Poster #55

Aquaplanet Hydrologic Cycle Sensitivities to Model Configuration in Present and Future Climates

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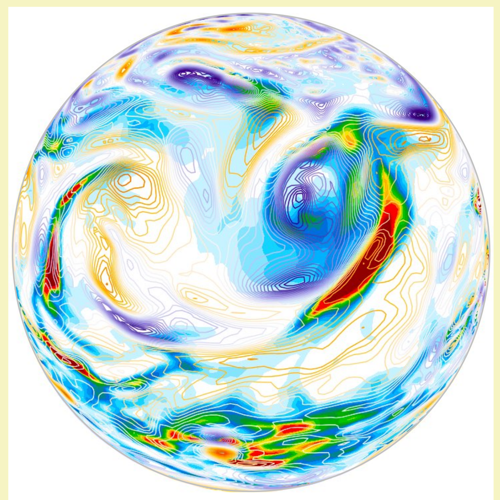
Background & Motivation



Aquaplanets—global climate models devoid of land masses—distill salient features of Earth's climate by damping or removing processes that may be of secondary importance (e.g., land-sea contrasts, seasonality). They provide a clean platform to examine sensitivities of simulated climate to model configuration. Like other reduced-complexity models, aquaplanets bridge gaps in our understanding between comprehensive Earth System Models and idealized models[1]; they are a vital component within hierarchies of model complexity. Here, we review sensitivities of the **CESM2** aquaplanet hydrologic cycle to model formulation in present-day and global warming climate states. Identifying and understanding such sensitivities reveals fundamental uncertainties in the present-day climate and can guide appropriate interpretation of hydrological cycle changes in warming climates.

Motivating Questions

- ***How does aquaplanet precipitation compare to Earth-like CESM simulations?*** *(Similar in the extratropical time-zonal mean and in binned distributions within Tropics)*
- ***To what aspects of model formulation is aquaplanet precipitation most sensitive?*** *(Primarily choice of physics, but also grid resolution)*
- ***Are aquaplanet precipitation sensitivities consistent between present-day and warmer climate states?*** *(Changes in time-zonal mean P and extremes are physics dependent)*

Modeling Strategy

Present-day and global warming CESM2 aquaplanet simulations:

- Physics: CAM4, CAM5*, and CAM6#
- Grid resolution: 1° & 2° (physics-dependent vertical resolution)
- Dynamical core: Finite volume
- Solar: Perpetual equinox; diurnal cycle retained
- Ocean types (all aspects are zonally uniform and equatorially symmetric):
  - Fixed-SST — (1) present-day CO_2 with QOBS[2] SST profile ("CTL"), (2) $4xCO_2$ with with QOBS SST, (3) present-day CO_2 with QOBS SST+4K
  - Slab ocean (SOM) — using Q-fluxes computed from corresponding fixed-SST run and a globally constant 30 m mixed-layer depth: Present-day CO_2 ("CTL"), abrupt $4xCO_2$, CO_2 increased at 1%/year and capped at 4xCO2

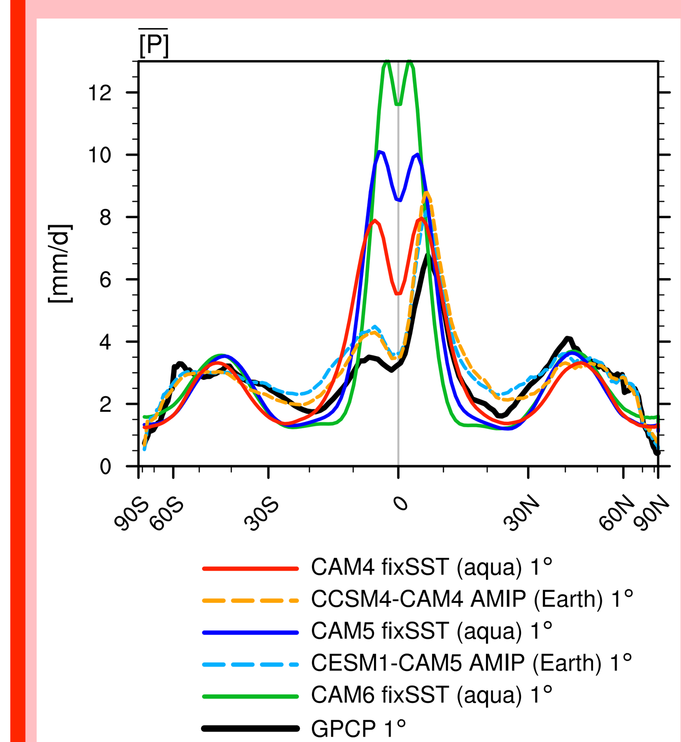
** MG1 microphysics with constant cloud liquid and ice crystal number concentrations used for simplicity*
 # MG2 microphysics with constant cloud liquid and ice crystal number concentrations used for simplicity; multi-decadal SOM climate runs delayed, awaiting final changes to CESM2 model

