Stochastic plume ensembles for an unified shallow-deep mass-flux cumulus parameterization in the Community Earth System Model (CESM)

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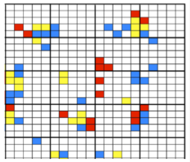
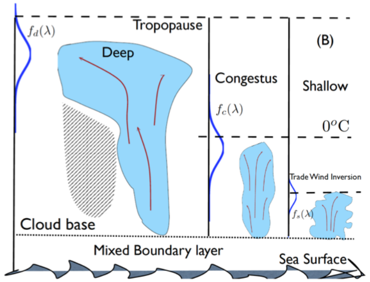
INTRODUCTION

We introduce some modifications to the Zhang and McFarlane (1995) cumulus parametrization by essentially changing the way the plume ensemble mass flux is computed in order to produce a fully stochastic plume ensemble cumulus scheme. We combine a purely stochastic counting process, of the number of plumes that are launched at a given time and location with the stochastic multicloud lattice model of Khouider et al. 2010. The counting process combines the approach used by Cohen and Craig 2006 of assuming a Poisson process for the number of plumes and the approach of Gentine et al. 2013 of prescribing a distribution of plume detrainment levels, applied to various cloud types as predicted by the stochastic multicloud model. One important modification made here for the multicloud model however, is to consider shallow, congestus, and deep cloud types instead of congestus, deep, and stratiform, as done in Khouider et al. (2010) and in Khouider (2013). However, the mathematical derivations in both Khouider et al. (2010) and Khouider (2013) (without and with local interactions, respectively) apply.

By construction, the proposed framework englobes both sallow and deep convection, as well as mid-level congestus clouds. Ideally, the stochastic model is some kind of shell that permits the shallow and deep convection schemes to communicate with each other.





- A square lattice
- $N_L \times N_L$ lattice sites
  - ✓ Let z_k be fixed vertical level on the GCM grid
- $P_{n,m,k}$ the number of plumes that are launched over the lattice site $n;m$, which detrain at an arbitrary level $z_D \geq z_k, 1 < n,m \leq N_L$
- 4 types of plumes (SC,C,D,S) according to their detrainment levels.
  - ✓ Shallow cumulus detrain near the trade wind inversion,
  - ✓ Congestus detrain above the trade wind inversion and below or near the freezing level
  - ✓ Deep detraining above this level
  - ✓ The cloud types are intentionally allowed to overlap so that each cloud type has its own special distribution of detrainment heights centered around some appropriate level.
- An order parameter $\sigma_{n,m}$ that takes values $0,1,2,3, or\ 4$ at each site $n;m$
- For $n;m$ fixed, let P_k be the number of plumes with a detrainment level $z_D \geq z_k$ originating over the lattice site $(n;m)$
- Let
  - ✓ d_σ be the detrainment level of a random plume of type σ
  - ✓ P_σ be the probability distribution of d_σ
  - ✓ f_σ be the associated density functions

The steady state equation of conservation of moist static energy (h_c) of a rising plume.

$$\frac{dh_c}{dz} = \lambda(h - h_c), z_b \leq z \leq z_D,$$

A quick integration of the above ODE and then using the mean value approximation gives:

$$\lambda = -\frac{1}{\Delta z}\log\left(1 - \frac{h_0 - h^*}{h_0 - h_{\frac{1}{2}}}\right),$$

$$where\ h_{\frac{1}{2}} = h\left(\frac{z_D + z_b}{2}\right)\ and\ \nabla z = z_D - z_b$$

To complete the definition of the cloud top distributions $(f_j(\lambda), for\ j = sc, c, d\ and\ s$, in the schematic above) we need to specify the means and standard distribution parameters $\lambda_j\ and\ \alpha_j$. To do so we set,

$$\lambda_{sc} = \delta_{sc}\lambda_{lfc}$$

$$\lambda_c = \delta_c\lambda_{lfc} + (1 + \delta_c)\lambda_{frz}$$

$$\lambda_d = \delta_d\lambda_{frz} + (1 + \delta_d)\lambda_{lnb}$$

And,

$$\alpha_{sc} = \gamma_{sc}\lambda_{sc}$$

$$\alpha_c = \gamma_c(\lambda_{lfc} - \lambda_{frz})$$

$$\alpha_d = \gamma_d(\lambda_{frz} - \lambda_{lnb})$$

Where $0 < \delta_j < 1$ and $\gamma_j > 0$, be a set of parameters.

