AOS 801: Advanced Tropical Meteorology

Lecture 6   Spring 2023

Convective Quasi-Equilibrium

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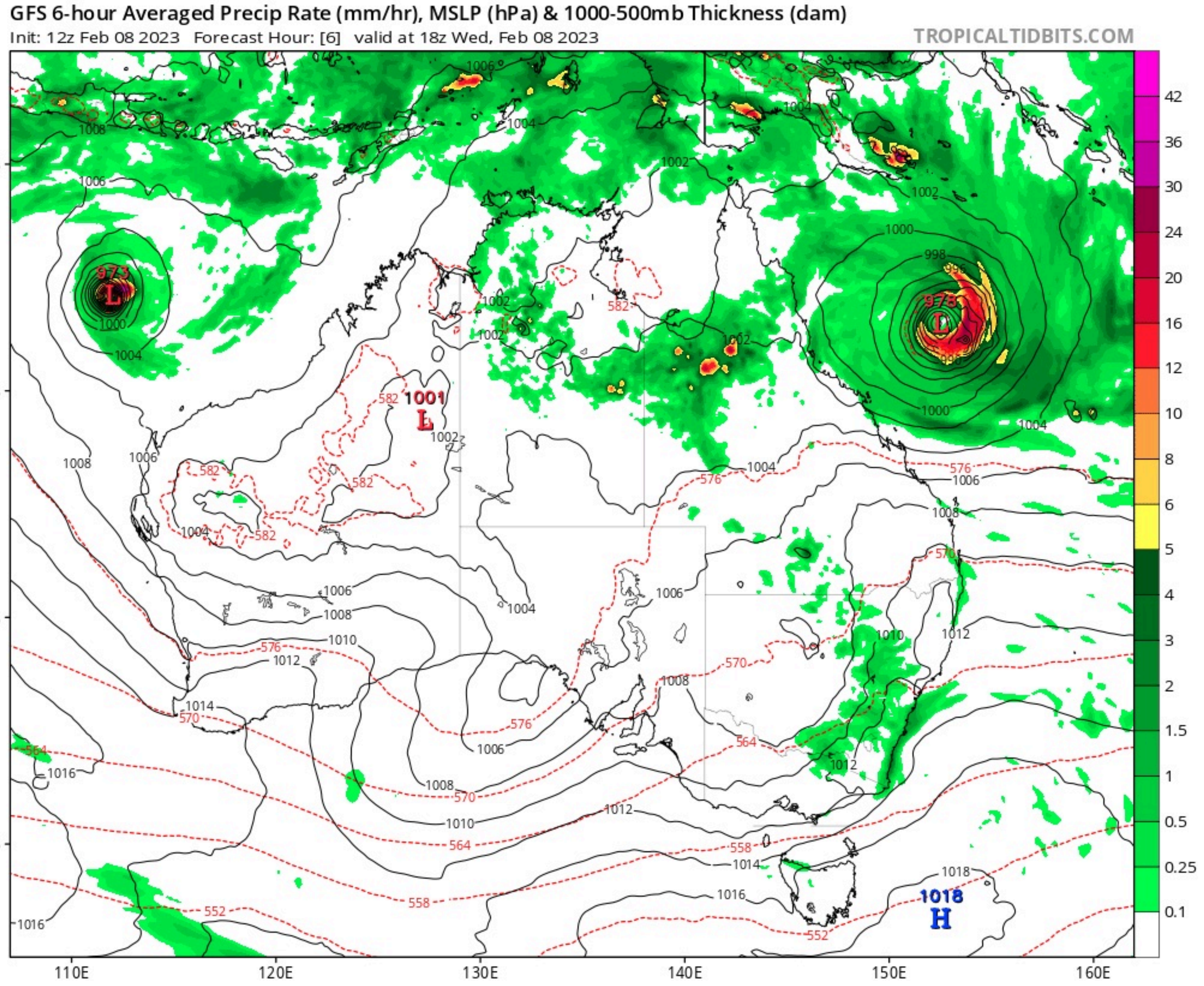
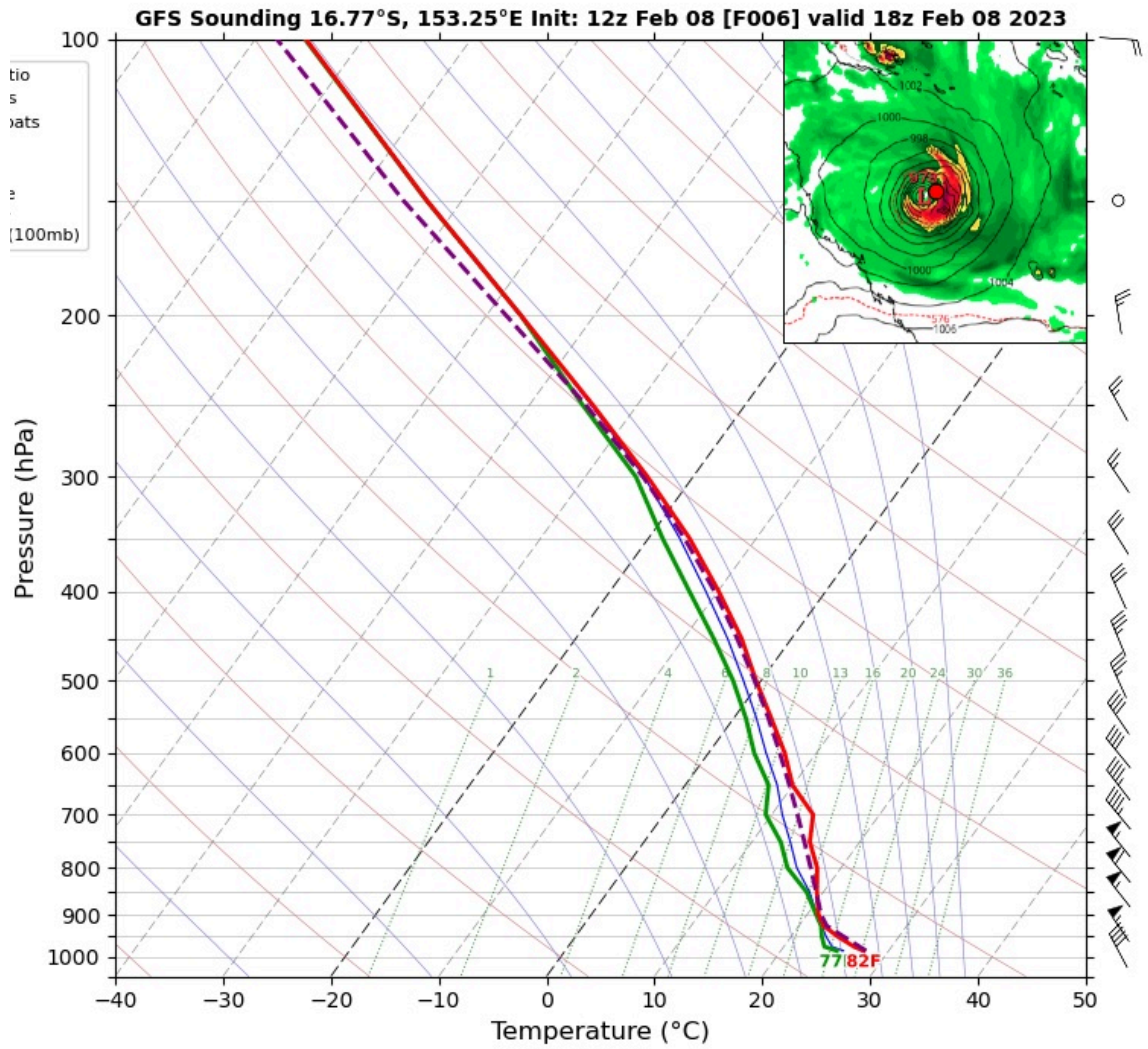
Convective Quasi-Equilibrium

Deep convection is more widespread in the deep tropics than anywhere else on Earth

How is so much convection sustained in the absence of widespread instability?

