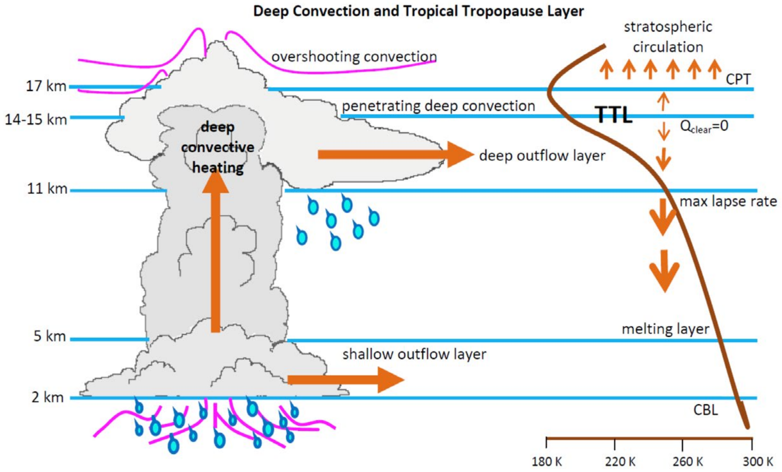
AMWG - The Vertical Extent of Convection in CAM7: A Simple Total Energy Approach

Rich Neale* (rneale@ucar.edu) *and Cecile Hannay
Climate and Global Dynamics Lab. (CGD)
NSF National Center for Atmospheric Research (NCAR)

29th Annual CESM Workshop, Boulder, CO (June 10th, 2024)

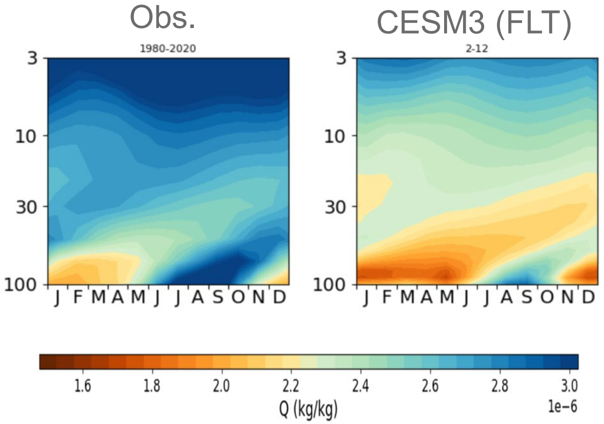
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Deep Convective Overshoot

