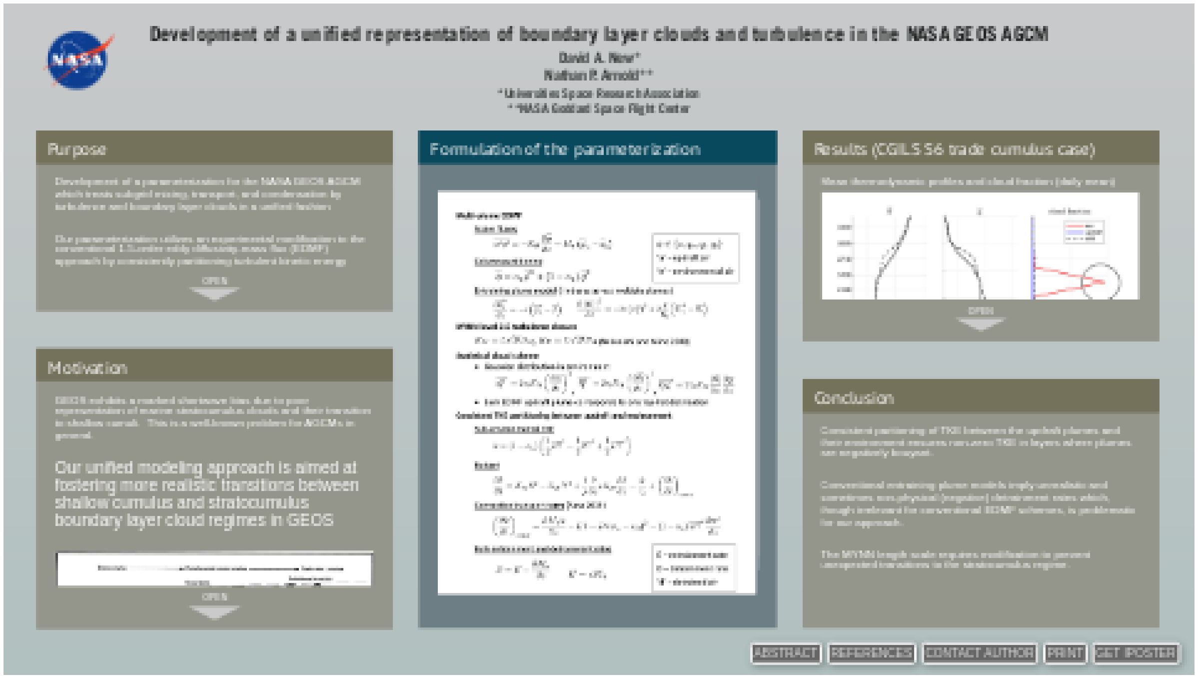
Development of a unified representation of boundary layer clouds and turbulence in the NASA GEOS AGCM



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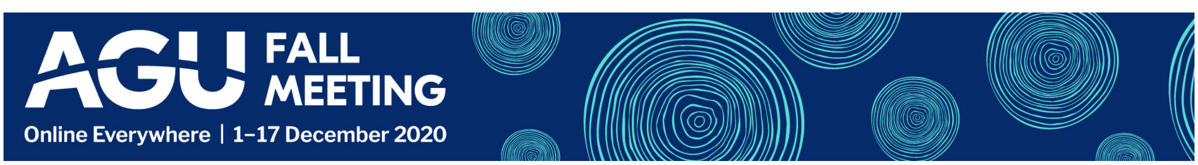