Convective Quasi-Equilibrium





Convective Quasi-Equilibrium

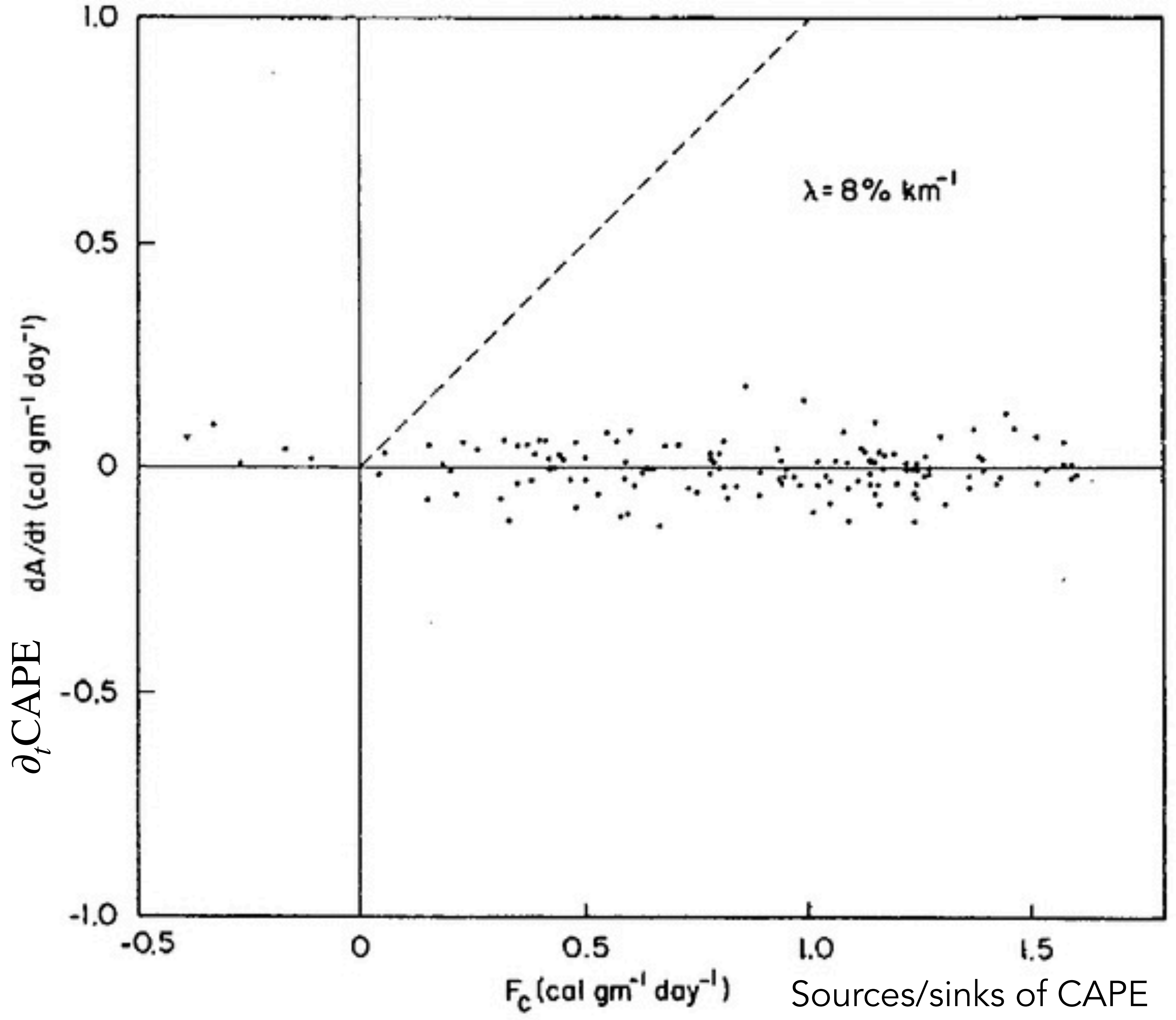
What characteristics of the tropics have we found are determined by the convection?

