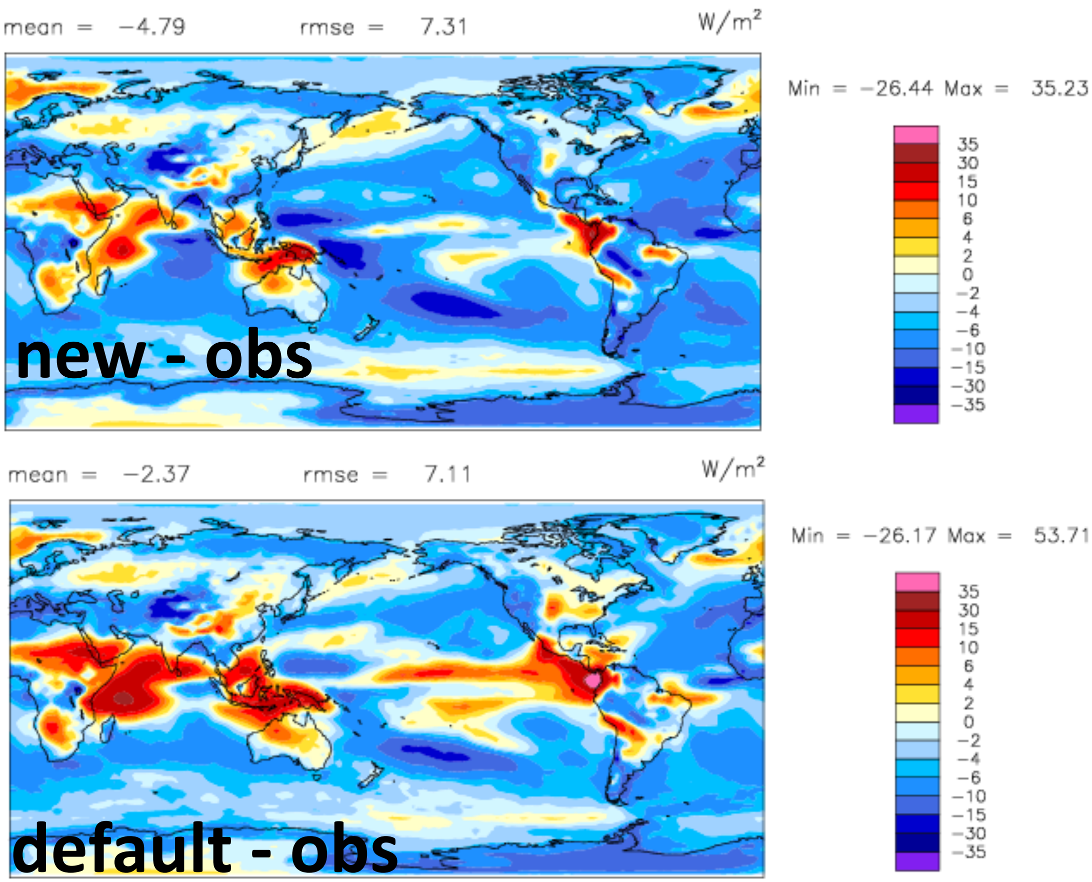


Fig: Shortwave Cloud Forcing (SWCF) bias from default and new runs. Obs = CERES-EBAF

- SWCF improves
- since default model tuned to compensate SST bias ⇒ out of rad balance?
  - TOA net rad=2.3 W/m^2 vs 0.3 for new