PURPOSE

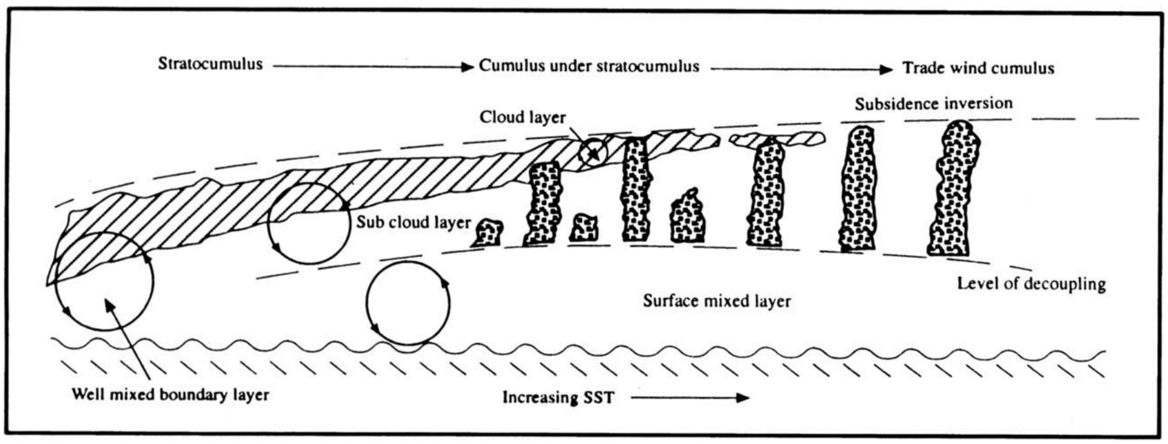
Development of a parameterization for the NASA GEOS AGCM which treats subgrid mixing, transport, and condensation by turbulence and boundary layer clouds in a unified fashion

Our parameterization utilizes an experimental modification to the conventional 1.5-order eddy diffusivity-mass flux (EDMF) approach by consistently partitioning turbulent kinetic energy (TKE) between EDMF updraft plumes and their environment. (New 2019)

MOTIVATION

GEOS exhibits a marked shortwave bias due to poor representation of marine stratocumulus clouds and their transition to shallow cumuli. This is a well-known problem for AGCMs in general.

Our unified modeling approach is aimed at fostering more realistic transitions between shallow cumulus and stratocumulus boundary layer cloud regimes in GEOS



FORMULATION OF THE PARAMETERIZATION

Multi-plume EDMF

Scaler fluxes

$$\overline{w'\phi'} = -K_H \frac{\partial \overline{\phi}}{\partial z} + M_u \left(\overline{\phi}_u - \overline{\phi}_e \right)$$

Column partitioning

$$\overline{\phi} = a_u \overline{\phi}^u + (1 - a_u) \overline{\phi}^e$$

$\phi \in \{s, q_v, q_l, q_i\}$
'u' – updraft air
'e' – environmental air

Entraining plume model (i indexes across multiple plumes)

$$\frac{\partial \overline{\phi}_i^u}{\partial z} = -\varepsilon \left(\overline{\phi}_i^u - \overline{\phi} \right) \qquad \frac{\partial \left(\overline{w}_i^u \right)^2}{\partial z} = -2\varepsilon \left(\overline{w}_i^u \right)^2 + 2 \frac{g}{\theta_0} \left(\overline{\theta_v}_i^u - \overline{\theta_v} \right)$$

MYNN level-2.5 turbulence closure

$K_M = L\sqrt{2k} S_M$, $K_H = L\sqrt{2k} S_H$ (Nakanishi and Niino 2009)

Statistical cloud scheme

- Gaussian distribution in environment

$$\overline{q_t'^2}^e = 2\tau_\theta K_H \left(\frac{\partial \overline{q_t}}{\partial z} \right)^2, \quad \overline{\theta_l'^2}^e = 2\tau_\theta K_H \left(\frac{\partial \overline{\theta_l}}{\partial z} \right)^2, \quad \overline{\theta_l' q_t'}^e = 2\tau_\theta K_H \frac{\partial \overline{\theta_l}}{\partial z} \frac{\partial \overline{q_t}}{\partial z}$$

- Each EDMF updraft plume corresponds to one top-hat distribution

Consistent TKE partitioning between updraft and environment

Sub-environmental TKE

$$k = (1 - a_u) \left(\frac{1}{2} \overline{u'^2}^e + \frac{1}{2} \overline{v'^2}^e + \frac{1}{2} \overline{w'^2}^e \right)$$