Convective Quasi-Equilibrium

Convection quickly eliminates convective instability from the column, resulting in small CAPE values that vary little in time.

$$\frac{\partial \mathrm{CAPE}}{\partial t} \simeq 0. \qquad \mathrm{CAPE} = \int_{LFC}^{LNB} B dz$$

This hypothesis is known as **Convective Quasi-Equilibrium**



Arakawa and Schubert (1974)

Convective Quasi-Equilibrium

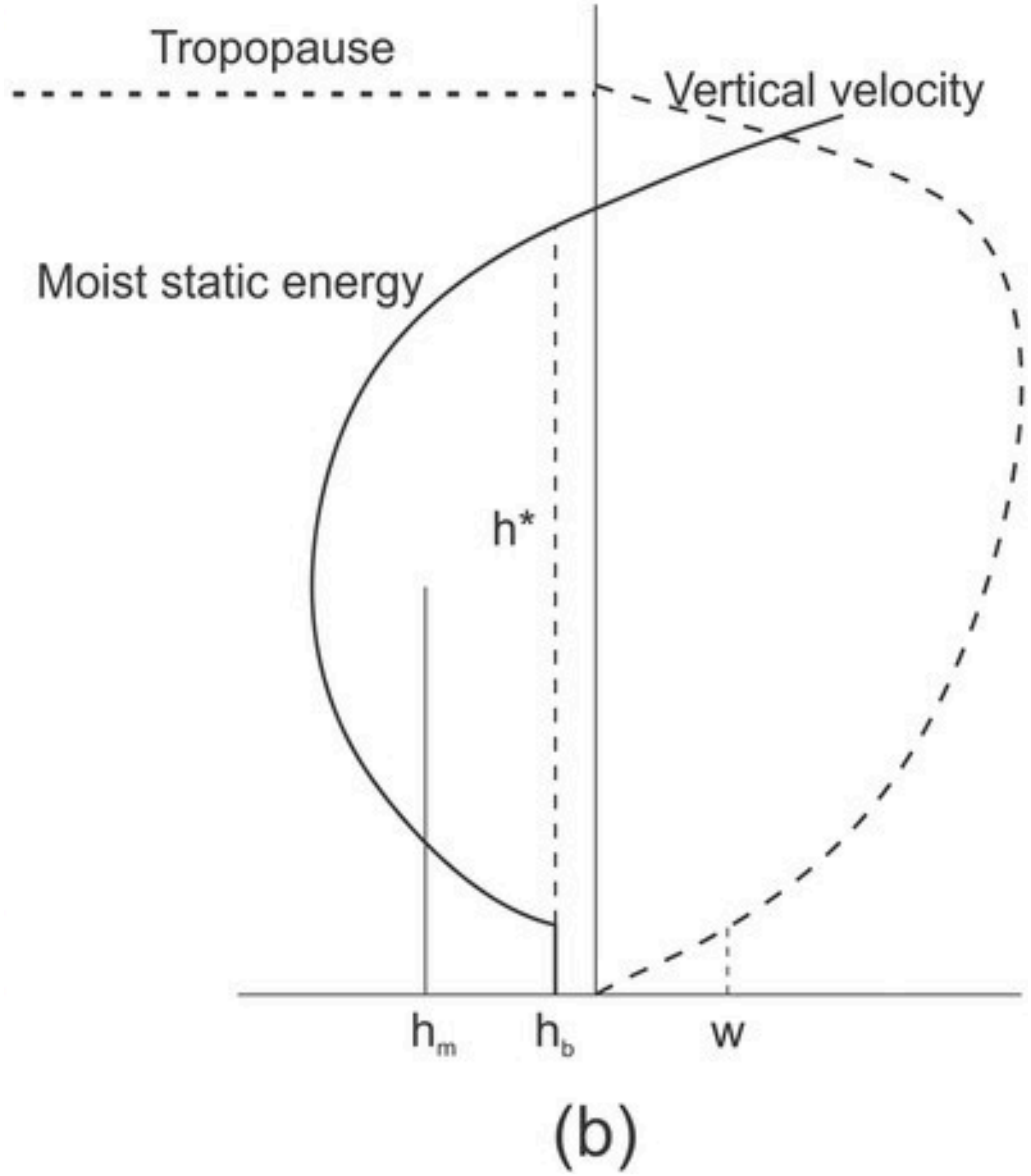
If we assume that parcels rise moist adiabatically above the boundary layer we have that