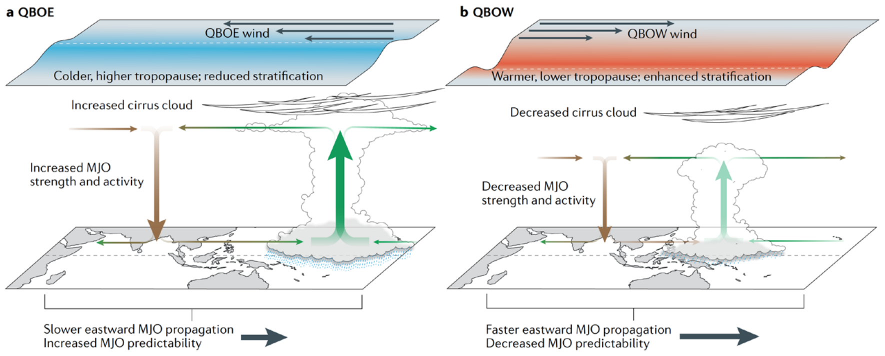


Young (2012): 10.13140/RG.2.1.2699.2720

Tape Recorder



MJO-QBO Interaction



Martin et al. (2021): 10.1038/s43017-021-00173-9

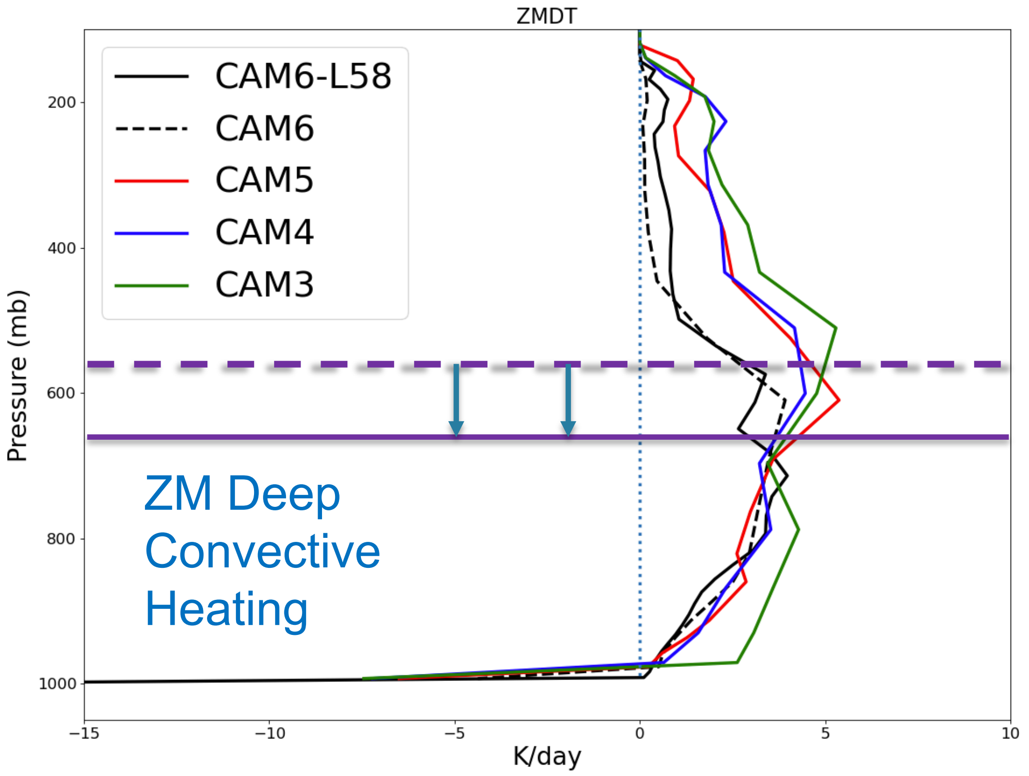
Convective overshoot

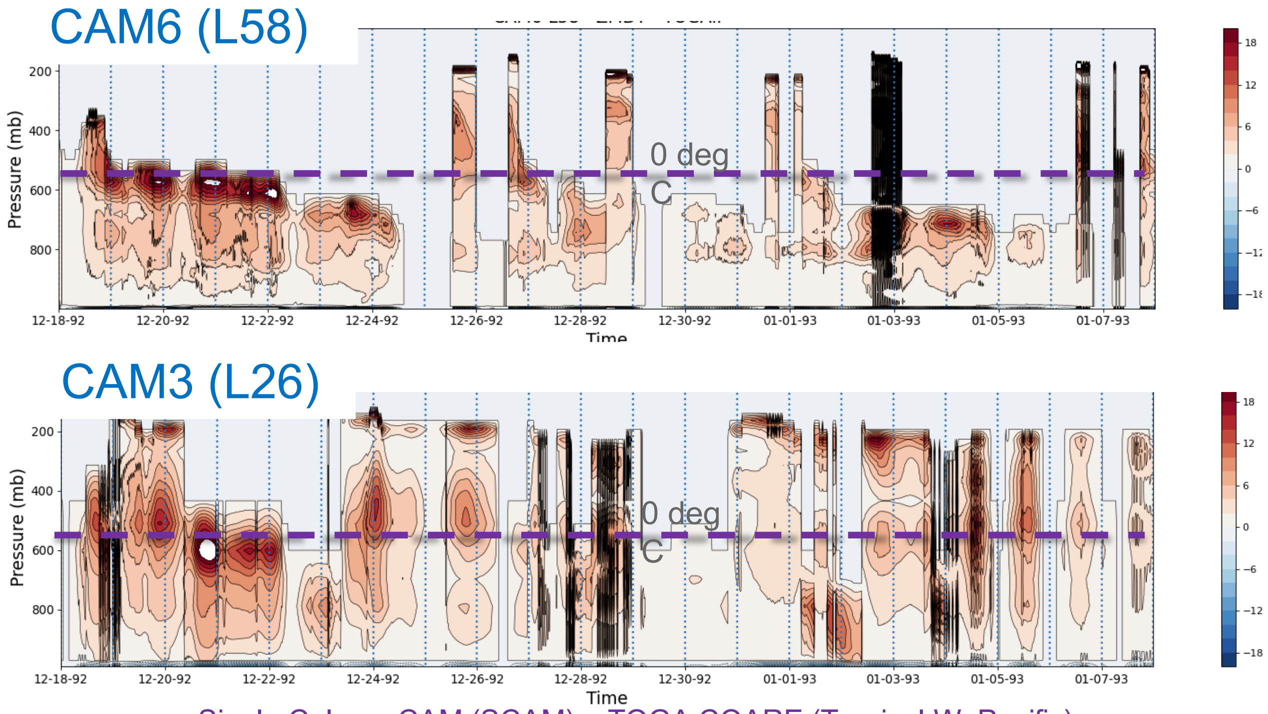
- A few percent of the time (especially over land)
- Above the level of neutral buoyancy
- Zhang-McFarlane deep convection cannot represent this
- Equilibrium potential energy (CAPE) framework

Remaining Deep Convection Issues

Top Heaviness

- Zhang McFarlane behavior has shallowed over time CAM3->CAM6
- Increased sensitivity to moisture (good for MJO, diurnal cycle)
- Compensation from non-convection physics
- Implications for lower stratosphere (QBO, tape recorder)?





Single Column CAM (SCAM) – TOGA COARE (Tropical W. Pacific)

Simple Plume Dynamics (KE/PE)

Reference	Acronym	Equation	a	b	Remarks
Simpson and Wiggert (1969)		(1)	$\frac{2}{3}$		$\frac{1}{2}\frac{\partial w_c^2}{\partial z} = aB_c - 0.18\frac{w_c^2}{R}$, where R is cloud radius
Bechtold et al. (2001)	BBGMR	(12)	$\frac{2}{3}$	1	
Gregory (2001)	G01	(11)	$\frac{1}{6}$	1	$\frac{1}{2}\frac{\partial w_c^2}{\partial z} = aB_c - (b'\delta + b\epsilon)w_c^2, b' = \frac{1}{2}$
Von Salzen and McFarlane (2002)	SF	(29)	$\frac{1}{6}$	1	
Jakob and Siebesma (2003)	JS	(7)	$\frac{1}{3}$	2	
Bretherton et al. (2004)	BMG	(17)	1	2	
Cheinet (2004)	C04	(1)	1	1	
Soares et al. (2004)	SMST	(6)	2	1	
Rio and Hourdin (2008)	RH	(5)	1	1	$\frac{\partial \sigma w_c^2}{\partial z} = a\sigma B_c - b'\delta\sigma w_c^2, b' = \frac{1}{2}$ b value found after substitution of Eq. (4)
Neggers et al. (2009)	NKB	(12)	1	$\frac{1}{2}$	$\frac{1}{2}(1-2\mu)\frac{\partial w_c^2}{\partial z} = aB_c - b\epsilon w_c^2, \mu = 0.15$
Pergaud et al. (2009)	PMMC	(7)	1	1	
Rio et al. (2010)	RHCJ	(9)	$\frac{2}{3}$	1	$\frac{1}{2}\frac{\partial w_c^2}{\partial z} = aB_c - (b' + b\epsilon)w_c^2, b' = 0.002$
De Rooy and Siebesma (2010)	RS	(27)	0.62	1	
ECMWF (2010)	ECMWF	(6.9)	$\frac{1}{3}$	1.95	
Kim and Kang (2011)	KK	(11)	$\frac{1}{6}$	2	$\frac{1}{2}\frac{\partial w_c^2}{\partial z} = a(1 - C_\epsilon b)B_c, C_\epsilon = 1/\overline{RH} - 1$

Roode, Stephan R. et al. "Parameterization of the Vertical Velocity Equation for Shallow Cumulus Clouds." *Monthly Weather Review* 140 (2012): 2424-2436.

Bulk Convective Parcel Energetics

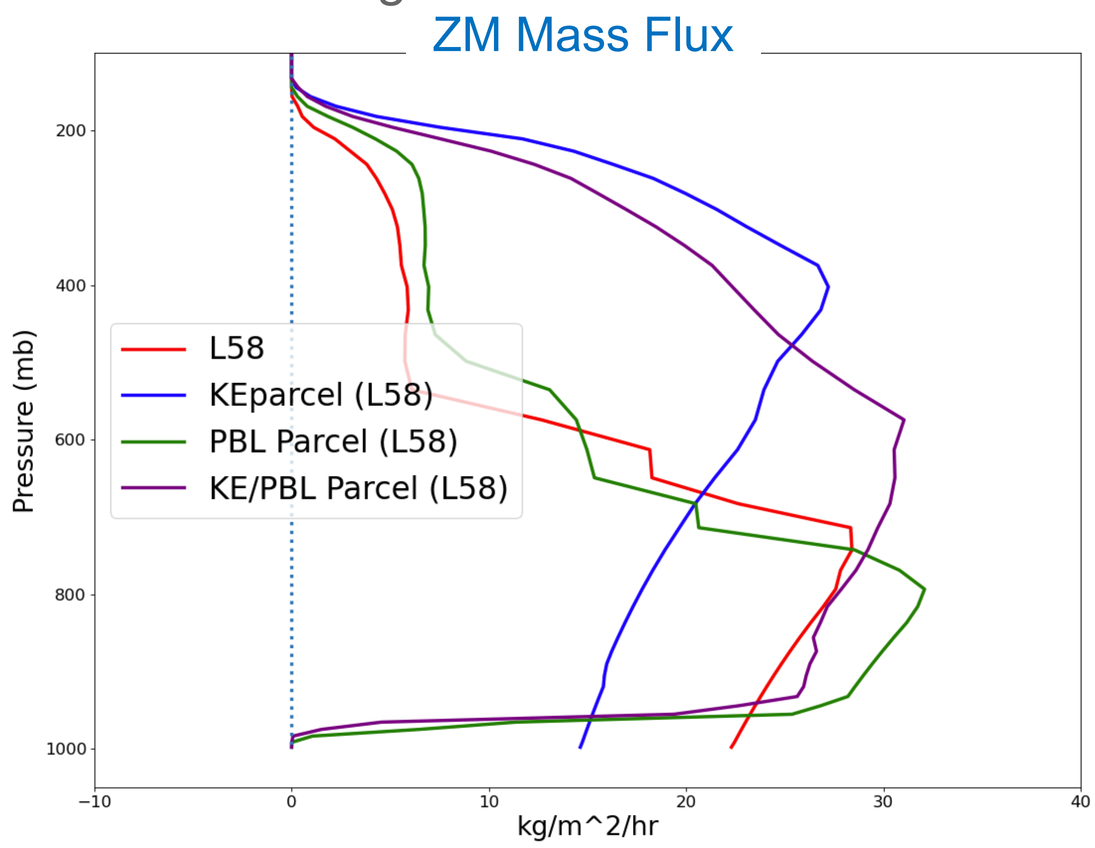
$KE_p(k) = pe2ke\_eff * PE_p(k) + KE(k-1) + KE_{LS}(k)$