The framework

We have the bulk mass flux equation,

$$M(z) = \Lambda \int_0^{\lambda_z} M_\lambda(z) F(\lambda) d\lambda,$$

where $M_\lambda(z)$ is the mass flux of the plume of type λ, i.e, a plume with a constant entrainment rate λ, given by

$$M_\lambda(z) = \begin{cases} M_b e^{\lambda(z - z_b)}, z_b \leq z \leq z_\lambda \\ 0, otherwise. \end{cases}$$

Here z_b and z_λ represent the level of cloud base and the level at which the type-λ plume detrains and M_b is the cloud base mass flux. $F(\lambda)$ is the plume probability density given by

$$F(\lambda) = \frac{1}{N_L^2}[N_{sc}f_{sc}(\lambda) + N_c f_c(\lambda) + N_d f_d(\lambda)]$$

with f_{sc}, f_c, f_d are plume distributions of shallow cumulus, congestus, and deep cumulonimbus cloud-types, respectively in the schematic above, while λ_z is the entrainment rate of plumes that detrain at level z.

As for the steady state plume model, we assume that the bulk mass flux satisfies the conservation equation

$$\frac{1}{M}\frac{\partial M}{\partial z} = \epsilon(z) - \delta(z),$$

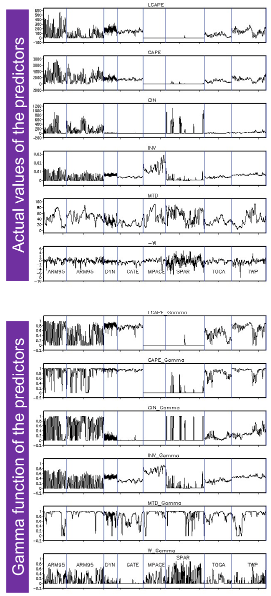
where $\epsilon(z)$ and $\delta(z)$ are the bulk entrainment and detrainment rates, respectively.

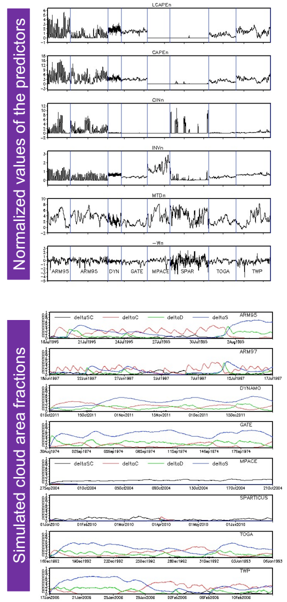
To Compute $M(z), \epsilon(z)$ and $\delta(z)$ we assume simple Gaussian shapes for the distributions f_{sc}, f_c, f_d as,

$$f_j(\lambda) = \frac{1}{\sqrt{2\pi}\,\alpha_j} e^{-\frac{(\lambda - \lambda_j)^2}{2\alpha_j^2}}, j = sc, c, d, s$$

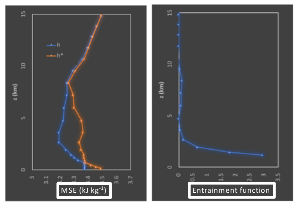
Pre-calibration of SMCM

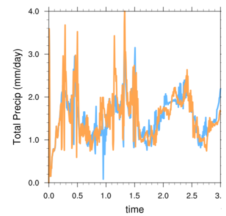
We run the SMCM in standalone mode in a single column setup, forced by different observations to simulate cloud area fractions. We qualitatively compare the different cloud area fractions with the observed rainfall in the backdrop of the background meteorological information relevant to a particular set of observations.

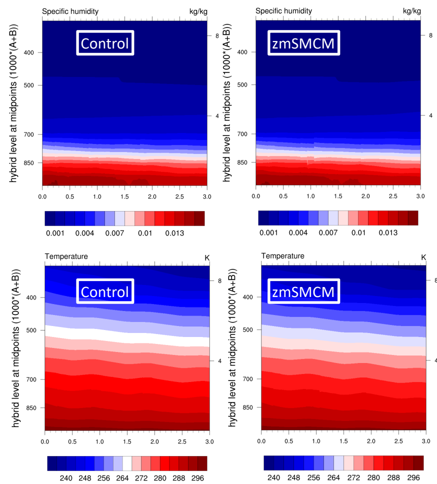




Results from /scratch/zmSMCM/scmRICO







WORK IN PROGRESS

- We are still in the process of finalizing the code .
- To run the model for different single column cases representing different regimes of clouds
- Finally goal is to implement the zmSMCM in full3D CESM.