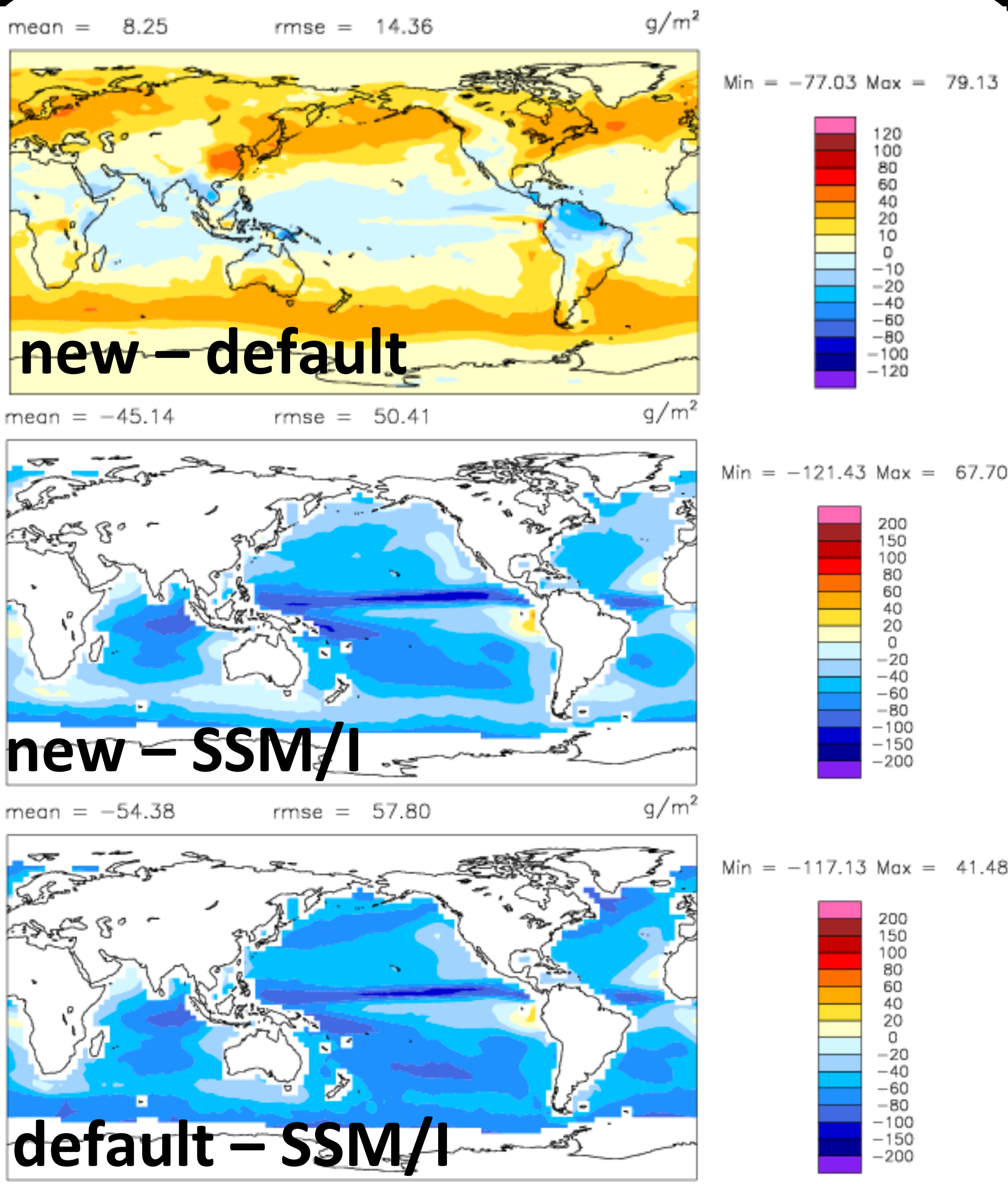
Longwave Cloud Forcing



- LWCF skill ~unchanged
- OLR improves by 2 W/m^2 (not shown)
- Less high clds ⇒ less +bias in convective regions, more -bias elsewhere.