Budget

$$\frac{\partial k}{\partial t} = K_M S^2 - K_H N^2 + \frac{1}{\rho} \frac{\partial}{\partial z} \rho K_M \frac{\partial k}{\partial z} - \frac{k}{\tau_k} + \left(\frac{\partial k}{\partial t} \right)_{conv}$$

Convective transport term (New 2019)

$$\left(\frac{\partial k}{\partial t} \right)_{conv} = \frac{\partial M_u k}{\partial z} - Ek + D \left(w_u - w_d \right)^2 - (1 - a_u) \overline{w'^2}^e \frac{\partial \overline{w}^e}{\partial z}$$

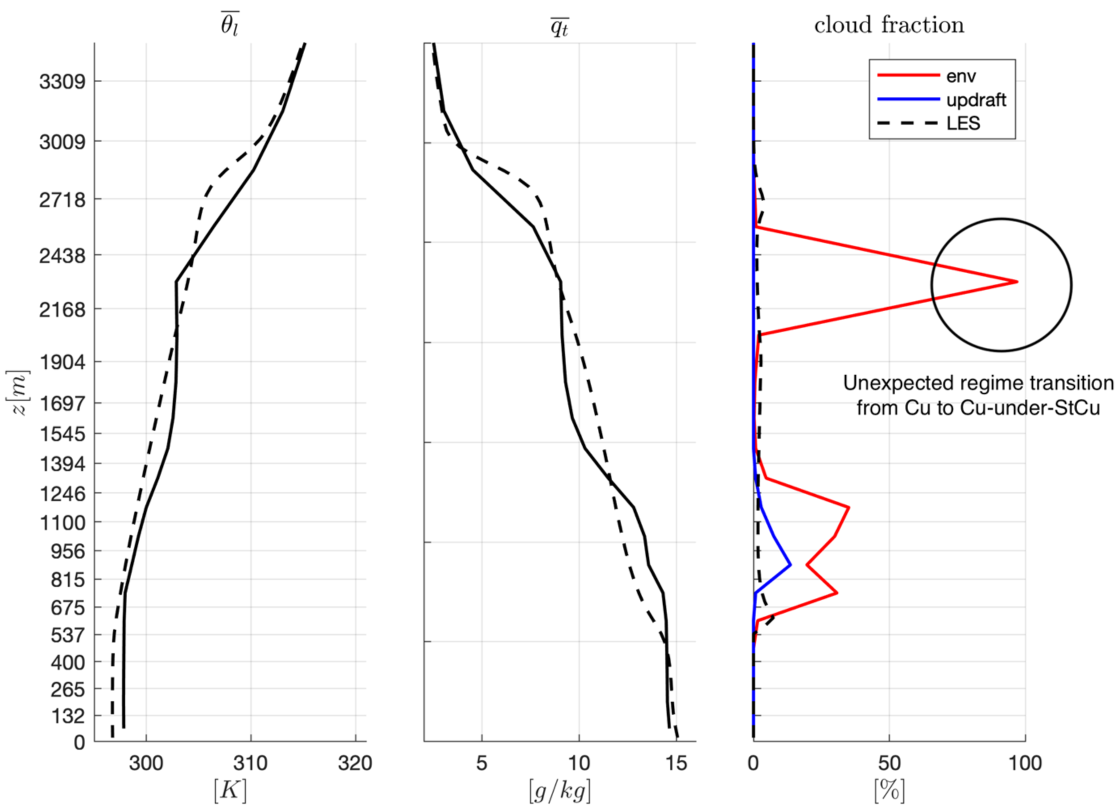
Bulk entrainment and detrainment rates

$$D = E - \frac{\partial M_u}{\partial z} \qquad E = \epsilon M_u$$

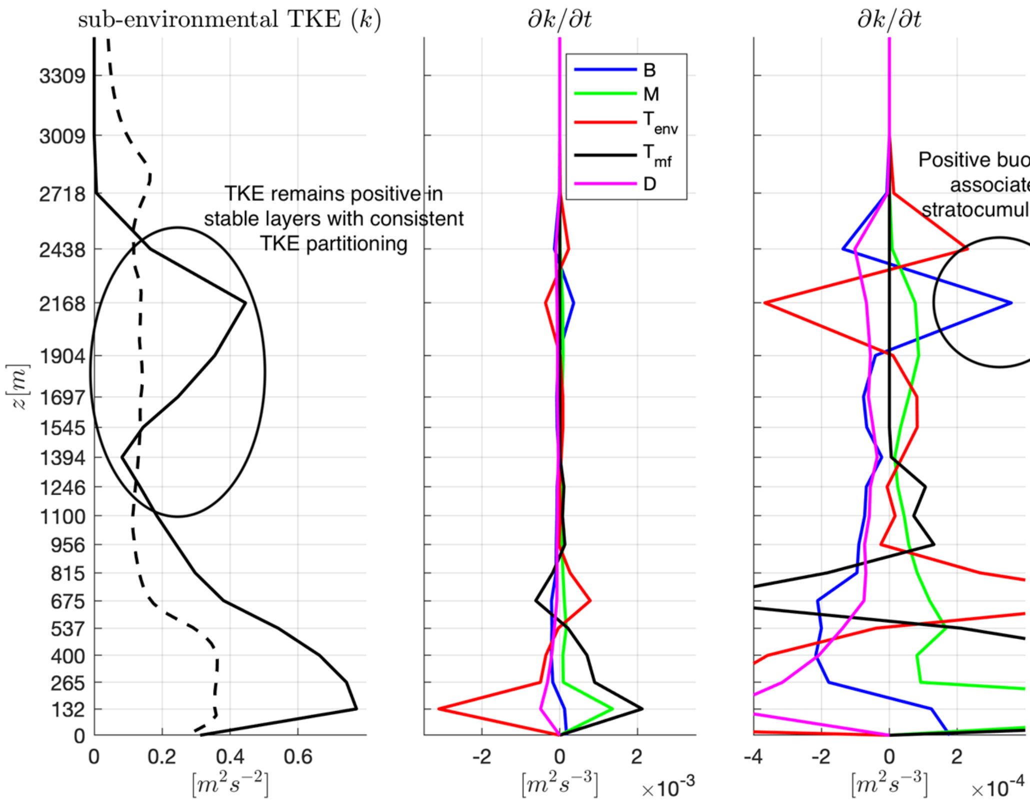
E – entrainment rate
D – detrainment rate
'd' – detrained air

RESULTS (CGILS S6 TRADE CUMULUS CASE)