CAM physics package comparison:

	CAM4	CAM5	CAM6
Convection - deep	ZM w/dilute CAPE & CMT	ZM w/dilute CAPE & CMT	ZM w/dilute CAPE & CMT
Convection - shallow	Hack	UW - Park & Bretherton	CLUBB
Microphysics	RK	MG1 (diag. precipitation)	MG2 (prog. precipitation)
Turbulence	Dry	Moist - Bretherton & Park	CLUBB
Radiation	CAMRT	RRTMG	RRTMG

Mean Hydrologic Cycle

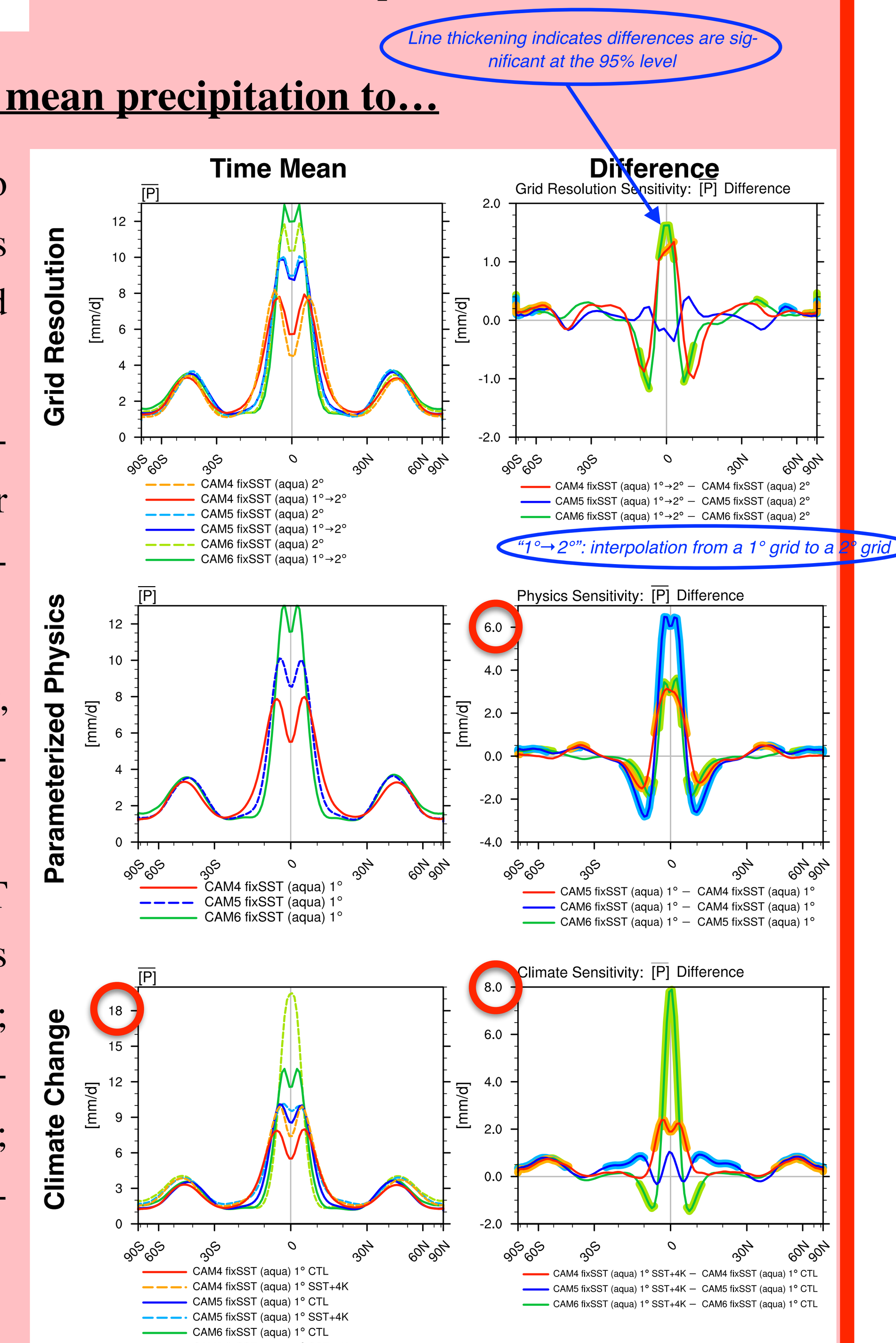
Time mean zonal mean precipitation



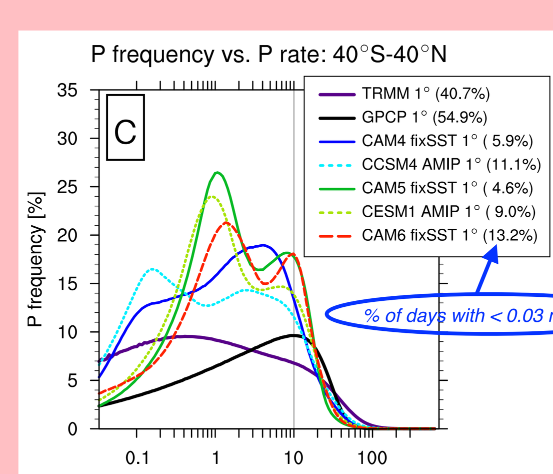
- Our CESM2 aquaplanet runs exhibit twin *P* maxima straddling the Equator
- **A narrowing, consolidation, and intensification of the ITCZ from CAM 4 → 5 → 6**
- Compared to *all-season* observations and Earth-like models, our perpetual-equinox CAM aquaplanet runs:
  - are wetter in Tropics
  - provide a decent estimate of midlatitude *P*
  - have snowier poles

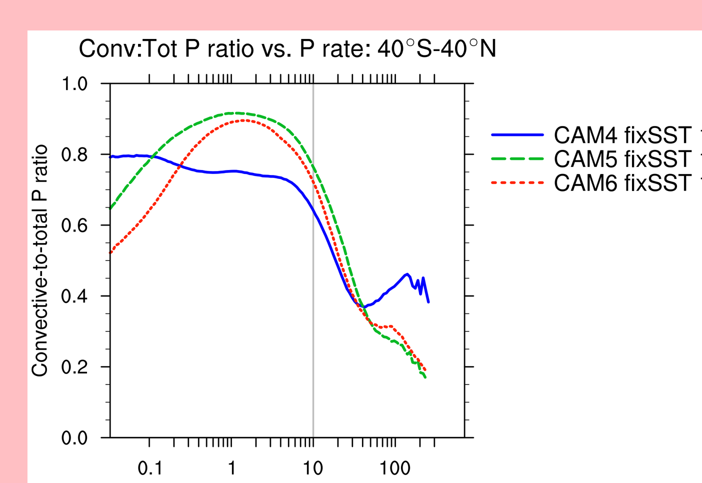
Sensitivities of time mean zonal mean precipitation to…

- OCEAN: Sensitivity of *P* to ocean formulation (**omitted**) is weakest, diffs are < 1 mm/d (~10%).
- RESOLUTION: Higher resolution generally results in larger equatorial *P*; resolution sensitivity weakest in CAM5
- PHYSICS: Trend of narrower, wetter ITCZ in later CAM versions
- CLIMATE: Comparing fixed-SST present-day to SST+4K, all runs show increased extratropical *P*; (prototype) CAM6 has remarkable intensification of ITCZ; CAM5 shows enhanced subtropical *P*.