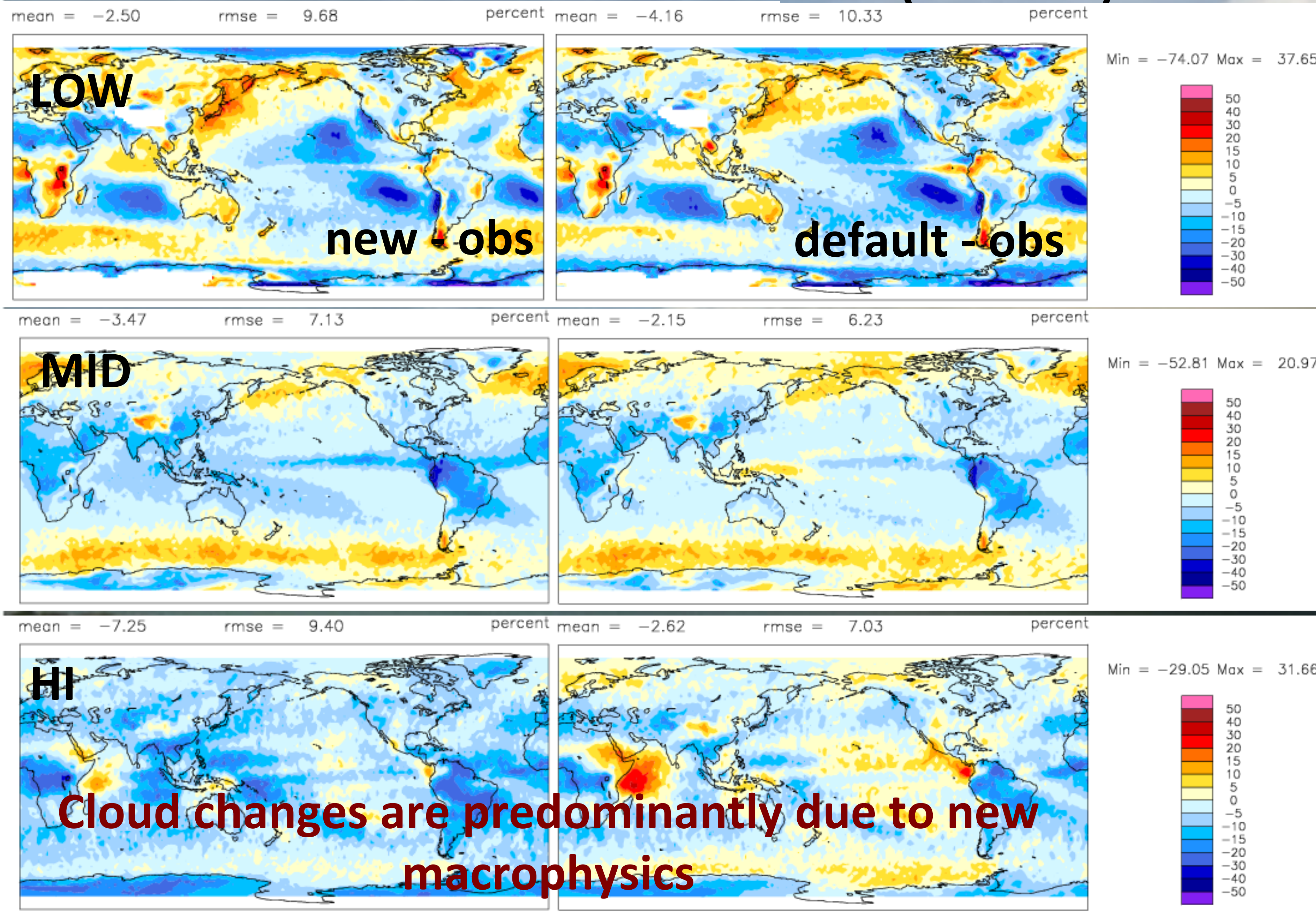
Fig: Longwave Cloud Forcing (LWCF) bias from default and new runs. Obs = CERES-EBAF