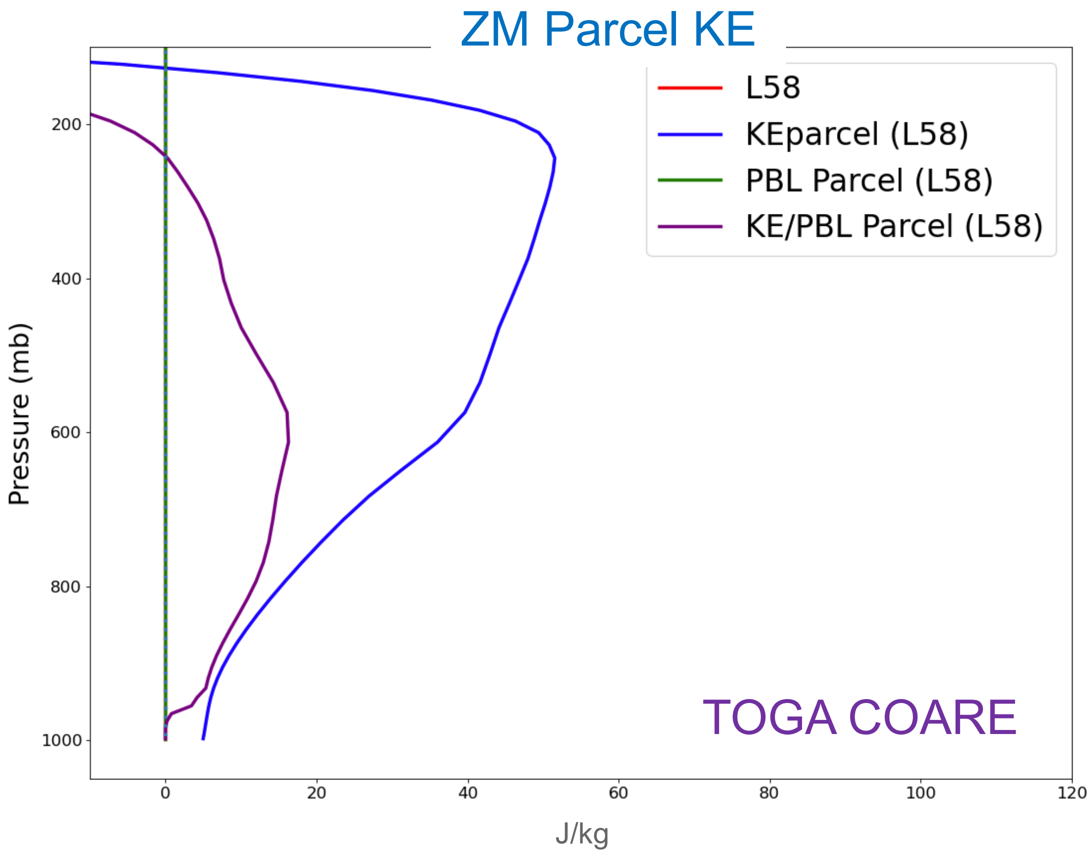
$KE_p(k)$ = Kinetic energy at level k
$PE_p(k)$ = Potential energy at level k (buoyancy based)
$KE_{LS}(k)$ = Kinetic energy of resolved K

pe2ke_eff = Efficiency PE->KE conversion (**0.1** – 0.05,0.2)
P_{ini} = Cloud base parcel energy (**5** – 2,20) J/kg

Vertical Profile of Convection

- Convective top is where KE equals zero
- Top heavy convective mass flux, steady increase near surface
- Overshooting?

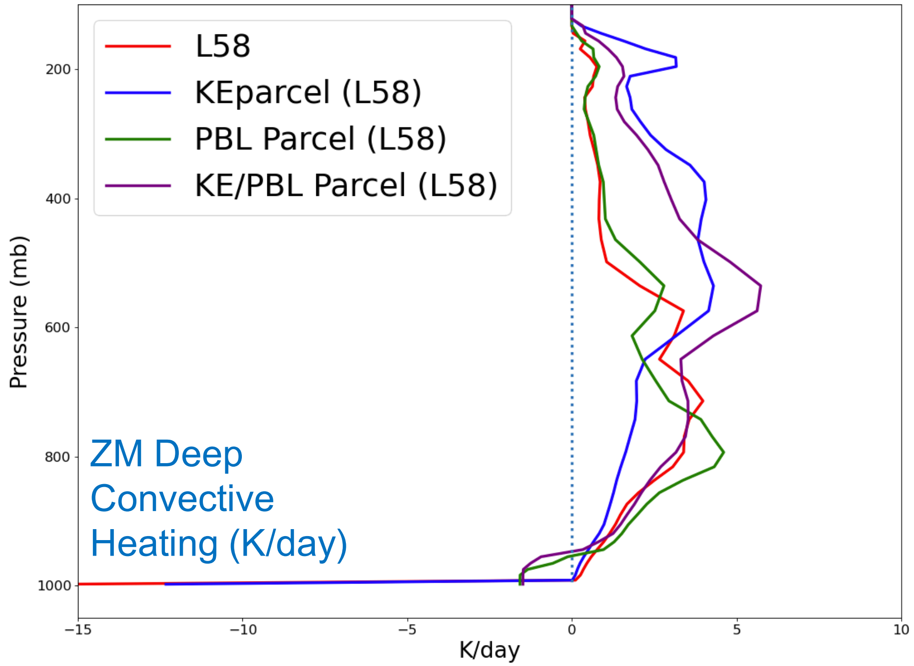




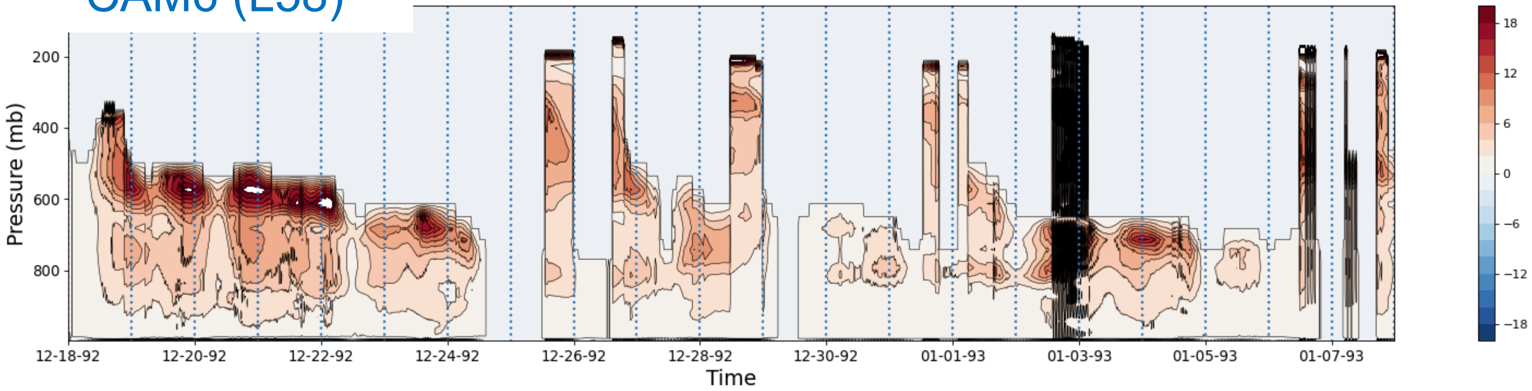
Is There a Convective Heating Change?