Precipitation amount and frequency distributions



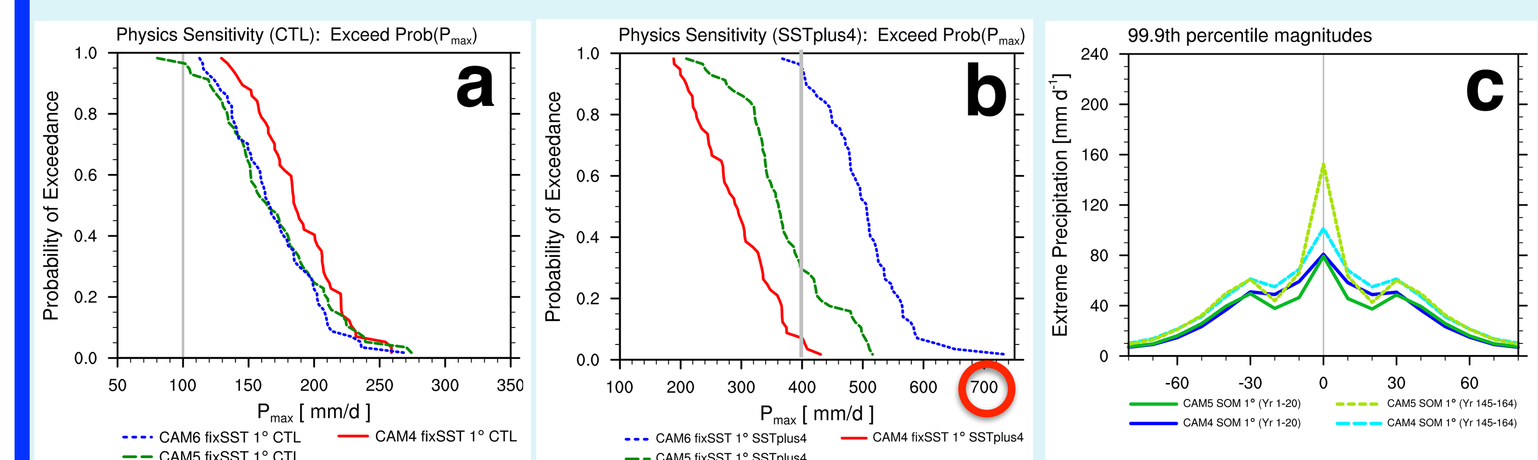


- (Above left) Aquaplanet precipitation frequency generally follows Earth-like CAM versions; Earth-like CAM overpredicts light *P* (<10 mm/d); aquaplanets exaggerate this but have similar distribution to Earth-like models
- (Above left) Dearth of "dry" days in CAM linked to surface moisture availability rather than biases in large-scale dynamics (not shown); some improvement in CAM6
- (Above right) Overabundant drizzle linked to convective precipitation; extreme precipitation linked to resolved-scale processes; CAM6 has similar profile to CAM5

Precipitation Extremes

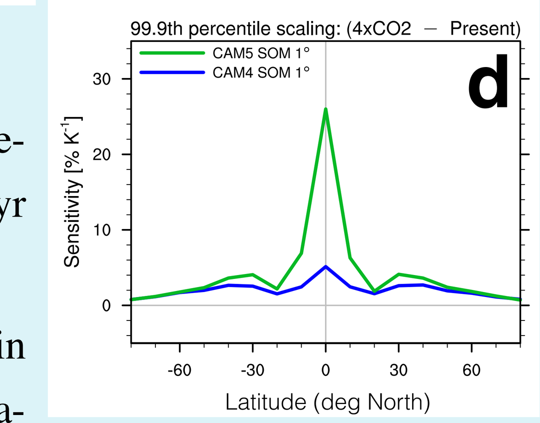
Precipitation exceedance probabilities ("extremes")

