Toward the use of Convective Quasi-Equilibrium as a predictor for changes in the seasonal cycle of tropical precipitation

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1. Background

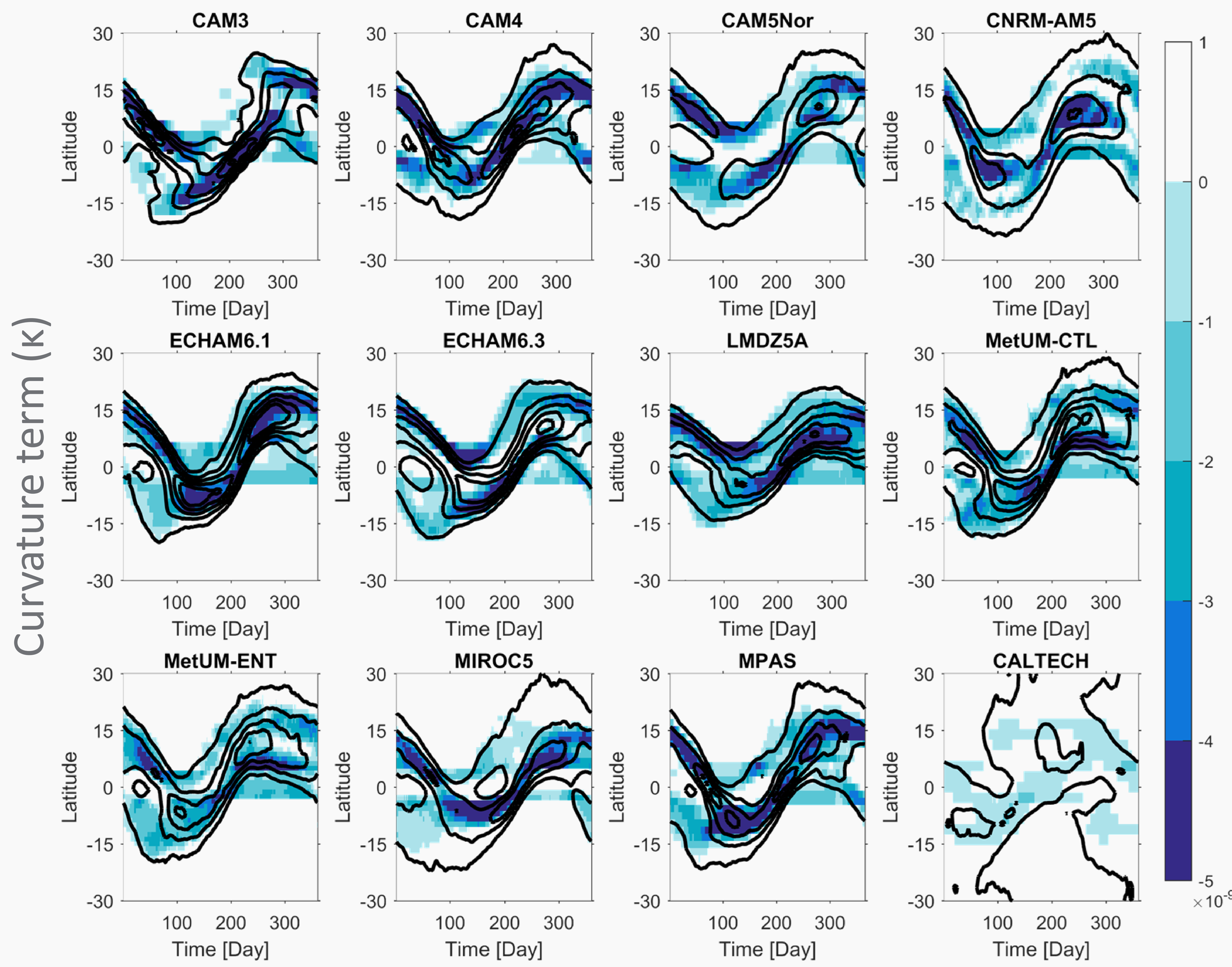
(Emanuel et al. 1994) suggested that stronger curvature of the sub-cloud moist entropy field ought to imply a stronger overturning circulation. Recently, (Singh et al. 2017) showed that the strength of the Hadley circulation was linearly related to the criticality condition of (Emanuel 1995) in an idealized modeling framework.

$$\kappa \equiv \sin\varphi\left[4\Omega^2\sin\varphi + \nabla\bullet\left(\frac{1}{\sin\varphi}(T_s - T_t)\nabla s_b\right)\right] < 0$$

From Emanuel JAS (1995)
ϕ is latitude
Ts is surface temperature
Tt is tropopause temperature
Sb is sub-cloud moist entropy

We analyze how well this criticality metric (κ) serves to predict changes in the seasonal cycle of precipitation in twelve aquaplanet simulations from the Tropical Rain belts with an Annual cycle and a Continent Model Intercomparison Project (TRACMIP; Voigt et al. 2016).