Top Heaviness

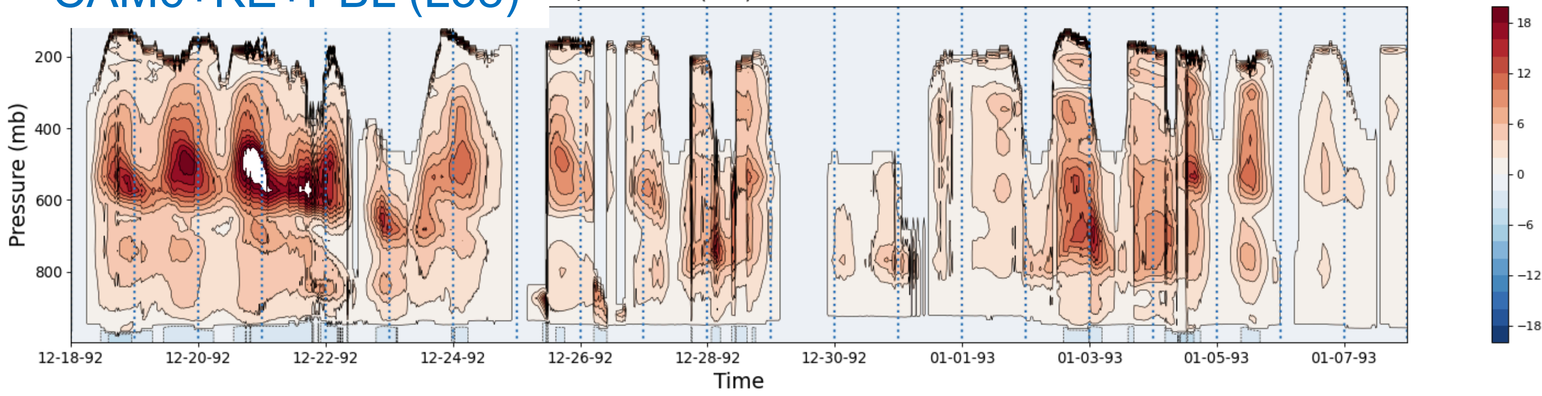
- Near surface tendencies reduced
- Deep heating restored
- Maximum convective heating elevated



CAM6 (L58)



CAM6+KE+PBL (L58)

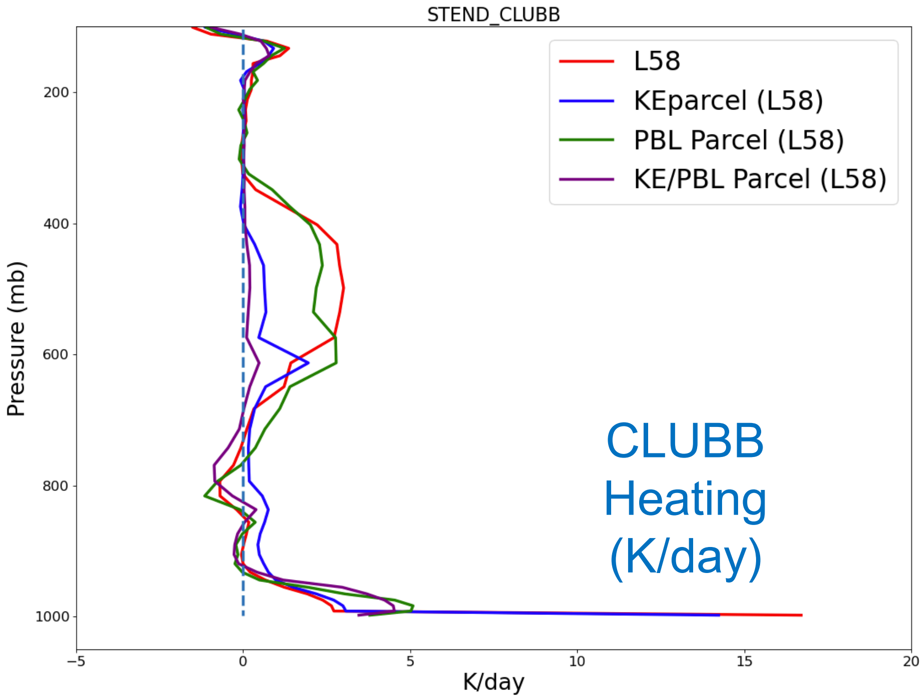


Single Column CAM (SCAM) – TOGA COARE (Tropical W. Pacific)

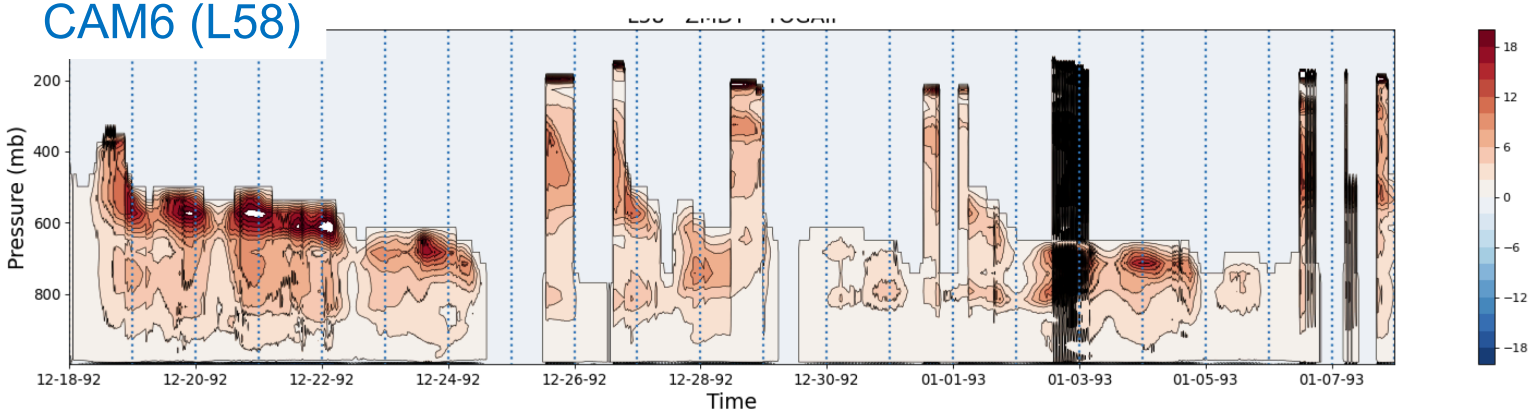
Convective Heating Change

Top Heaviness

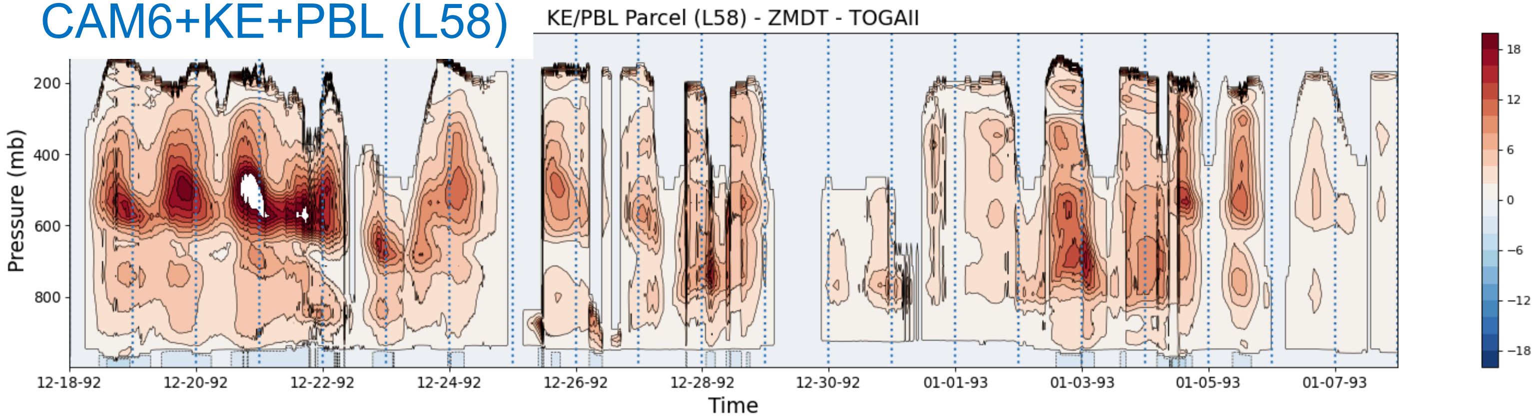
- Near surface tendencies reduced
- Deep heating restored
- Maximum convective heating elevated