$$\frac{\partial \mathrm{MSE}_c^*}{\partial z} = 0$$

If CAPE=0 we can use the definition of MSE and buoyancy to obtain:

$$\frac{\partial T_e}{\partial z} \simeq -\Gamma_m$$

Look familiar?



Emanuel (2018)

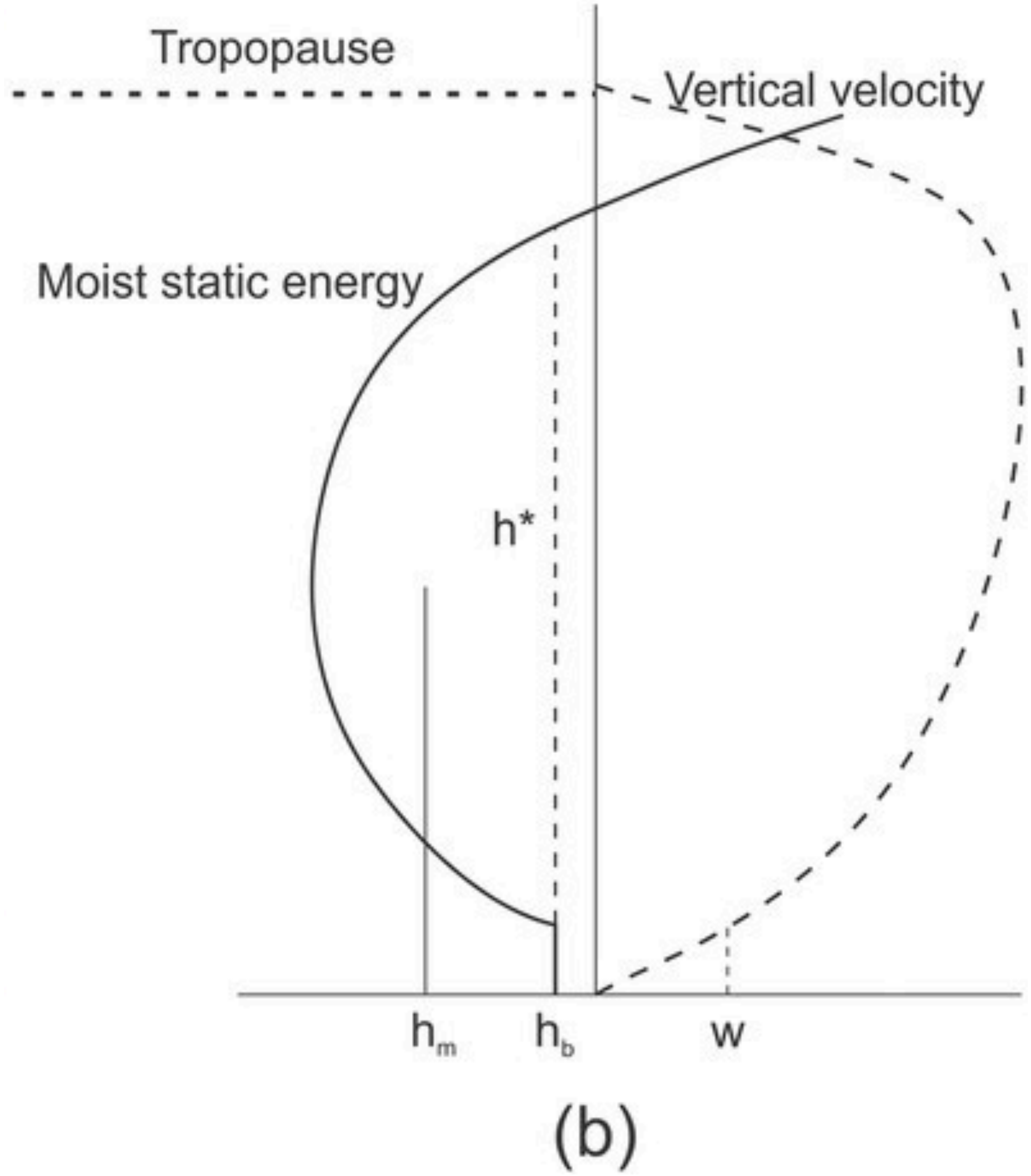
In pressure coordinates

$$\mathrm{CAPE} = \int_{p_{LNB}}^{p_{LFC}} (\alpha_p - \alpha_e)\,dp$$

Using hydrostatic balance and Maxwell's relations leads to the following result:

$$\bar{z}_t = \frac{1}{g}(\overline{T}_s - \overline{T}_t)\overline{\mathrm{MSE}_B}$$

The height of the tropopause ($\bar{z}_t$) is determined by the boundary layer MSE. **The thickness of the atmosphere is determined by convection.**



Emanuel (2018)

