# AOS 801: Advanced Tropical Meteorology

*Lecture 7   Spring 2023*

## Deep Convection

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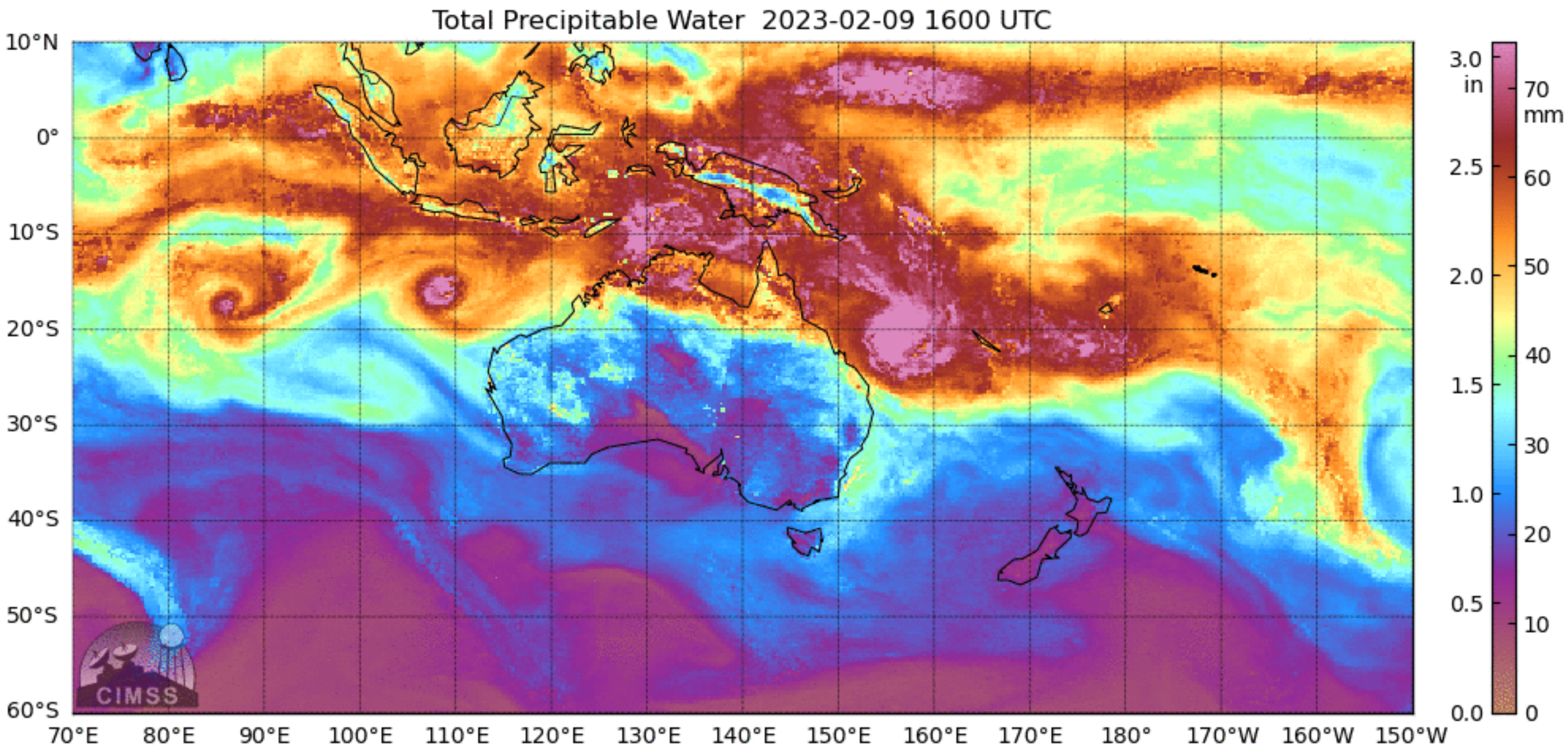
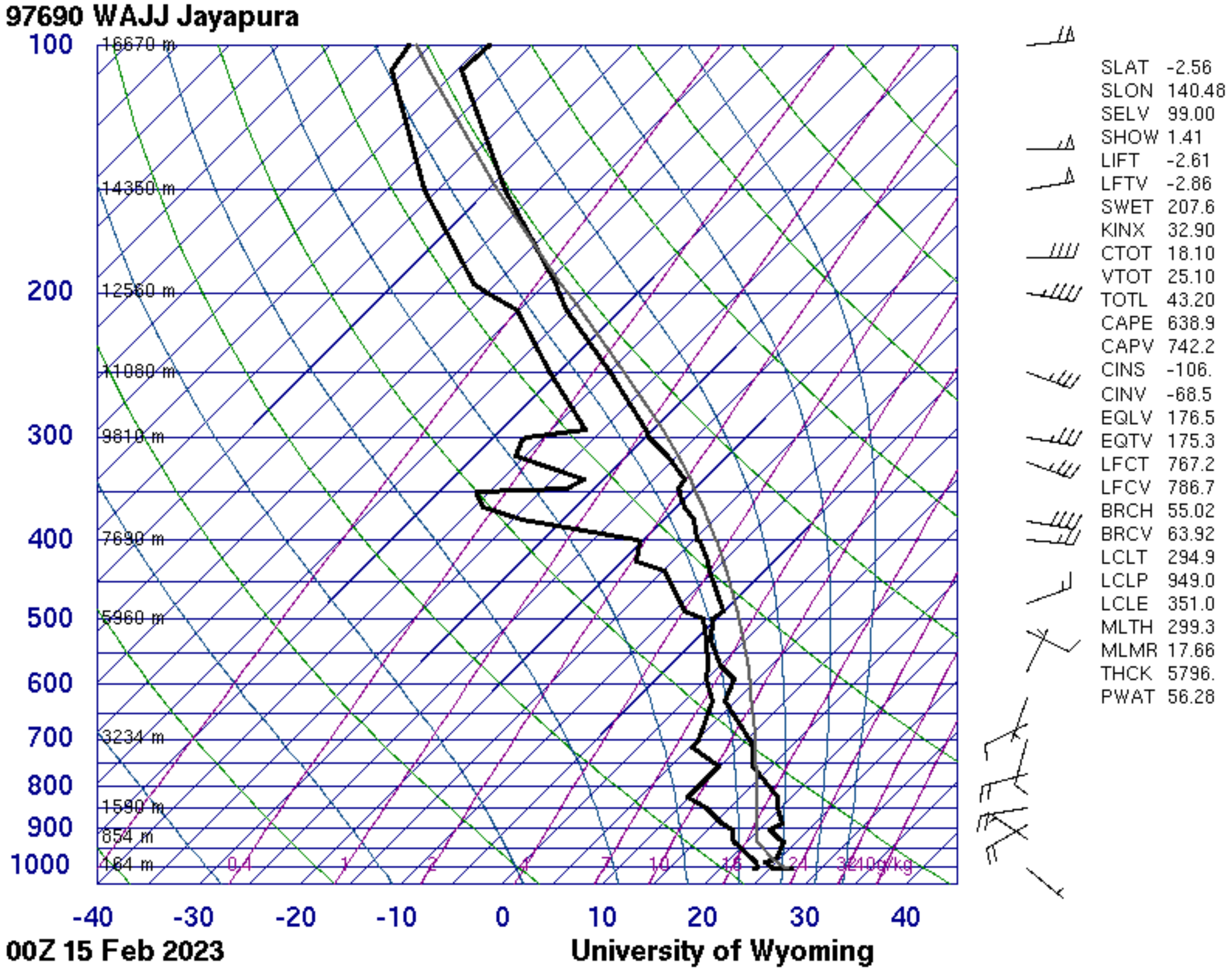
Courtesy of Kari Ledesma Maldonado