CAM6 (L58)

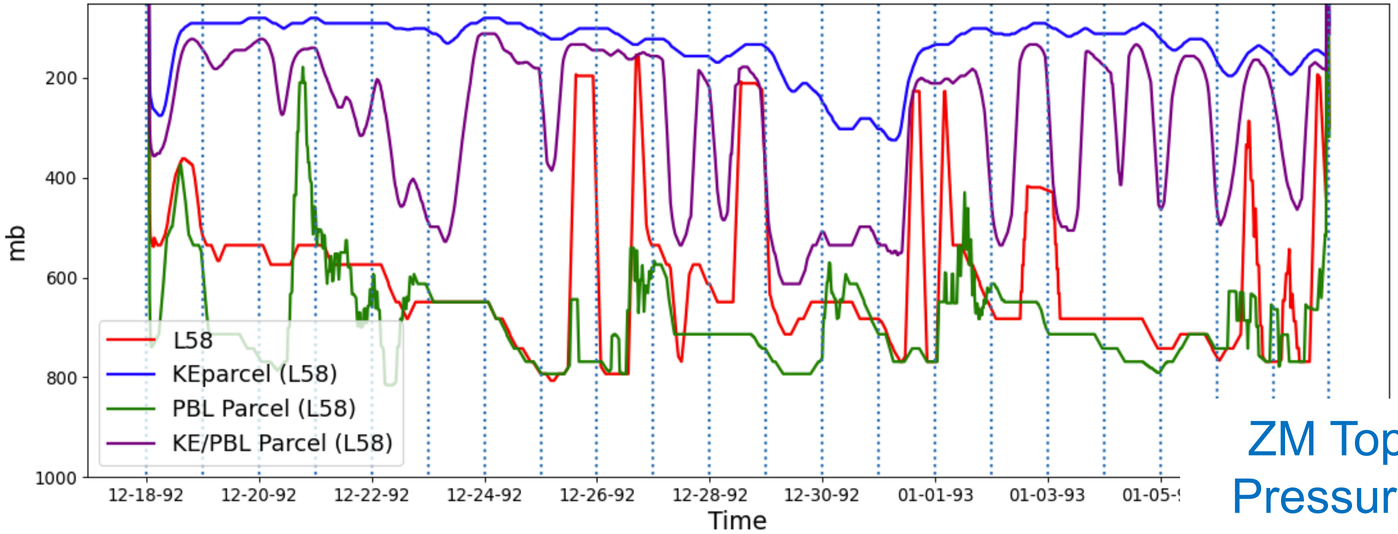


CAM6+KE+PBL (L58)



Single Column CAM (SCAM) – TOGA COARE (Tropical W. Pacific)

Cloud Top Height – Goldilocks Behavior



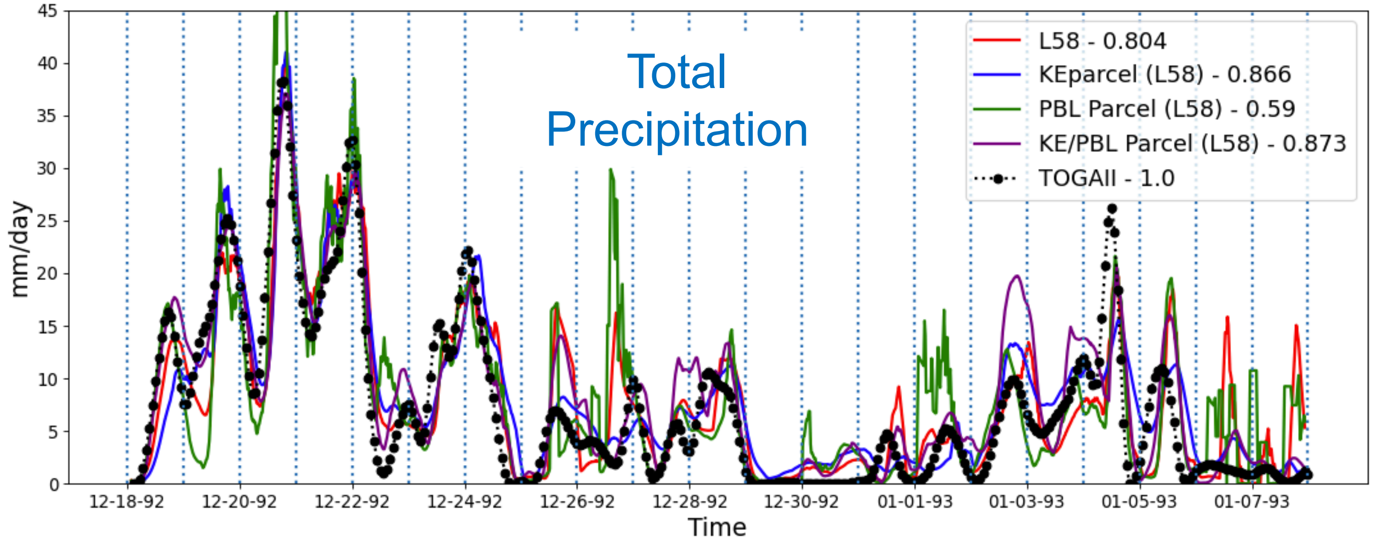
ZM Top Pressure

Occasionally deep, mostly shallow (L58)

Excessive, constant depth (+KE)

Nearly always shallow (+PBL)

Mostly deep, sensitive to stability (+KE/PBL)