LWP

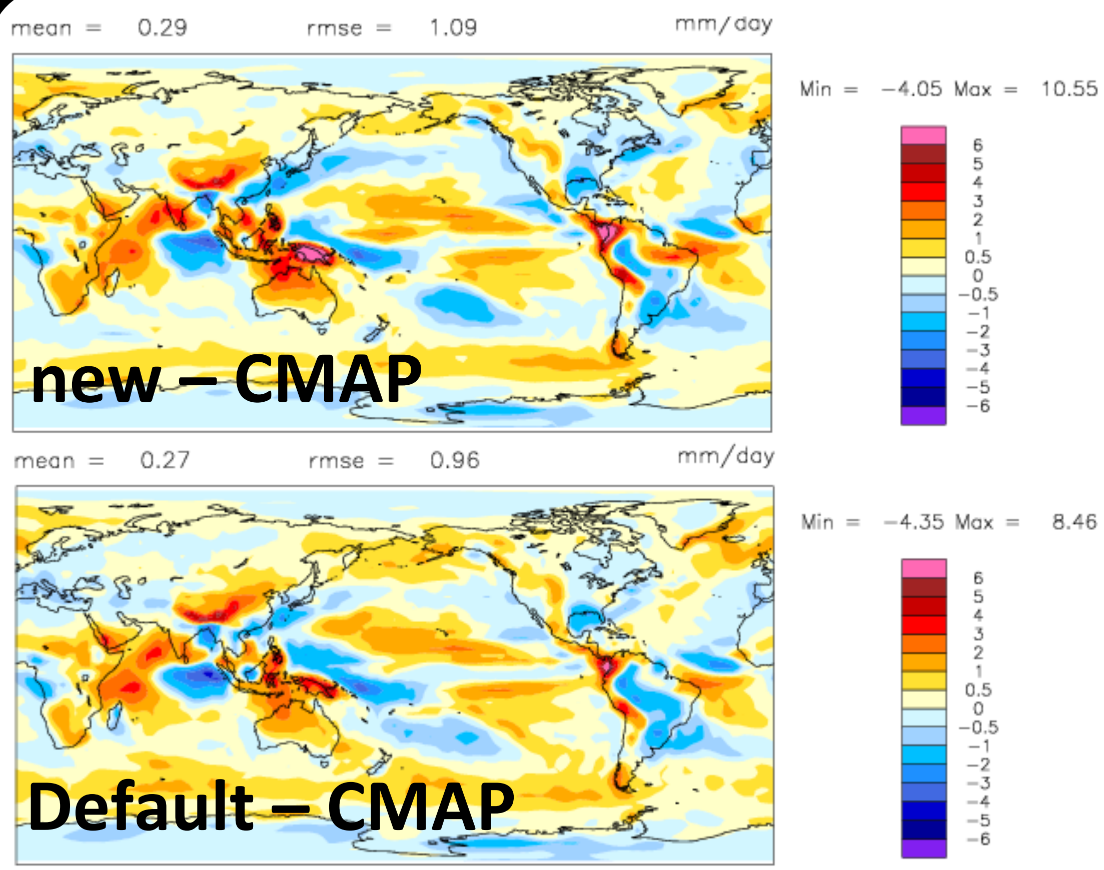


- Increases in storm tracks, decreases in tropics
- LWP bias and RMSE are greatly improved
- Change due to n_l, q_l consistency fix and Gaussian for microphysics (not shown)

Cloud Bias: CALIPSO (COSP)