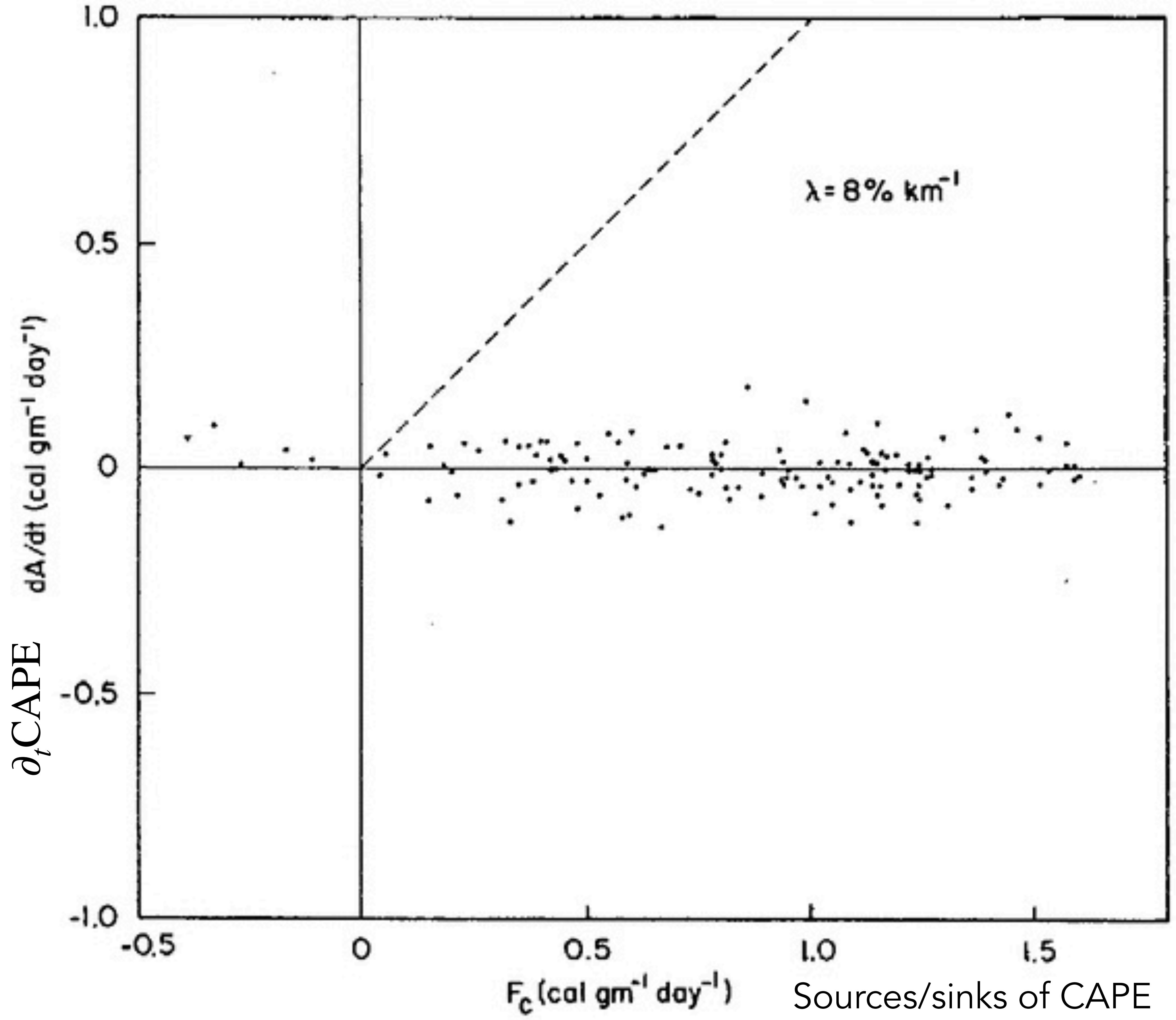
Something sinister

CAPE is not being changed in the presence of strong sources.

Using the thermodynamic equation and fixing the environmental temperature:

$$\frac{\partial \mathrm{CAPE}}{\partial t} = \frac{R_d}{C_p} \int_{LFC}^{LNB} \left(-\omega \frac{\partial \mathrm{DSE}}{\partial p} + Q_1 \right) d \ln p \simeq 0$$

But the right-hand side is the WTG approximation!



Something sinister

$$\frac{\partial \text{CAPE}}{\partial t} = \frac{R_d}{C_p} \int_{LFC}^{LNB} \left(-\omega \frac{\partial \text{DSE}}{\partial p} + Q_1 \right) d \ln p \simeq 0$$

The WTG approximation already has vertical velocity in it, so it doesn't tell us how the convection got there in the first place.

Take homes: RCE and CQE

Strengths:

1. Simplicity
2. They explain the thermodynamic mean state of the tropics when averaged as a whole.
3. Explain the mean tropical lapse rate.
4. Elucidate how central convection is in the tropics.

Weaknesses

1. Does not say what drives convection in the first place.
2. RCE does not explain circulations that occur within the tropics.
3. CQE often breaks down locally (e.g. diurnal cycles can lead to CAPE increase/decrease).

Explanations:

Boundary layer quasi-equilibrium (read at home)