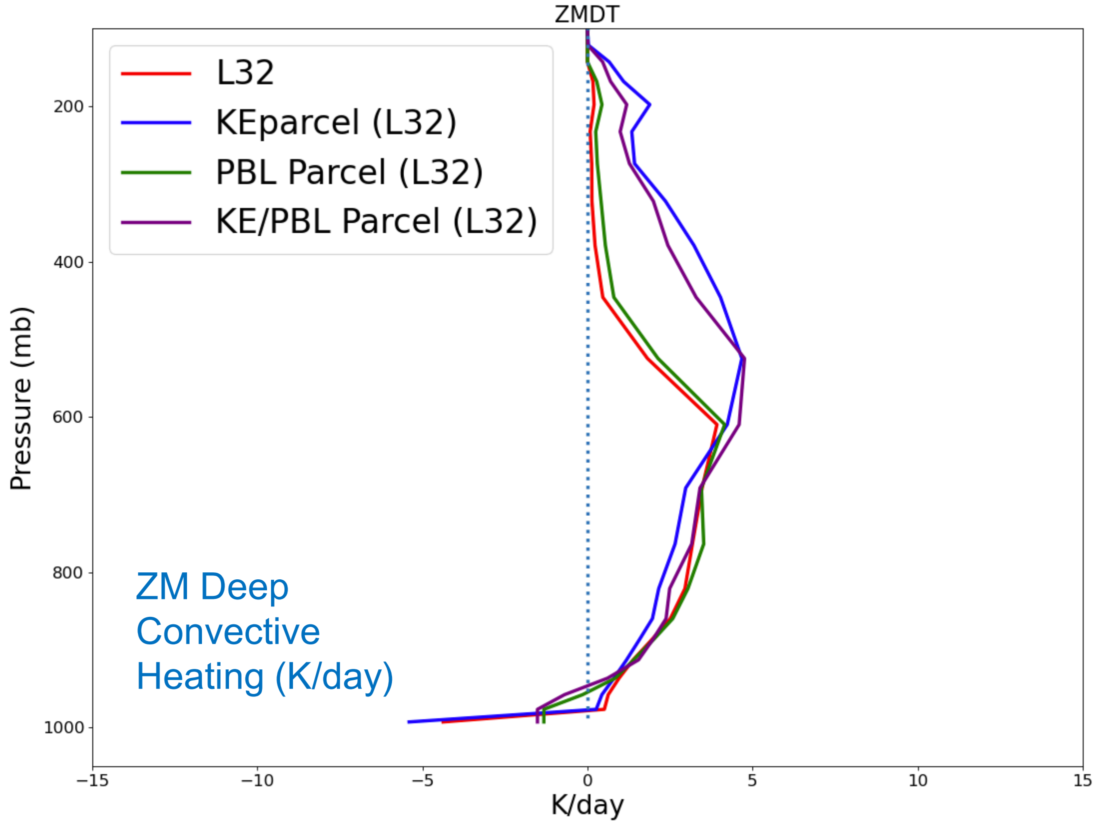
Total Precipitation

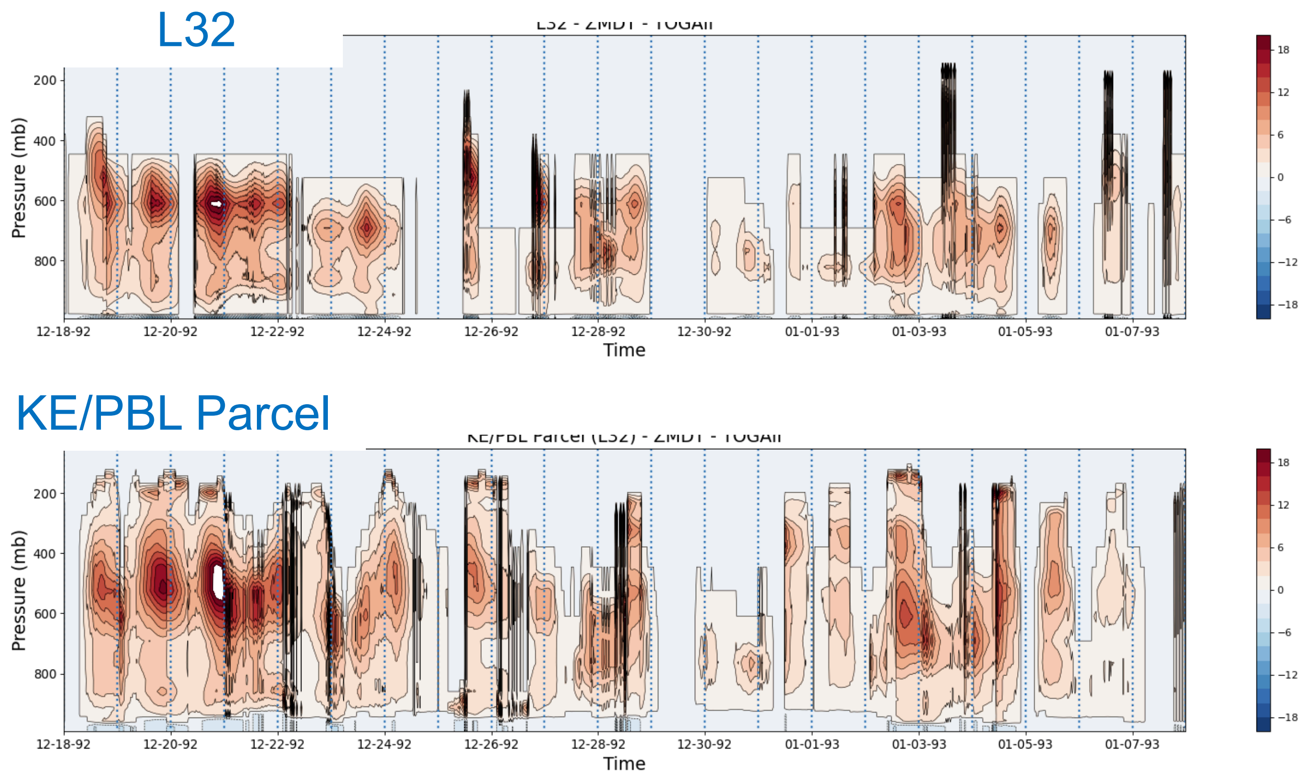
Single Column CAM (SCAM) – TOGA COARE (Tropical W. Pacific)

Parcel Vertical Range

- Cloud base more responsive to the environment with the PBL parcel changes
- Cloud top more responsive to the environment with the ZM KE changes

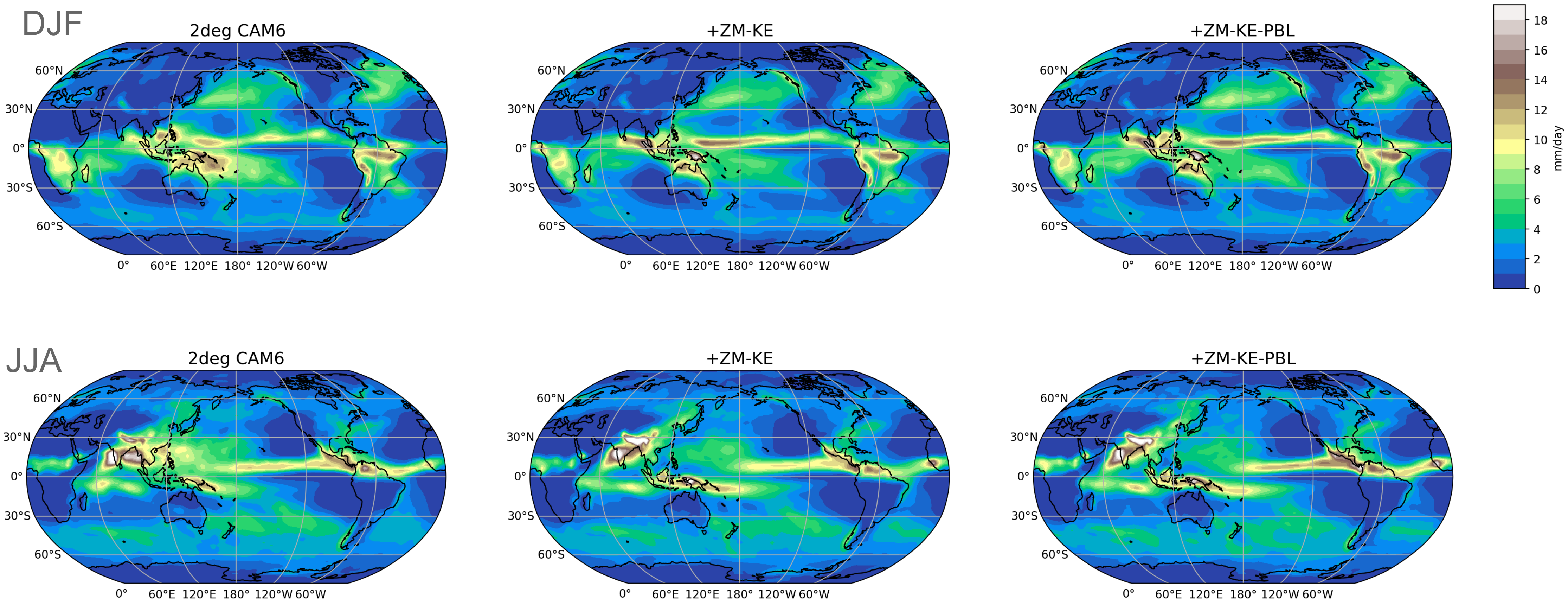
Single Column L32





Single Column CAM (SCAM) – TOGA COARE (Tropical W. Pacific)