# How many vortices can you find?




**https://earth.nullschool.net/#current/wind/isobaric/850hPa/overlay=total_precipitable_water/orthographic=90.13,-1.20,399**



97690 WAJJ Jayapura
00Z 15 Feb 2023
University of Wyoming
SLAT -2.56
SLON 140.48
SELV 99.00
SHOW 1.41
LIFT -2.61
LFTV -2.86
SWET 207.6
KINX 32.90
CTOT 18.10
VTOT 25.10
TOTL 43.20
CAPE 638.9
CAPV 742.2
CINS -106.
CINV -68.5
EQLV 176.5
EQTV 175.3
LFCT 767.2
LFCV 786.7
BRCH 55.02
BRCV 63.92
LCLT 294.9
LCLP 949.0
LCLE 351.0
MLTH 299.3
MLMR 17.66
THCK 5796.
PWAT 56.28

# "Pop Quiz"


If you saw Kari's poster on Monday you saw that hydraulic jumps can occur at the top of some thunderstorms. These jumps can humidify the stratosphere.

Where are these jumps most common?

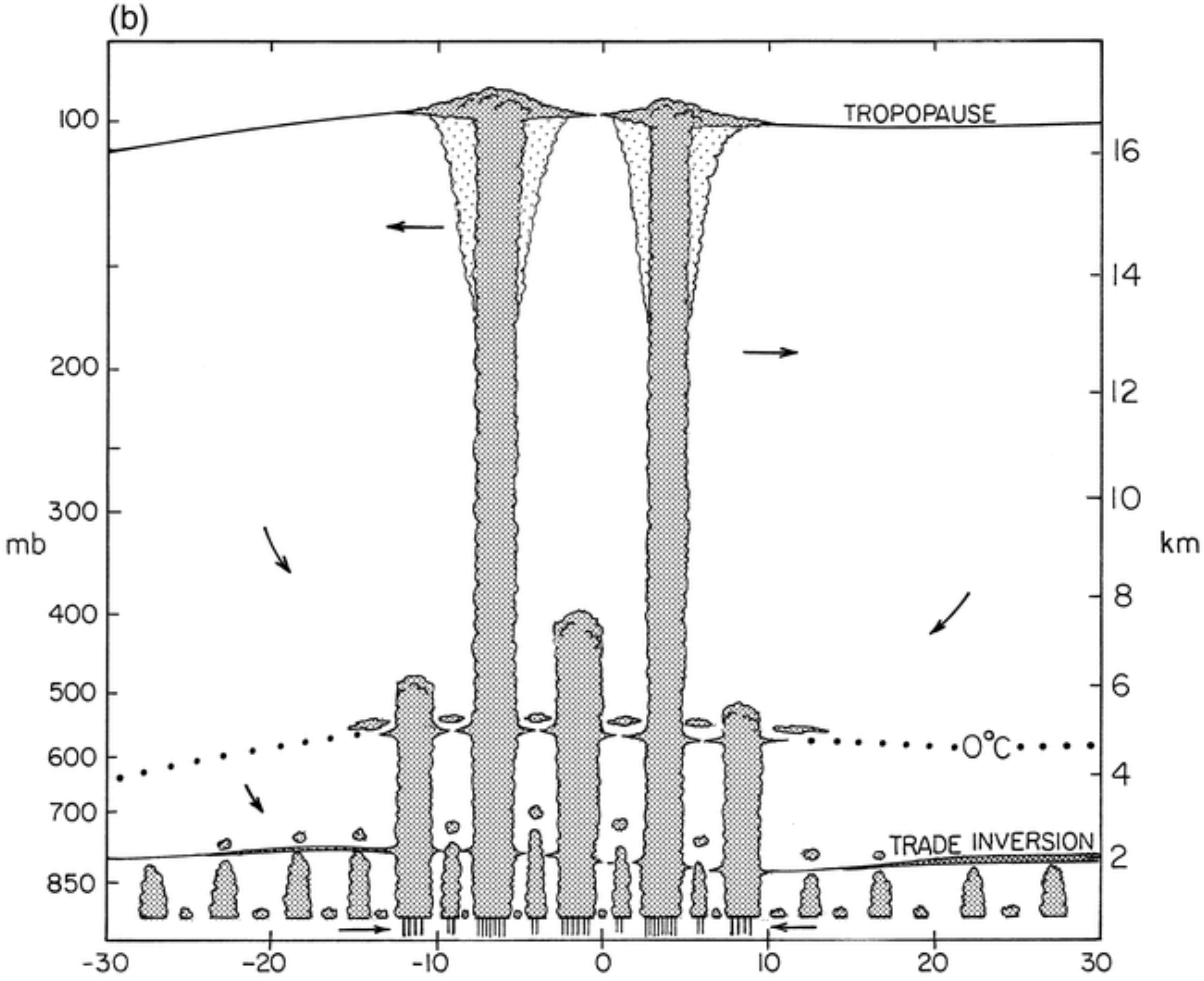
Clouds interact with their surrounding environment, and this interaction can be messy!

