Progress toward including deep convection in a unified representation of turbulence

CL33

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Background and Model Description

It is a goal of many parameterizations to unify the treatment of turbulence at all scales, but often this hits a bottleneck at trying to include deep convective clouds. The large nonlinearities and complex relationships between convection and its environment make this a particularly difficult task. We aim to accomplish this goal by utilizing the framework of eddy diffusivity/mass flux (EDMF) to augment the existing higher order closure (HOC) in the Community Atmosphere Model (CAM) single column model (SCM) with inexpensive stochastic mass flux (MF) plumes to extend clouds and convection through the troposphere. By doing this we are able to better sample the tails of the assumed distributions of temperature, water, and vertical velocity in order to build a fully unified turbulence scheme.

Model description:

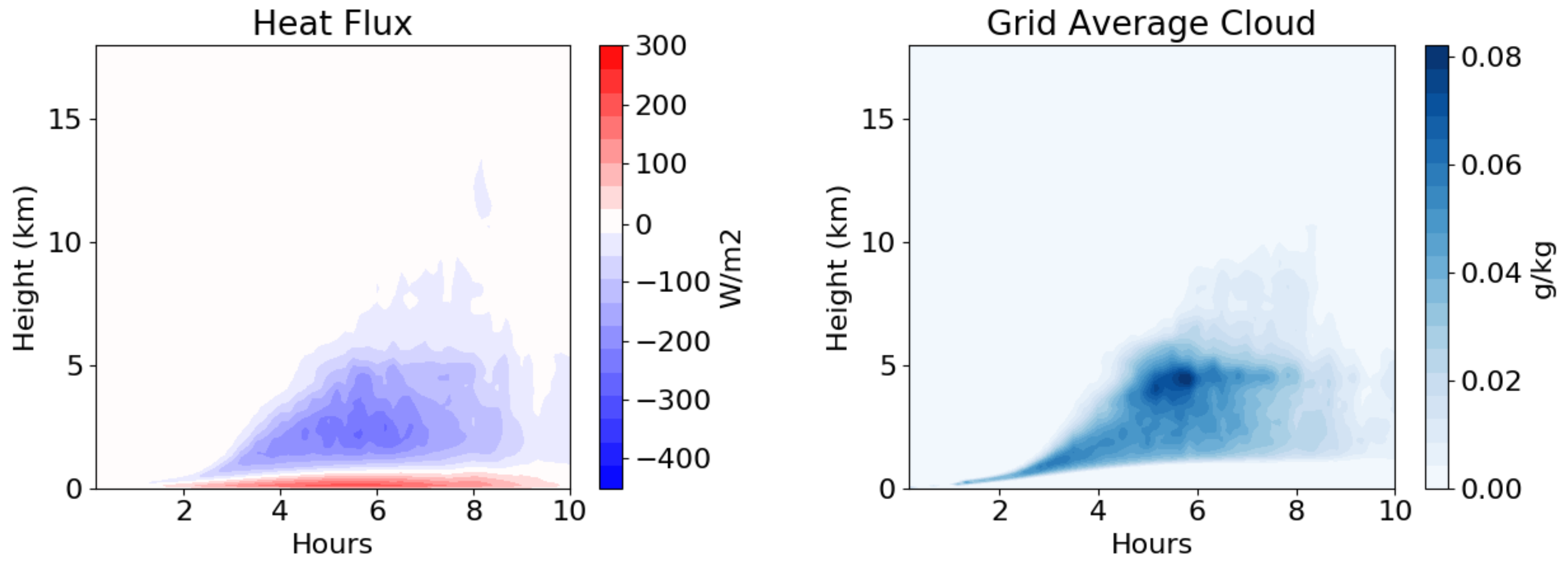
We use the single column version of the Community Atmosphere Model version 6.3 (SCAM). The default model configuration uses the Zhang McFarlane deep convection scheme (ZM) and Cloud Levels Unified by Binormals (CLUBB) as the higher order closure (HOC) for turbulence and shallow convection. All SCAM simulations are run with 58 vertical levels.

CLUBB+MF:

For more details about our implementation see Witte et al. 2022, and poster **CL08**.
We have augmented the CLUBB HOC with mass flux plumes to better capture the tails of the double gaussian distributions and provide vertically coherent transport through the troposphere. The plumes are based on the eddy diffusivity mass flux (EDMF) approach as implemented in the JPL EDMF model (Suselj et al 2013,2019). The plumes are integrated vertically assuming steady state vertical velocity, and are coupled to the main CLUBB code through their affect on the mean thermodynamic fields. For the simulations shown here using CLUBB+MF, ZM is turned off and 100 plumes are used.