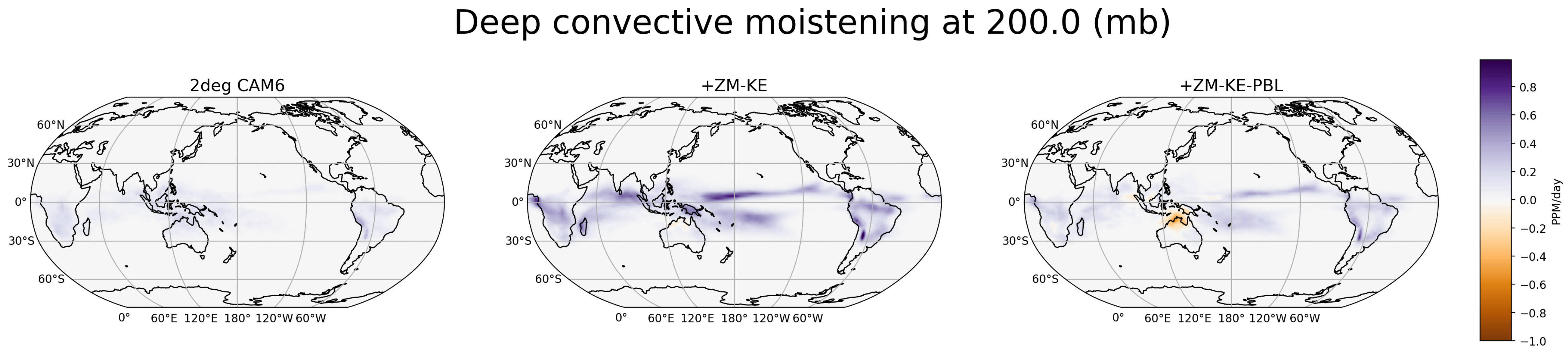
CAM Simulations (L32, 2 deg) - Precipitation

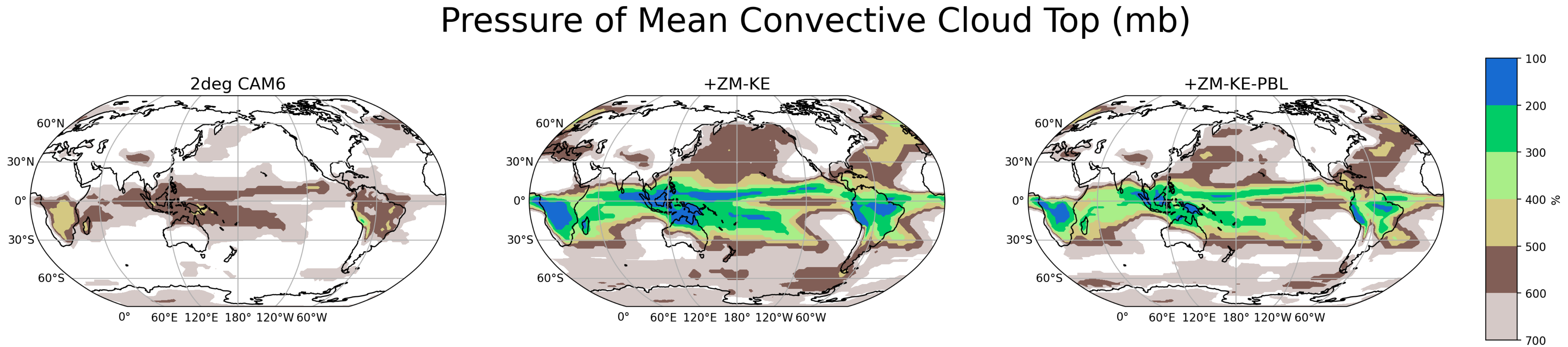


CAM6 Simulations

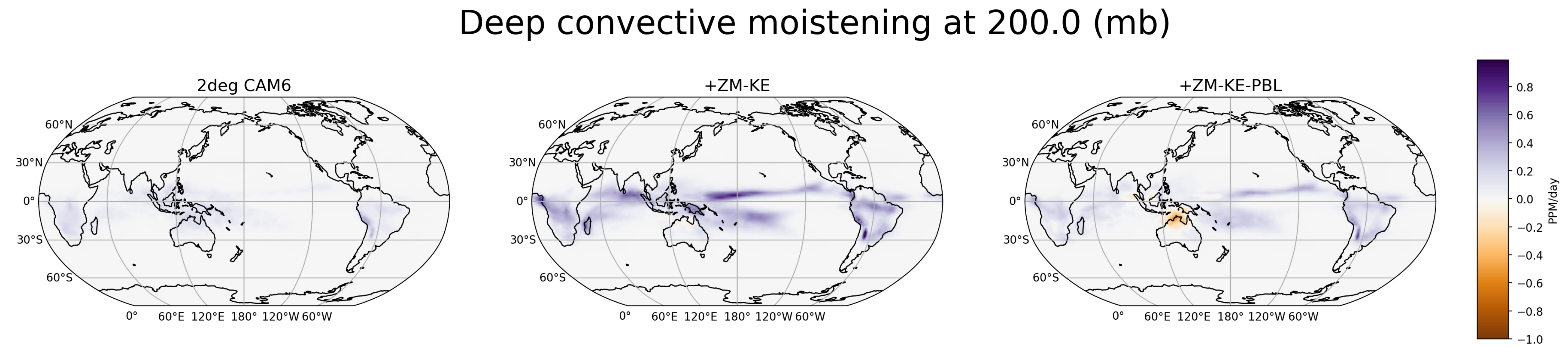
- 6 years, CAM6, F2000climo
- ZM total parcel energy (**KE**) and CAM7 near-surface mixing (**PBL**) + combined

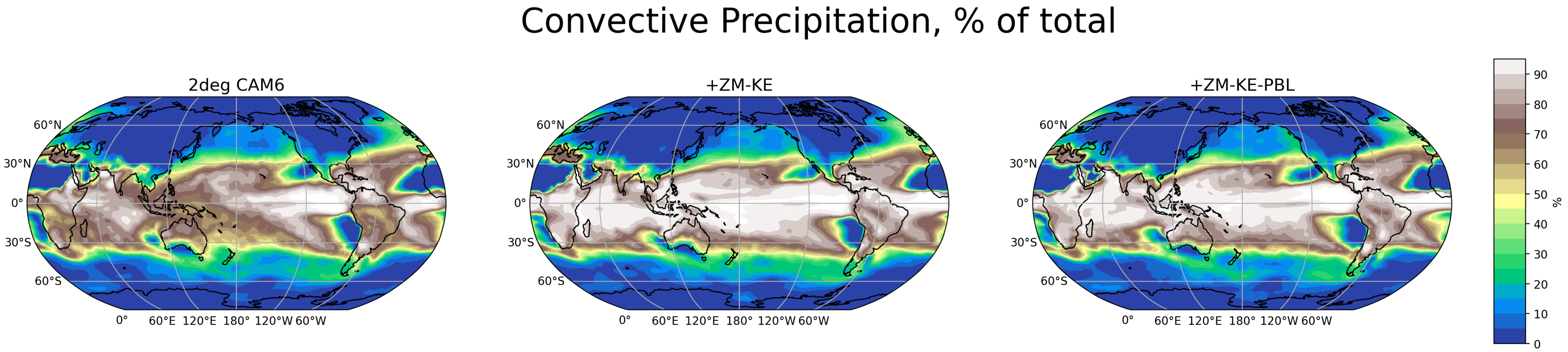
CAM Simulations (L32, 2 deg) – Deeper Convection (DJF)