Models of tropical deep convection

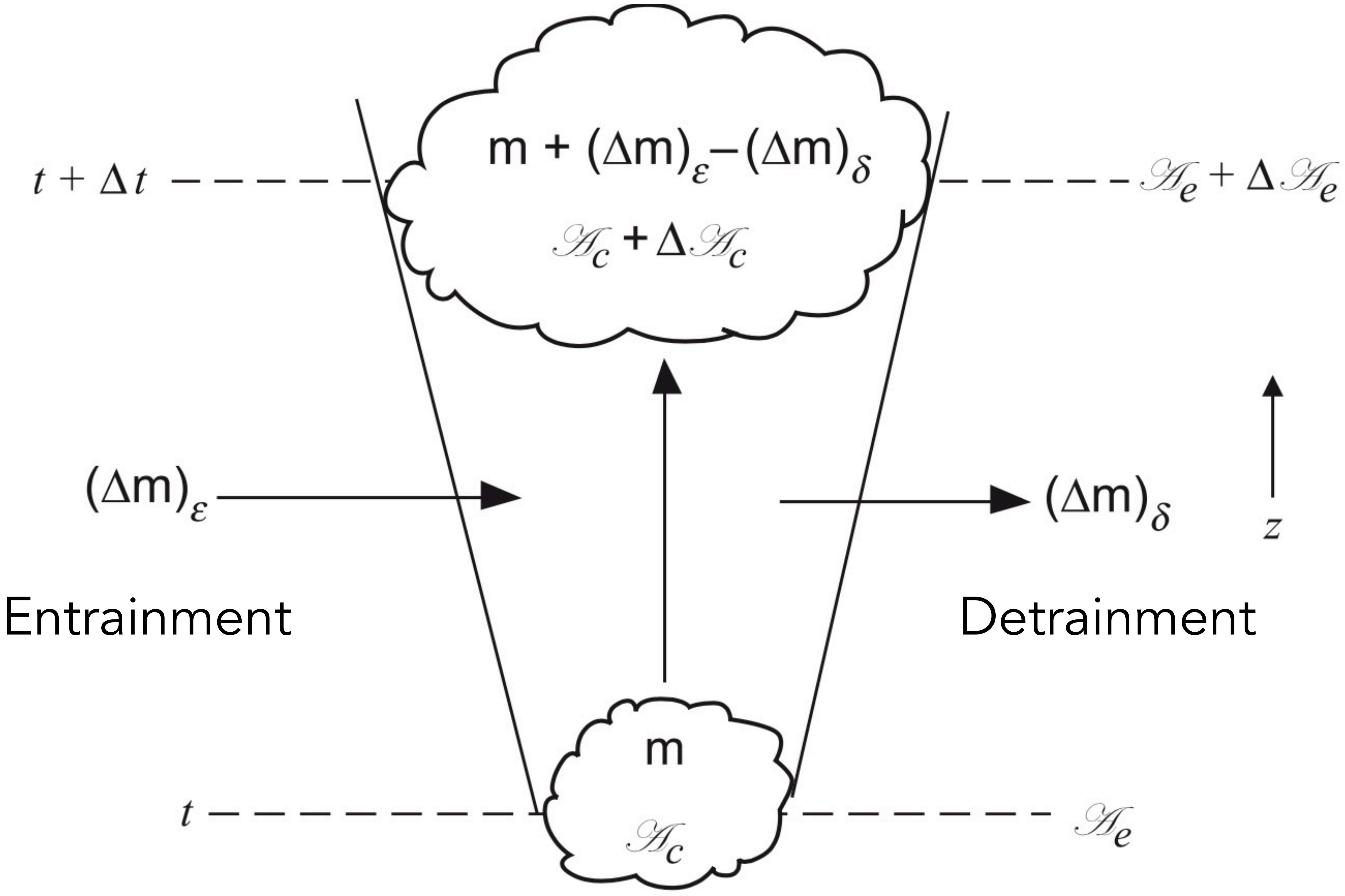
Clouds interact with their surrounding environment, and this interaction can be messy!

Cumulus clouds mix with the environment, changing the properties of the clouds and the environment alike.

Entrainment and Detrainment

Entrainment is the process in which environmental air mixes into the cumulus cloud.

Detrainment is the process in which air from the cumulus cloud mixes into the environment.



Houze (2014)

Entrainment and Detrainment

Most tropical convection experiences dilution by entrainment.

Very little air in the updraft hasn't mixed with the environment by the time the cloud reaches the LNB.

Wheel of fortune:
Where do you think you might see undiluted ascent in the tropics?