(Right) Precipitation vs κ for the twelve TRACMIP models used in this study.



2. Why is there a linear relationship?

We can rewrite the moisture budget making use of the Normalized Gross Moist Stability ($\Gamma = -(\nabla\cdot[\mathbf{v}h])/(\nabla\cdot[\mathbf{v}q])$) and breaking the flux of moist static energy (h) into a mean and eddy component, the latter of which is treated as a downgradient diffusion term.

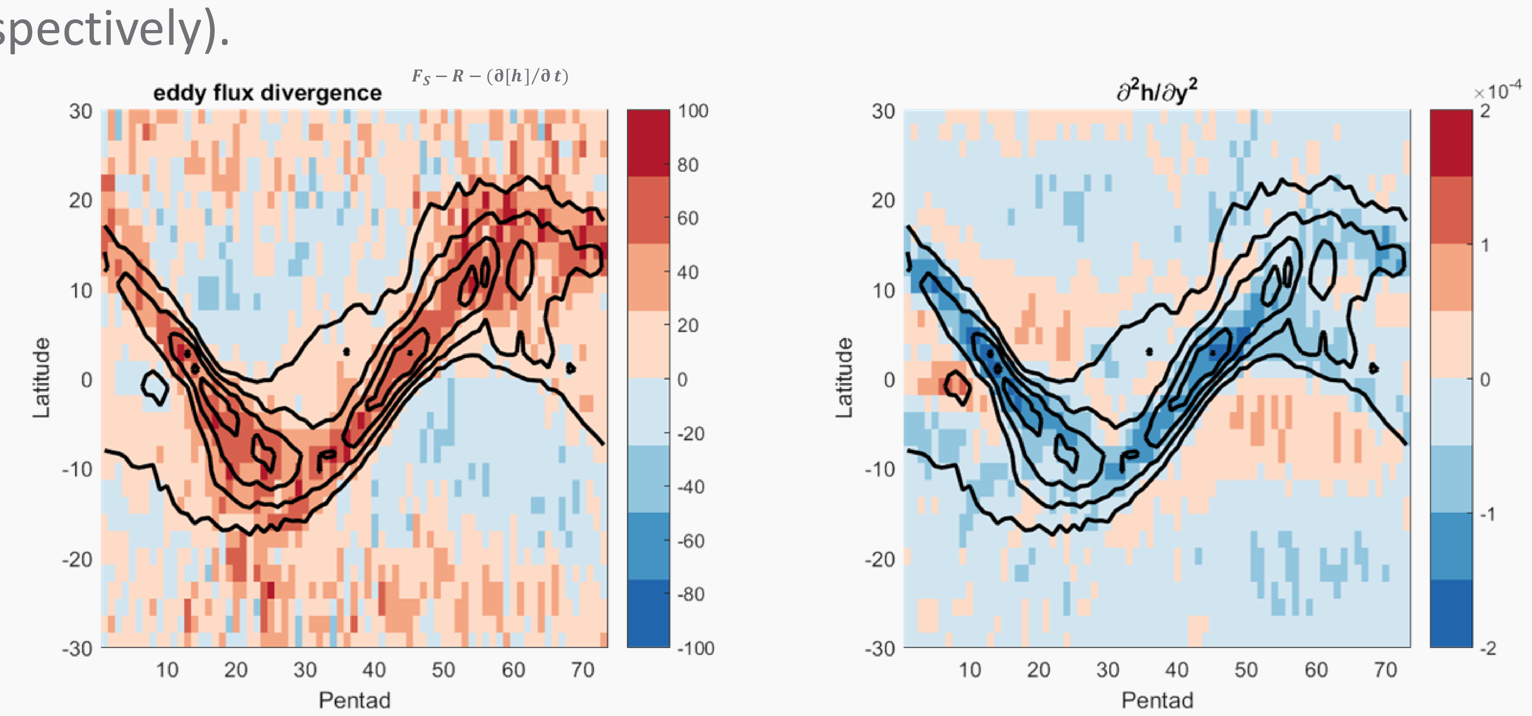
Convergence of moisture is well captured by the mean circulation (right top), but the divergence of moist static energy is not (right bottom). Instead, the latter is best captured by eddy circulations which may be approximated as diffusive and are well correlated with $\partial^2 h/\partial y^2$ ($r^2 = 0.40$; below). Both the eddy term and $\partial^2 h/\partial y^2$ are well correlated with P-E ($r^2 = 0.64$ and 0.40, respectively).