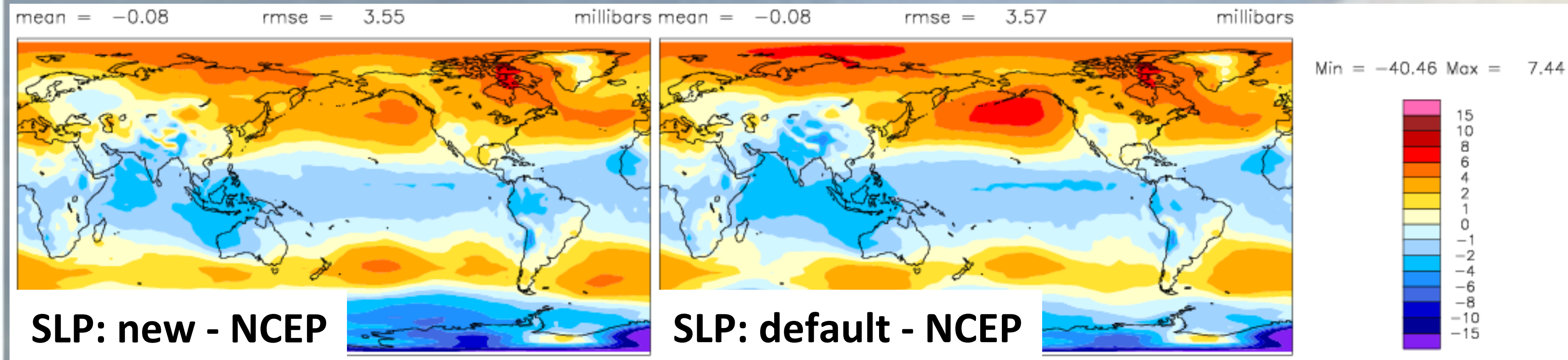


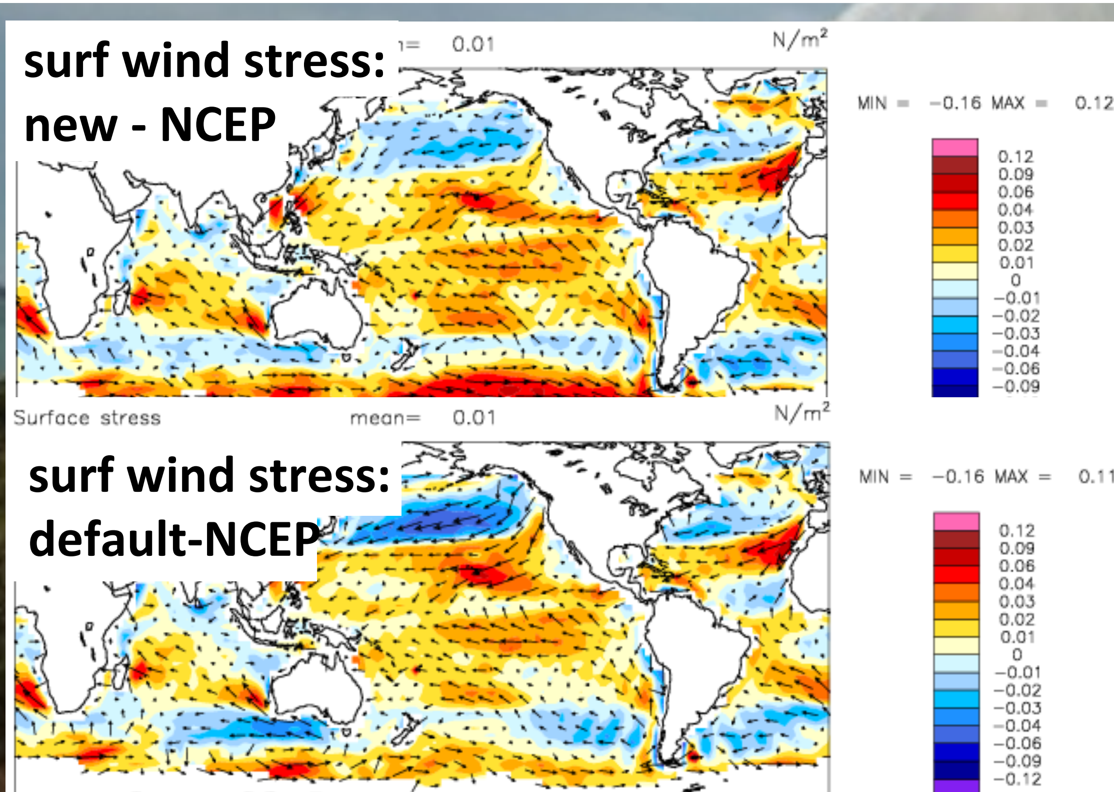
Precip



- Precip marginally worse in new ver
  - +bias amplifies over tropical land, otherwise precip decreases
- Main source of precip differences is macro+micro substepping (not shown)

Dynamics





- SLP bias ~unchanged
  - Aleutian Low much better
- Surface stress also better (?)

