New Approach to Organized Tropical Convection Parameterization for CAM

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Summary

Nonlinear dynamical models based on Lagrangian conservation principles are utilized as heat and momentum transport modules for Multiscale Coherent Structure Parameterization (MCSP). In gray-zone nomenclature, cumulus parameterization treats sub-grid convection and the dynamical models add organized transport. MCSP is implemented in the Community Atmosphere Model (CAM 5.5) – a minimalist proof-of-concept, an unambiguous measure of the upscale effects of organized deep convection on the global atmosphere, and computationally simple application.

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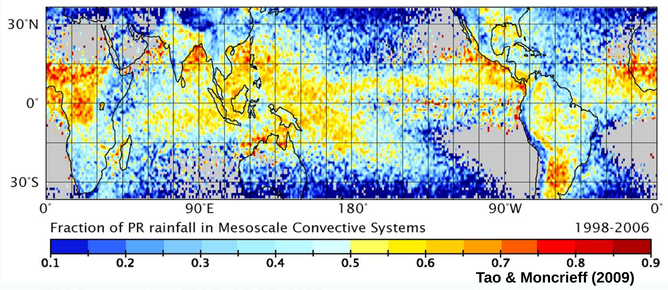
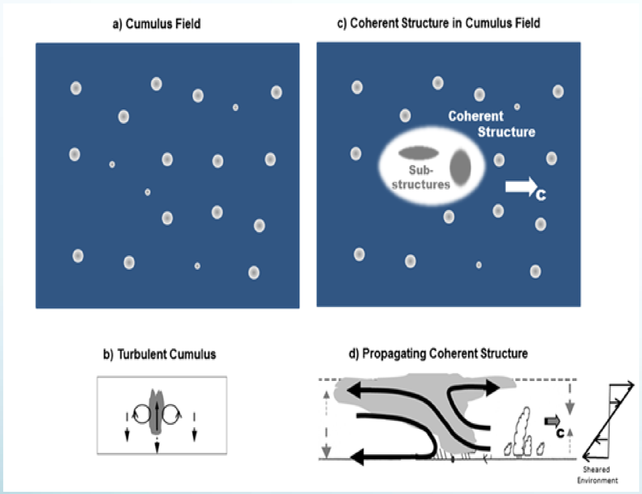
> 50% of Tropical Rainfall from MCS



- MCSs populate ITCZ, SPCZ, MJO, monsoons, continental regions
- MCS is missing from GCMs: neither parameterized nor resolved
- New paradigm needed to parameterize organized convection in GCMs (Moncrieff et al. 2012)

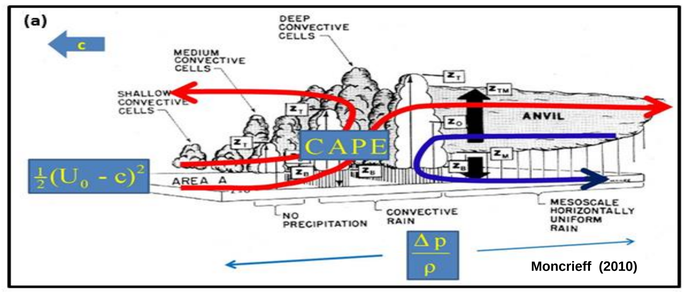
MCSP Paradigm

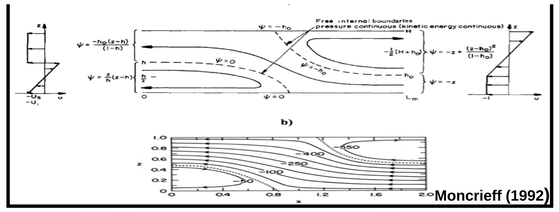


Moncrieff & Waliser (2015)

- Traditional cumulus parameterization is based on cumulus ensembles but the cumulus elements do not interact and are treated as vertical single-column models.
- Organized convection in sheared environments is treated as coherent dynamical structure in a turbulent environment that includes small cumulus.
- Nonlinear finite-amplitude slantwise overturning models approximate MCS-like coherent structures in sheared environments
- Rearward slant affects heat and momentum transports in ways that differ fundamentally from unorganized cumulus

Slantwise Overturning Models





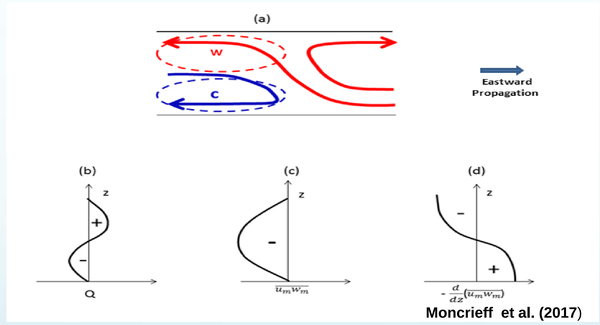
- Slantwise overturning models are solutions of the minimally approximated nonlinear vorticity equation, subject to appropriate boundary conditions:

$$\nabla^2\psi = G(\psi) + \int_{z_0}^{z}\left(\frac{\partial F}{\partial \psi}\right)_{z'} dz'$$

G is the environmental shear, *F* the parcel buoyancy, $z_0(\psi)$ trajectory inflow height

- Models approximate the characteristic rearward slant observed in squall-lines, MCSs, tropical superclusters, and convectively coupled waves, i.e., key self-similar or scale-invariant physical and dynamical properties
- Scale-separation is not assumed, grid-averaged quantities non-zero
- Lagrangian formulation directly links convective transports to mean-state variables (e.g., stratification, shear) -- a fundamental requirement not satisfied by traditional convective parameterizations