Diurnally Forced Convection over Land

The Large Scale Biosphere Atmosphere (LBA) case from Feb 23, 1999 is an often used example of diurnal convection over the Amazon. For LES reference we use a simulation as in Suselj et al. 2019, driven by changing surface fluxes.



Related Presentations:

Unified Boundary Layer and Convection Parameterizations in Global Models – Joao Teixeira

CL08 – Augmenting the double-Gaussian representation of atmospheric turbulence and convection via a coupled stochastic multi-plume mass flux scheme – Mikael Witte

CL16 – How can weather reanalyses contribute to atmospheric model parameterization development and validation? – Mark Smalley

CO67 – Improving shallow convection in the DOE SCREAM model with the Stochastic Moist Multi-Plume Mass-Flux parameterization – Maria Chinita

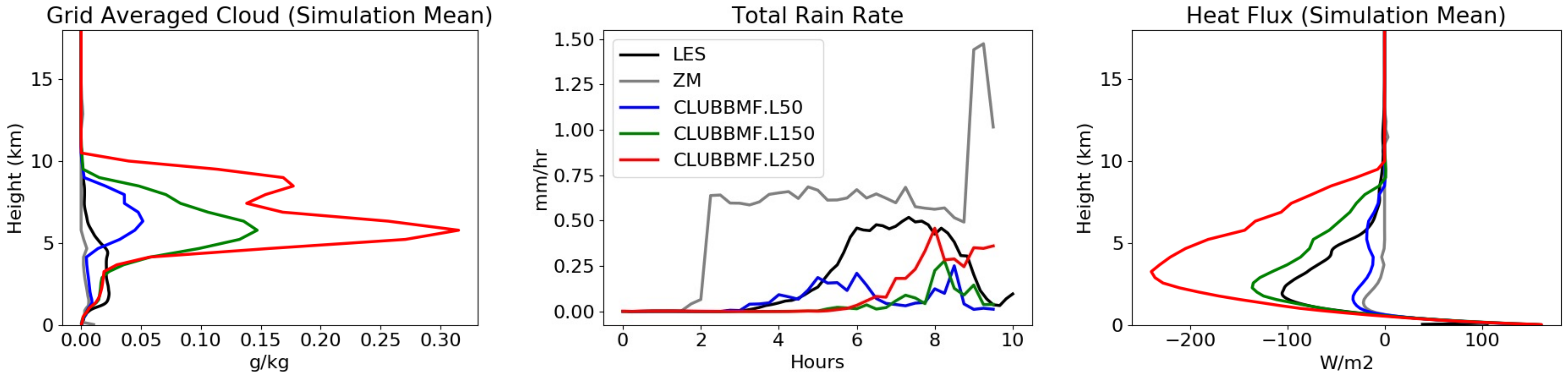
References:

Suselj, K., J. Teixeira, and D. Chung, 2013: A unified model for moist convective boundary layers based on a stochastic eddy-diffusivity/mass-flux parameterization. *J. Atmos. Sci.*, 70, 1929–1953.

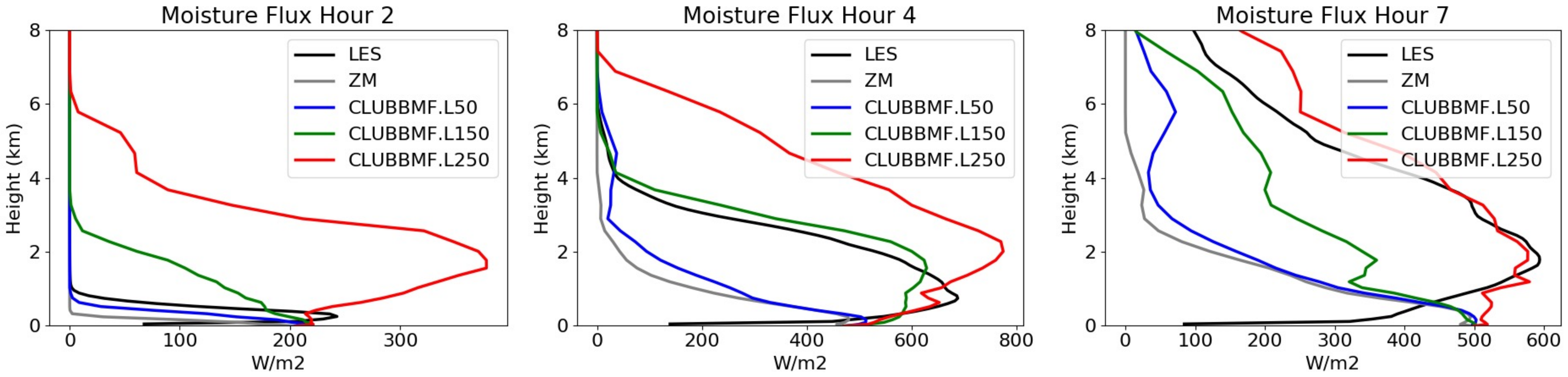
Suselj, K., M. J. Kurowski, and J. Teixeira, 2019b: A unified eddy-diffusivity/mass-flux approach for modeling atmospheric convection. *J. Atmos. Sci.*, 76, 2505–2537.