Aerosol Sensitivity

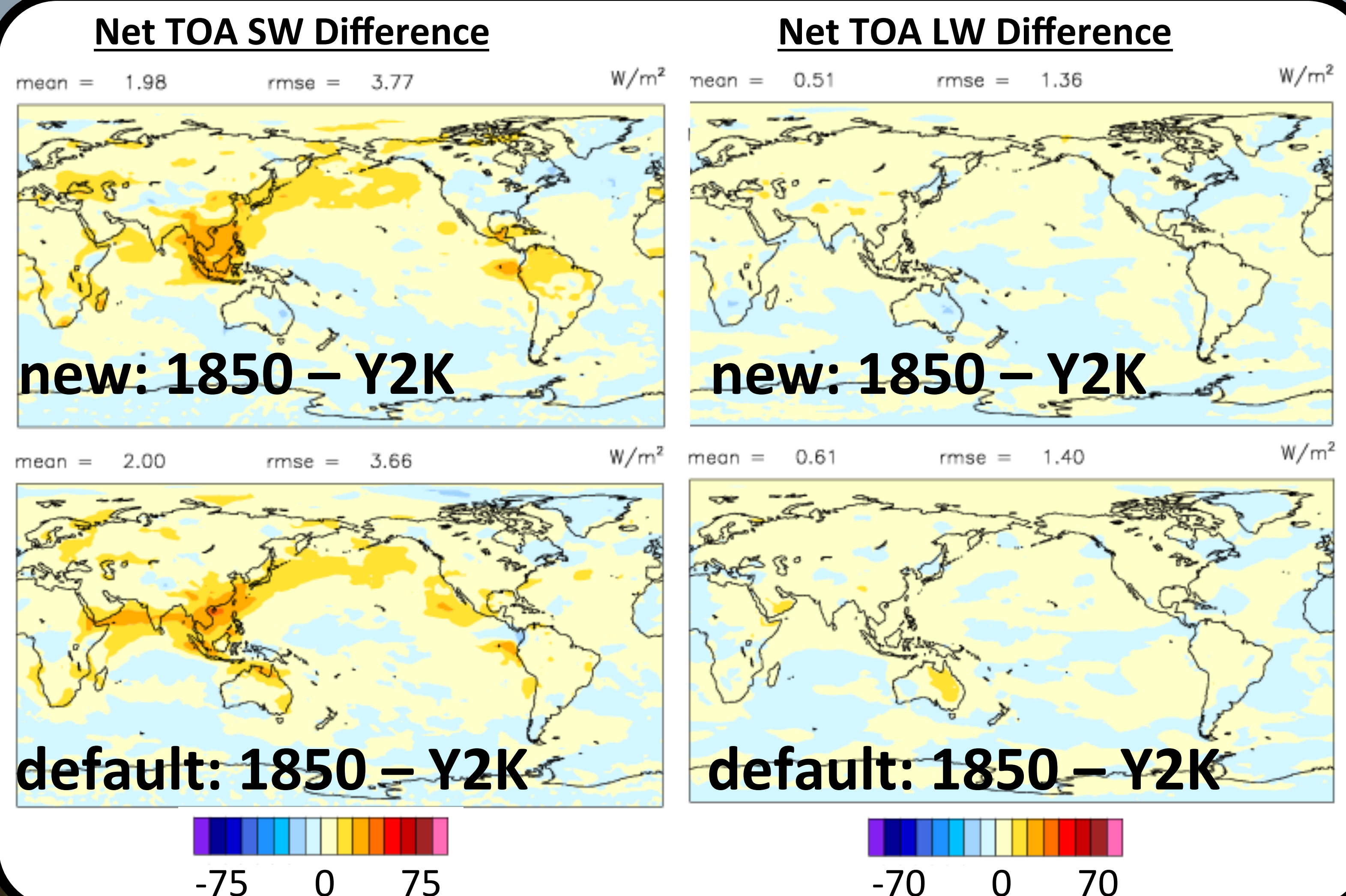


Fig:Effect of pre-industrial vs Y2K aerosol emissions on new and default CAM5.1 simulations. Based on 10 yr runs all using Y2K SST. Gaussian in NOT truncated for these runs.