Minimalist MCSP form: 2nd Baroclinic Tendencies

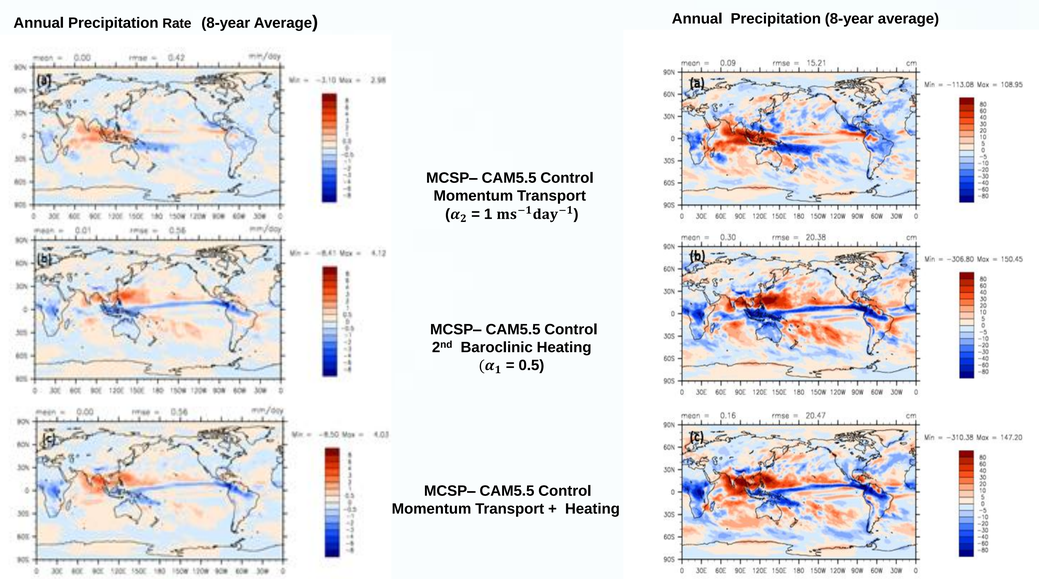


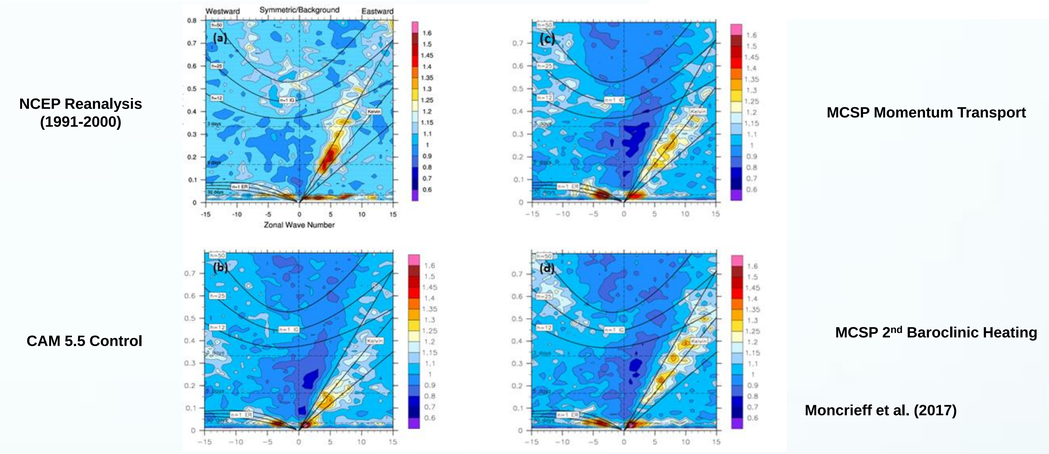
MCSP treats the convective heating rate, Q_m(p,t) and the convective momentum transport acceleration M_m (p,t). The traditional (unorganized) cumulus parameterization (Q_c) is retained so the total tendencies are Q = Q_c + Q_m and M = M_c + M_m and the grid-scale effect of organized convection is the difference between GCM integrations with and without MSCP. Mesoscale heating and momentum tendencies have an approximately 2nd baroclinic form. Non-Fickian counter-gradient momentum transport generates mean-flow kinetic energy (backscatter). The minimalist MCSP formulation is

$$Q_m(p,t) = -\alpha_1 Q_c(t) \sin 2\pi\left(\frac{p_s - p}{p_s - p_t}\right) \quad ; \quad M_m(p,t) = \alpha_2 \cos \pi\left(\frac{p_s - p}{p_s - p_t}\right)$$

where Q_c (t) is the vertically averaged cumulus heating rate, p_s, p_t are the cloud-base and cloud-top pressures, and α_1, α_2 are prescribed constants, respectively.

Large-scale Effects of MCSP in CAM 5.5





Development Strategy

Moncrieff et al. (2017) is focused on a minimalist proof-of-concept, next steps in MCSP development include:

- Observation-based values for α-parameters with attention to shear-selective application of MCSP
- Implement MCSP in other GCMs, noting its high computational efficiency will enable application in long integrations i.e., coupled models, ensemble prediction systems, and Earth-system models
- Investigate scale-selection mechanisms for large-scale coherent structures in the tropics utilizing the Khouider and Majda (2006) multicloud model, and the Majda (2007) mesoscale equatorial synoptic dynamical model
- Investigate the role of organized convection associated with the diurnal cycle over the Maritime Continent

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