Witte, M. K., Herrington, A., Teixeira, J., Kurowski, M. J., Chinita, M. J., Storer, R. L., Suselj, K., Matheou, G., & Bacmeister, J. (2022). Augmenting the double-Gaussian representation of atmospheric turbulence and convection via a coupled stochastic multi-plume mass flux scheme, *Monthly Weather Review* (early online release).

Initial SCAM tests of LBA



All versions of CLUBBMF outperform the ZM simulation. Looking at average profiles over the whole simulation, run CLUBBMF.L150 in which the entrainment length scale is equal to 150 m (L_ϵ = 150 m) seems to do the best at representing vertical turbulent transport relative to the LES. However, throughout the day it is clear that a constant value for L_ϵ is not able to properly capture the deepening turbulence and convection. A larger L_ϵ is needed as the day goes on.



Updating CLUBB+MF Entrainment

Entrainment (ϵ_i) for each ith plume as a function of layer depth is given by the following equation:

$$\epsilon_i(\Delta z) = \frac{\epsilon_0}{\Delta z} P_i(\Delta z) \frac{\Delta z}{L_\epsilon}$$

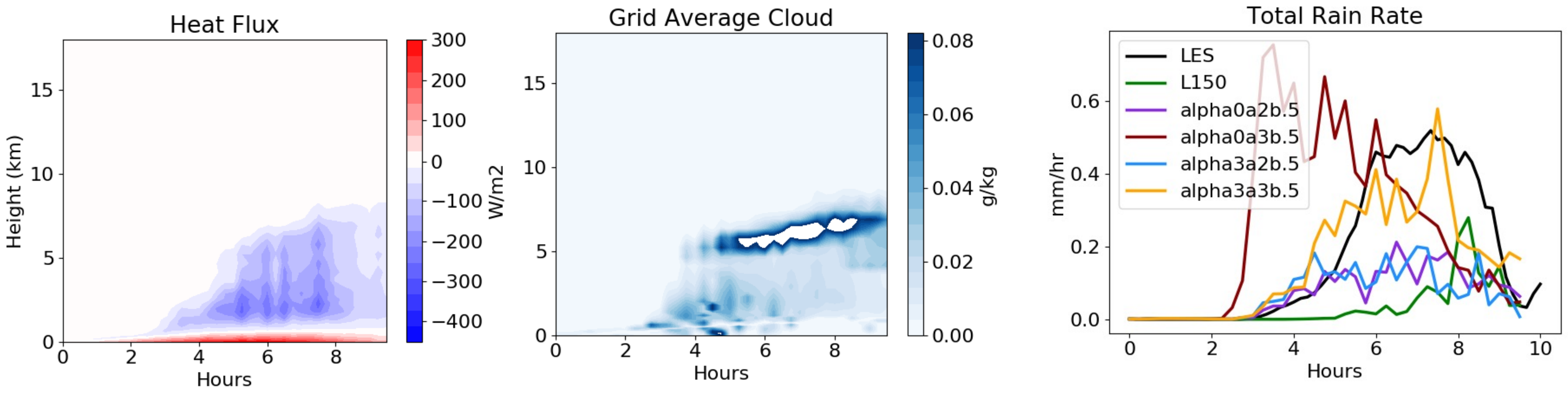
where ϵ_0 is the fractional entrainment rate per entrainment event, set to a constant value of 0.22; P is the stochastic probability of an entrainment event occurring, based on draw from the Poisson distribution; and L_ϵ is a length scale which represents the average distance between entrainment events.

The current default CLUBB+MF configuration uses a constant value L_ϵ= 50m which works well for shallow convection (see Witte et al. 2022, and poster **CL08**). In order to better represent the full spectrum of turbulence and convection, we introduce a diagnostic L_ϵ based on a representative convective layer depth Z_{TOP} using the following relationship:

$$L_\epsilon = \alpha Z_{TOP}^{\beta}$$

A few options have been tested for Z_{TOP}, however currently the most promising option is to use the maximum plume depth averaged over the previous time step. This way the entrainment length scale has a 'memory' and can grow in time as the boundary layer deepens and instability grows.

LBA with new dynamic L_ϵ



With a L_ϵ that evolves throughout the simulations, CLUBB+MF is better able to capture the growth of convection and the diurnal cycle of precipitation