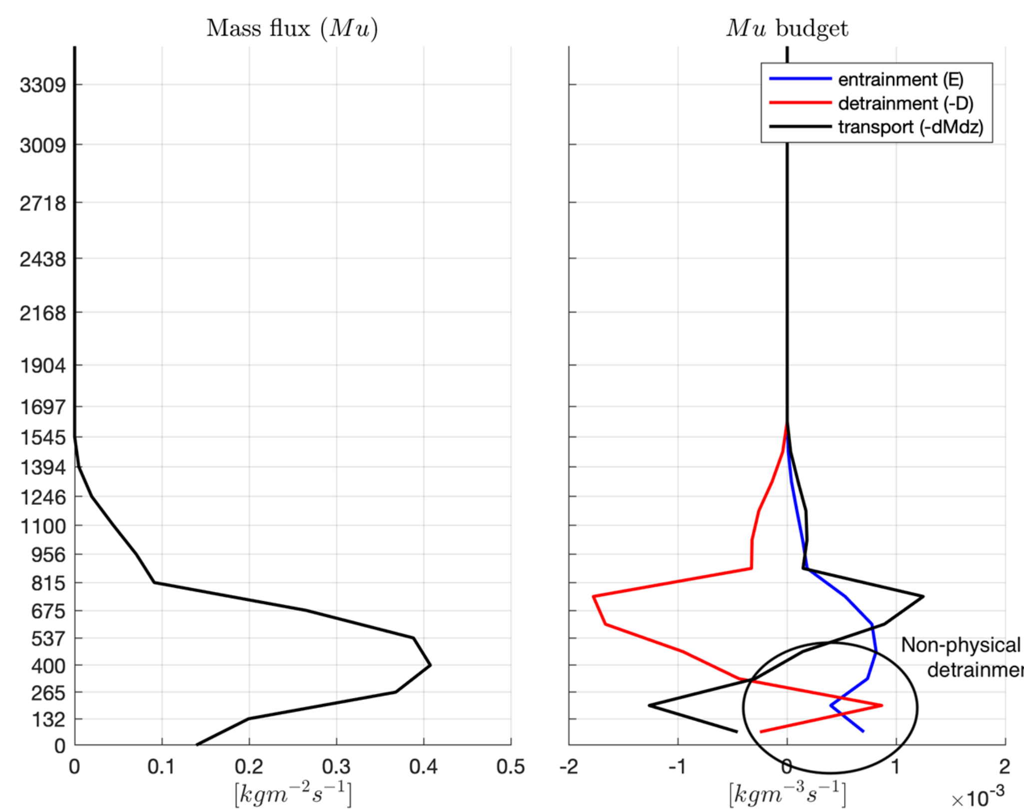
Mean thermodynamic profiles and cloud fraction (daily mean)



TKE profile and budget (daily mean)



Updraft mass flux profile and budget (daily mean)



CONCLUSION

Consistent paritioning of TKE between the updraft plumes and their environment ensures non-zero TKE in layers where plumes are negatively bouyant.

Conventional entraining plume models imply unrealistic and sometimes non-physical (negative) detrainment rates which, though irrelevant for conventional EDMF schemes, is problematic for our approach.

The MYNN length scale requires modification to prevent unexpected transitions to the stratocumulus regime.

ABSTRACT

The representation of boundary layer clouds remains a key source of uncertainty in weather and climate prediction. Unification of turbulence, dry and shallow convection processes into a single parameterization has long been recognized as a necessary condition for remedying these model errors.In this study, we summarize our experience implementing such a unified parameterization in the Goddard Earth Observing System (GEOS) atmospheric general circulation model. Our scheme combines two well-known methods, the eddy diffusivity-mass flux (EDMF) and high-order closure-assumed distribution(ADHOC) approaches. The local component of EDMF mixing/transport is modeled using the Mellor-Yamada-Nakanishi-Niino (MYNN) level-2.5 turbulence closure, while the non-local EDMF component uses a multiple mass flux scheme developed at NASA JPL. The ADHOC method is applied via the assumption that the jointv ariability of heat, moisture, and momentum in a grid cell has a doubleGaussian distribution, with one component Gaussian distribution quantifying variability within the mass flux scheme’s updraft ensemble while the other quantifies variability inside the environment of the ensemble. Unlike conventional EDMF schemes, the second-order moments of heat, moisture, and momentum are consistently partitioned between these two parts of the grid cell, thereby determining the shape of the double Gaussian distribution without requiring a predictive or diagnostic equation for third-order moments. Rather, the mass flux scheme implicitly determines such skewnesses via its entraining plume equations. Moreover, turbulent kinetic energy (TKE)is consistently partitioned in the same way, eliminating spurious sources and sinks of energy due to double counting of buoyant production/destruction.Instead, organized TKE associated with the rising updraft plumes and subsiding environment interacts with TKE within the environment via entrainment, detrainment, and subsidence. Results will be presented for single column model simulations of several standard marine boundary layer cloud cases using our new parameterization in GEOS. Considerations and challenges associated with energetic consistency and numerical stability will be discussed as well as considerations for future development and testing in three-dimensional simulations of GEOS.

REFERENCES

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