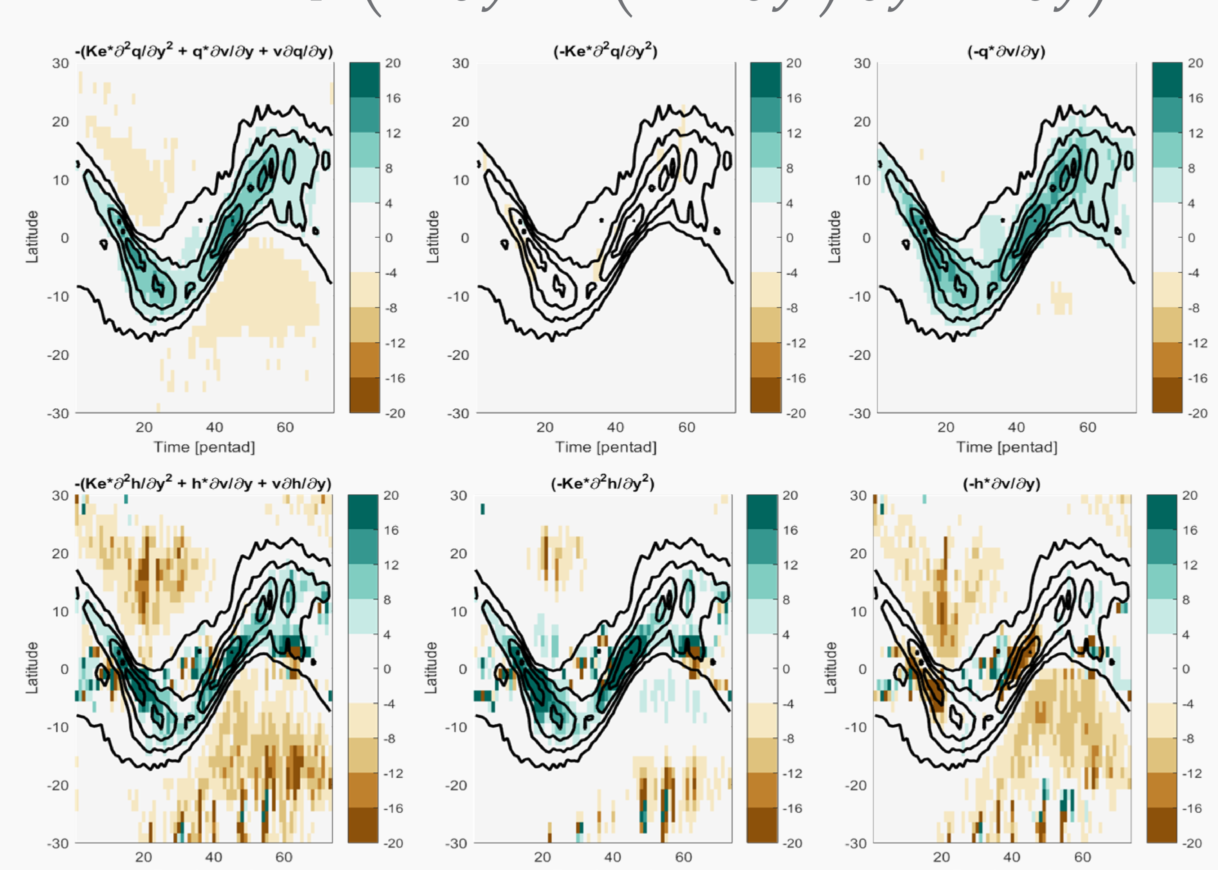
$$\frac{\partial[q]}{\partial t} + \nabla\cdot[\mathbf{v}q] = E - P$$

$$P - E \approx -\nabla\cdot[\mathbf{v}q] = \frac{1}{\Gamma}\nabla\cdot[\mathbf{v}h] = \frac{1}{\Gamma}\frac{\partial}{\partial y}\left[\overline{v'h'} + \bar{v}\bar{h}\right]$$

$$let\ h = [h]\ \&\ v = \frac{[vh]}{[h]};\quad v'h' = K_e\frac{\partial\bar{h}}{\partial y}$$