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

# Trimodal nature of tropical clouds

There are three types of cumuliform clouds that you often see in the tropics:

1. Shallow cumulus (and stratocumulus).
2. Cumulus congestus
3. Cumulonimbus

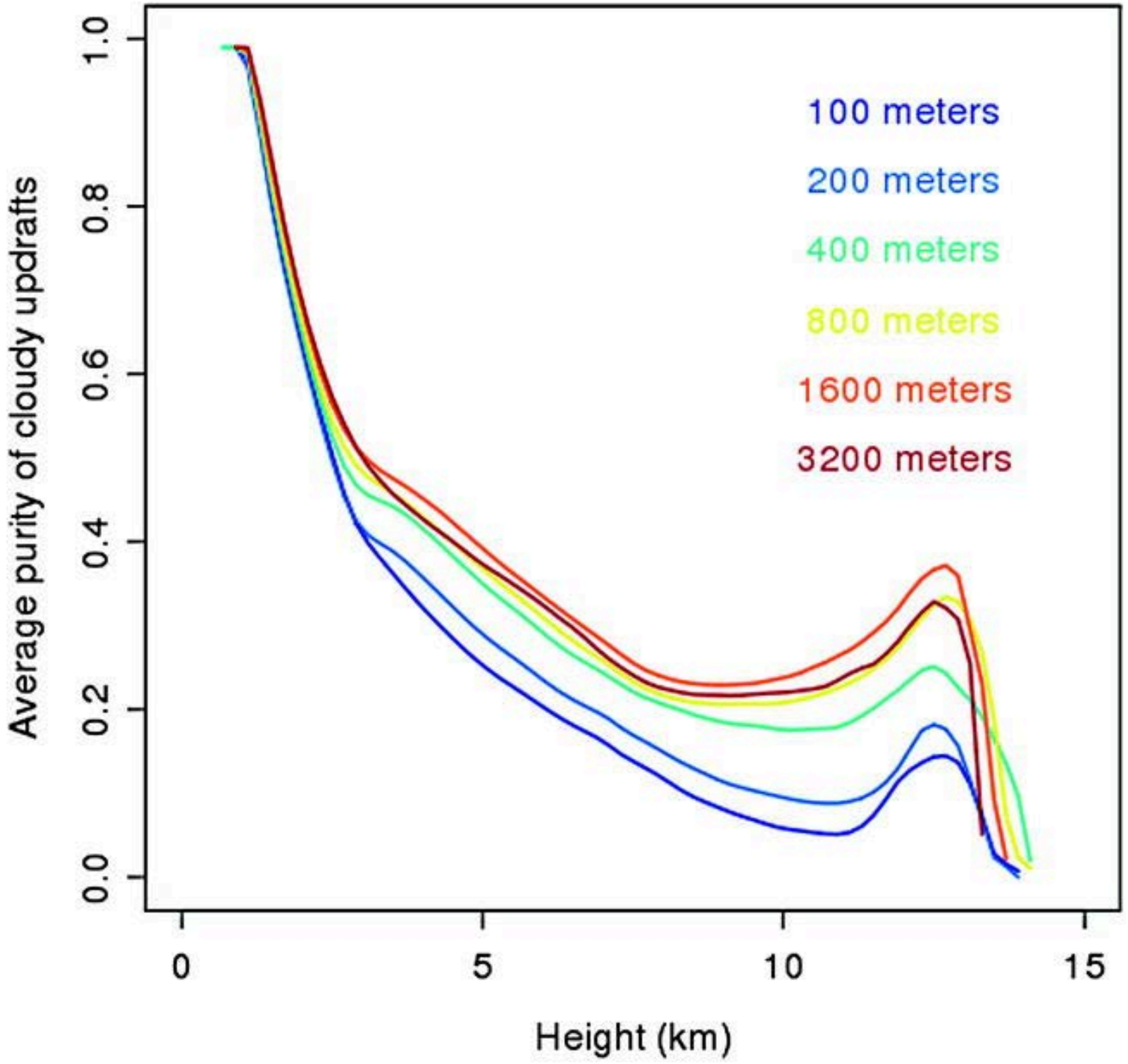


# Entrainment and Detrainment

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.