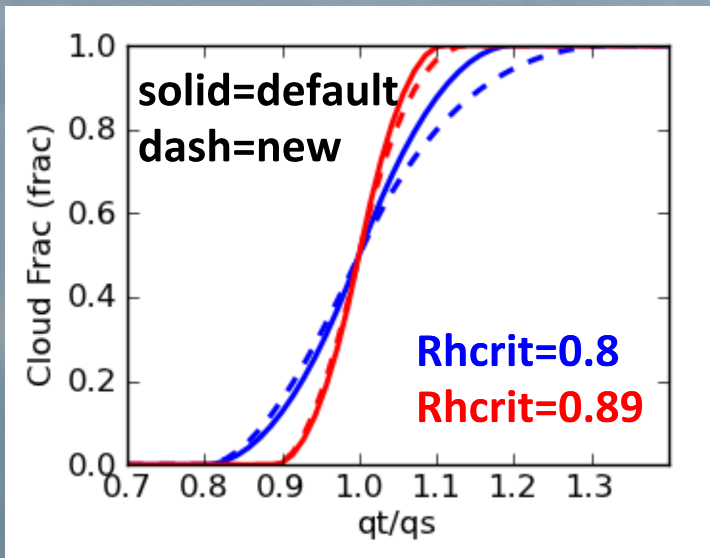
No change in total SW effect, more for LW

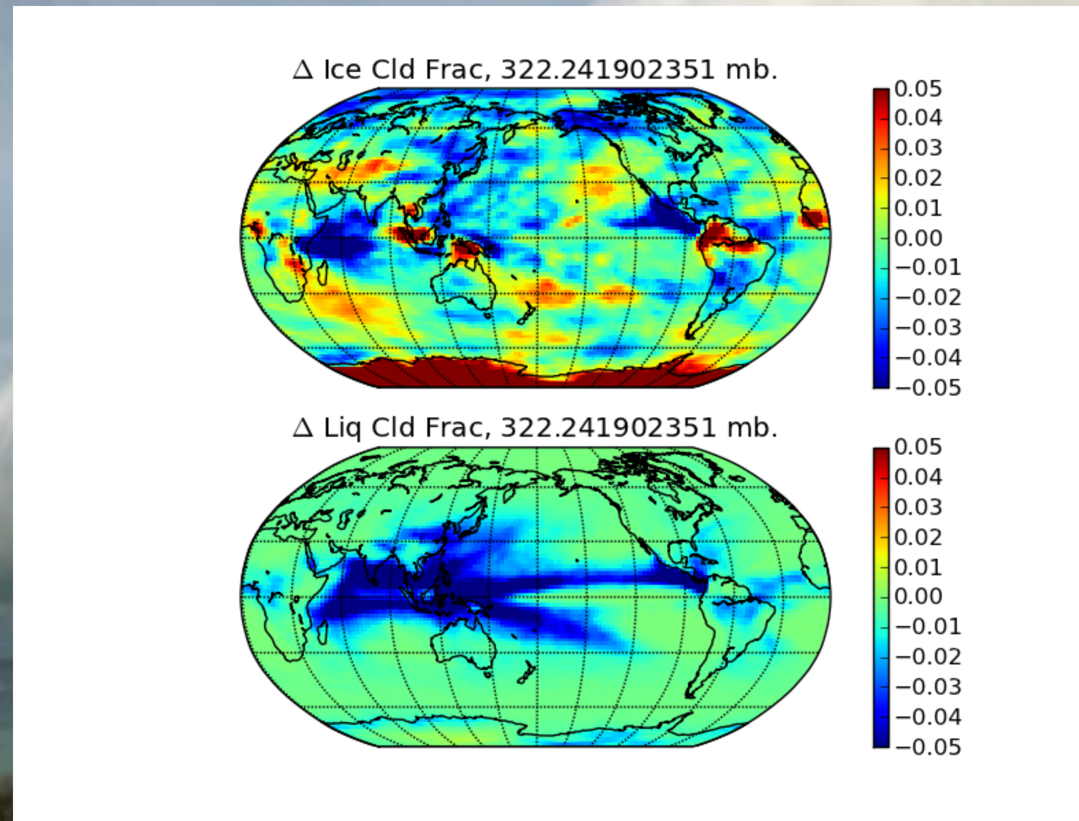
Conclusions:

- 4 physically-motivated model improvements are tested in AGCM mode
- PDF macro results in ~8% model speed up, substepping macro removes this advantage
- LWP is greatly improved

This configuration should be an option on the trunk soon

Why does Tropical High Cloud Decrease?





- Decrease at high latitudes largely due to stratiform liquid CF change due to using width based on qt instead of T.