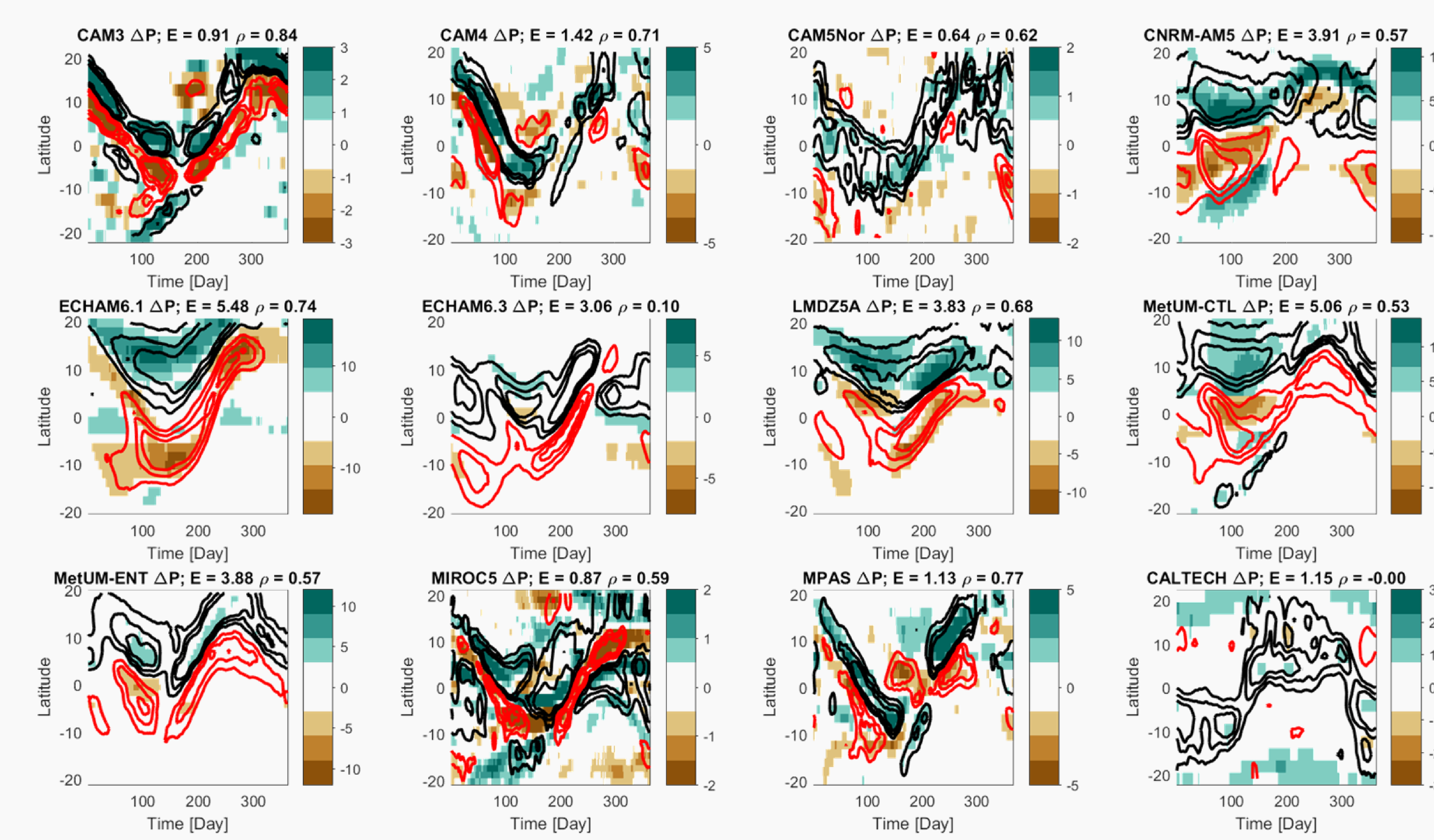
$$P - E \approx \frac{1}{\Gamma}\left(K_e\frac{\partial^2\bar{h}}{\partial y^2} + \left(\bar{v} + \frac{\partial K_e}{\partial y}\right)\frac{\partial\bar{h}}{\partial y} + \bar{h}\frac{\partial\bar{v}}{\partial y}\right)$$