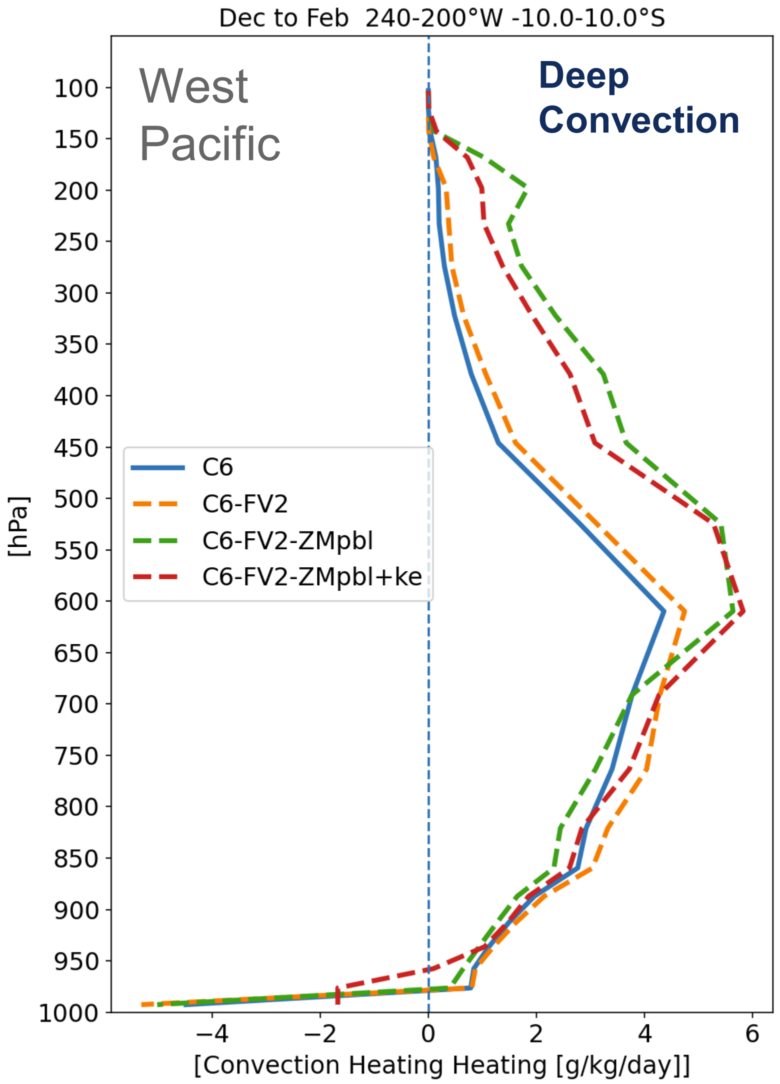


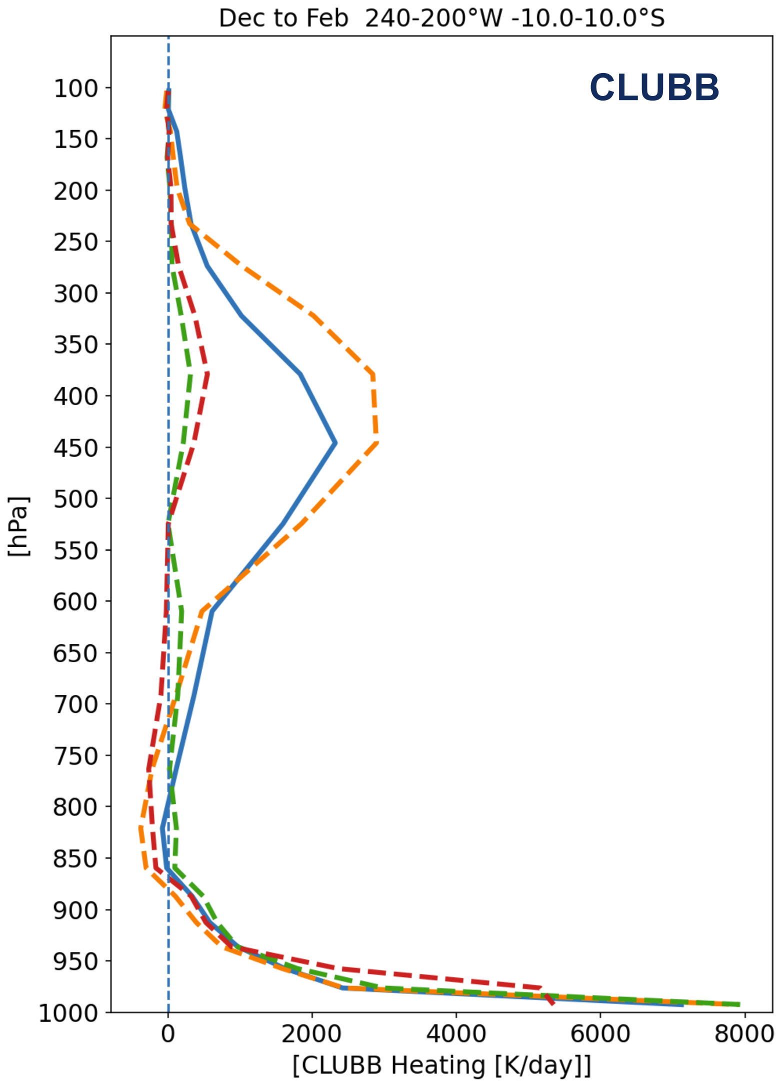
CAM Simulations (L32, 2 deg) – Deeper Convection (DJF)



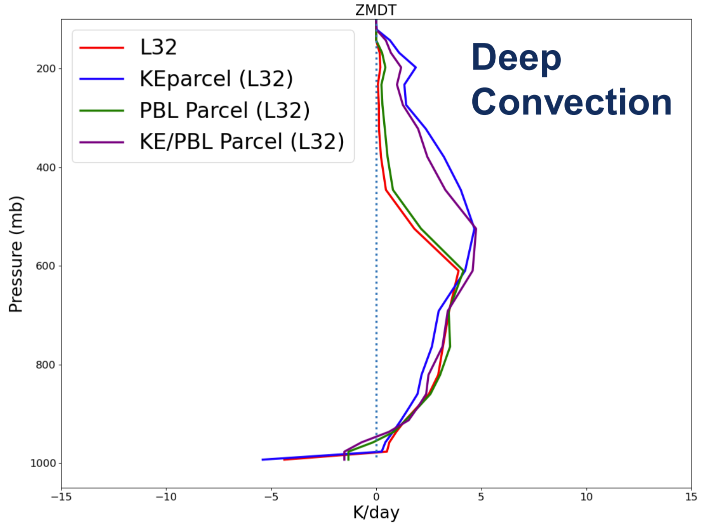


CAM Simulations (L32, 2 deg) – Top Heavy (DJF)





SCAM



Summary

Motivation

ZM PBL-based launch level properties in CAM6-dev

Decreased ZM deep heating came in at CAM6 (single layer stability)

Potential for L58 to be more sensitive (2x thinner layers)

Talk

Implemented a total energy criteria (PE+KE>0) for ZM plume viability -> SCAM

TOGA: Performs well for tropics; noise, deep heating, convective top

ARM site: Marginal improvements, tuning of parameters needed

Low-resolution CAM6 simulations: Consistently deeper convection (tunable!)

Next steps:

CAM7 simulations 1deg L58

Improve realism of energetics (initial plume energy, conversion efficiency

Implement a KE_{ini} based on CLUBB TKE (CLUBB-MF definitely better)