- Probability that daily rainfall at any tropical gridpoint will exceed a specific value in any given month
- **(a)** Present-day (fixed-SST) extreme *P* largest in CAM4; CAM5 & CAM6 similar
- **(b)** Large increase in extreme *P* values with warmer (prescribed) SST: probability of 400 mm/d rain event in any month 5% in CAM4 but 95% in CAM6



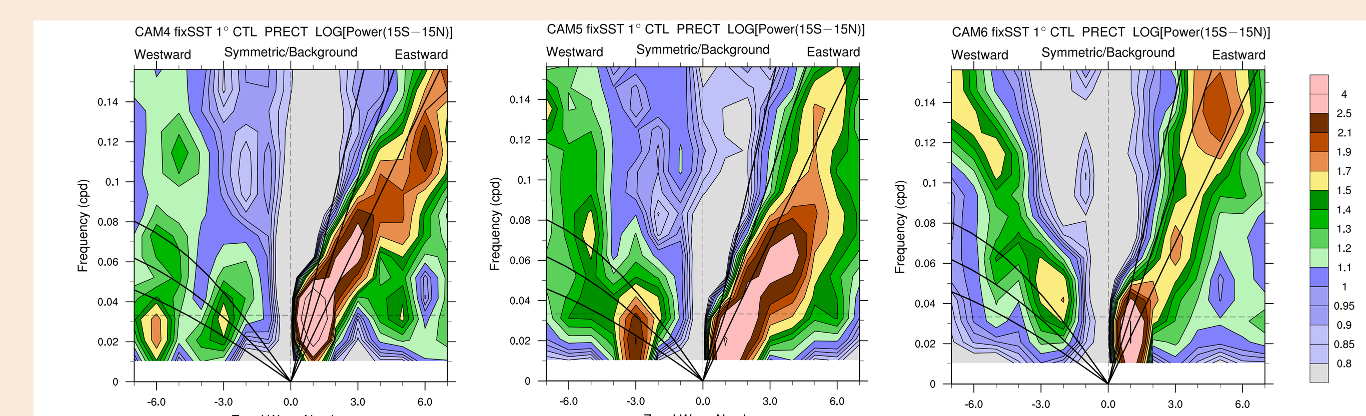
Scaling of extreme precipitation with warming

- **(c)** 99.9th percentile of *P* increases at all latitudes between Years 1-20 & 145-164 in a SOM run with 1%/yr CO2 increase; increase largest in Tropics for CAM5
- **(d)** Sensitivity of extreme tropical *P* much larger in CAM5 than CAM4; CMIP5 RCP8.5 multi-model equatorial min/median/max[3]: 0, 8, 35 % K^{-1}



- **(d)** Likely that prototype CAM6 will have larger extreme *P* scaling than CAM5

Intraseasonal precipitation variability, present-day



- Prototype CAM6 (right) shows improved consolidation of power in MJO spectral region but faster equatorial Rossby waves and more active easterly waves
- CAM6 has excessive MJO power for prescribed SST+4K relative to CAM4/5 (omitted)

Key Findings & Next Steps

- Aquaplanet ITCZ narrows, consolidates, intensifies from CAM4 to CAM5 to CAM6
- Continued overabundance of drizzle in all CAM versions, but drizzle peak somewhat reduced from CAM5 to CAM6; drizzle peak linked to convective rain, not grid-scale
- Extreme precipitation in tropics: Prototype CAM6 highly sensitive to warming
- Present-day climate results published in: Benedict, Clement, Medeiros, Pendergrass, 2017 (*JAMES*), DOI: http://dx.doi.org/10.1002/2016MS000891
- Next: Examine CAM6 aquaplanet SOM; run experiments to explore physics-dependent ITCZ differences; investigate extreme *P* event characteristics and tropical-extratropical interactions across model hierarchy

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