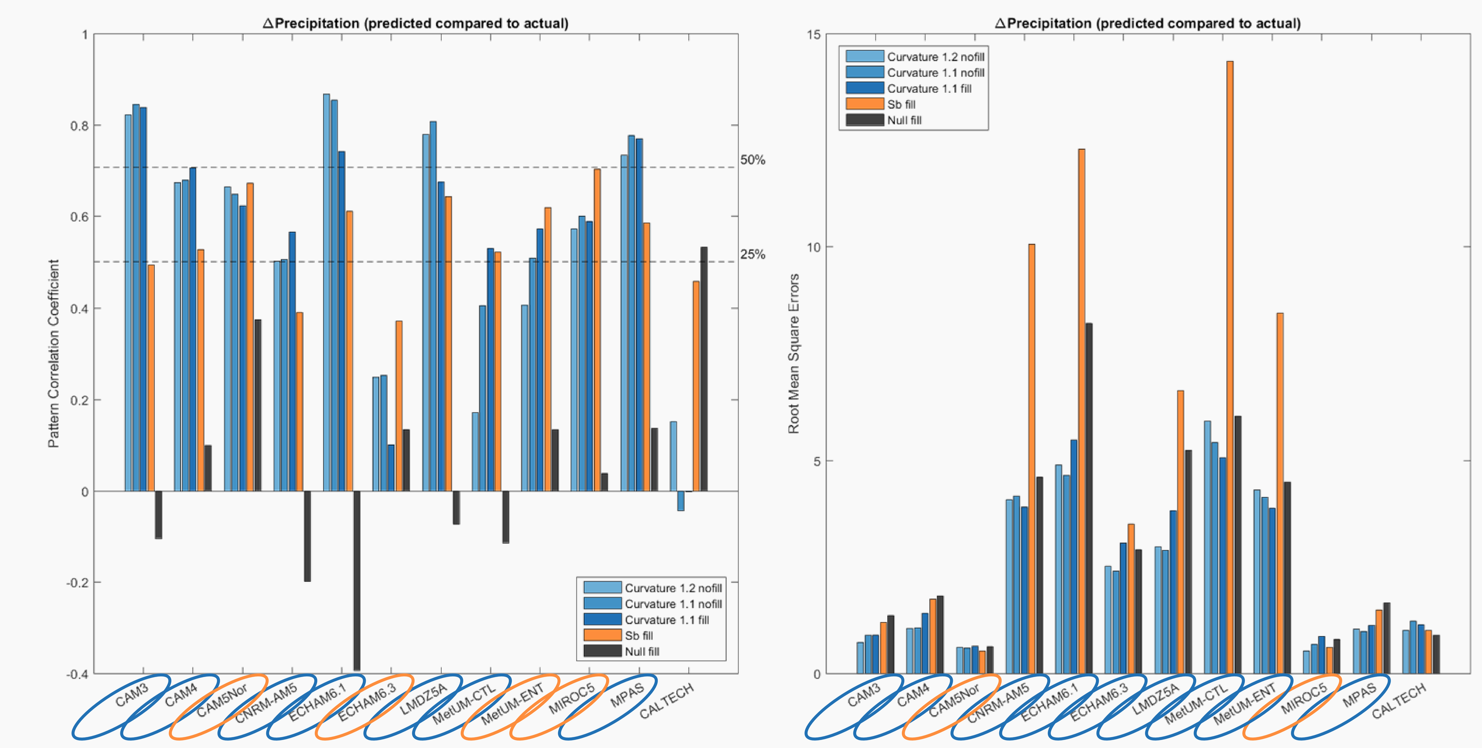




3. κ as a predictor of ΔP

We can use κ as a predictor of precipitation changes owing to increases in CO2. (Top) we show the change in precipitation between 4xCO2 and the control (contours) and that predicted by κ (colors). (Bottom) comparison of r and RMSE for each run compared to a 'wet-get-wetter' null hypothesis where precipitation increases by a fixed percentage (equal to the tropical average).





4. Conclusions

We show κ to be a skillful predictor of ΔP compared to a simple wet-get-wetter type null hypothesis. The skill in κ derives from the diffusive nature of the energy fluxes, i.e. the eddy fluxes are strongly correlated with $\partial^2 h/\partial y^2$ ($r^2 = 0.40$). Much of the spatiotemporal variations in column-integrated MSE (h) are equivalent to the variations in the sub-cloud moist entropy, such that the curvature of both are nearly identical. Hence, large (negative) κ values approximate areas where the divergence of MSE by eddies is larger, and hence is a good marker of precipitation in many of these models.

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