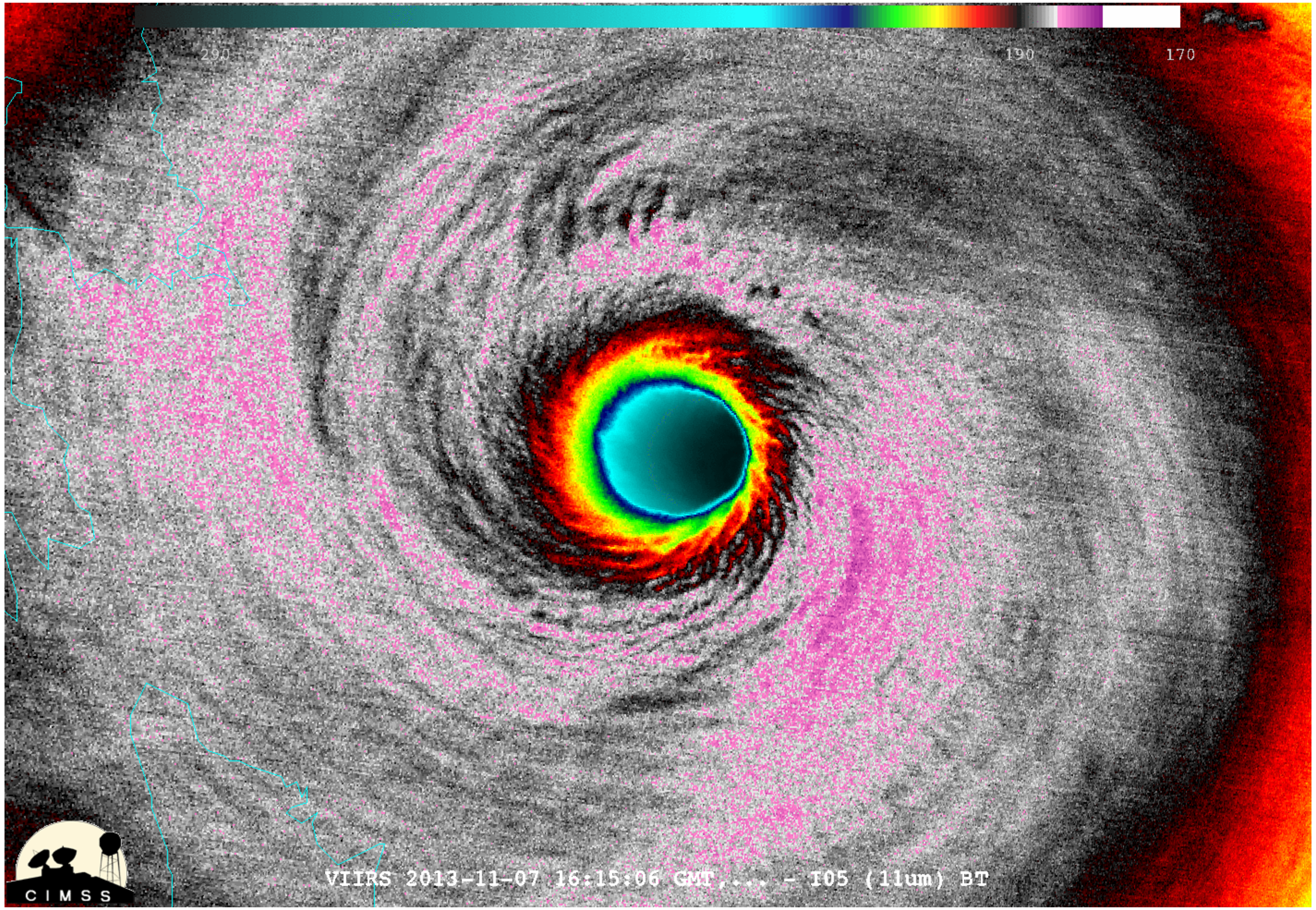
Where do you think you might see undiluted ascent in the tropics?



# Possible exception

Strong axisymmetric TCs can have undiluted ascent in their eyewall.

However, even this idea is contentious



# Turbulent vs. dynamical entrainment

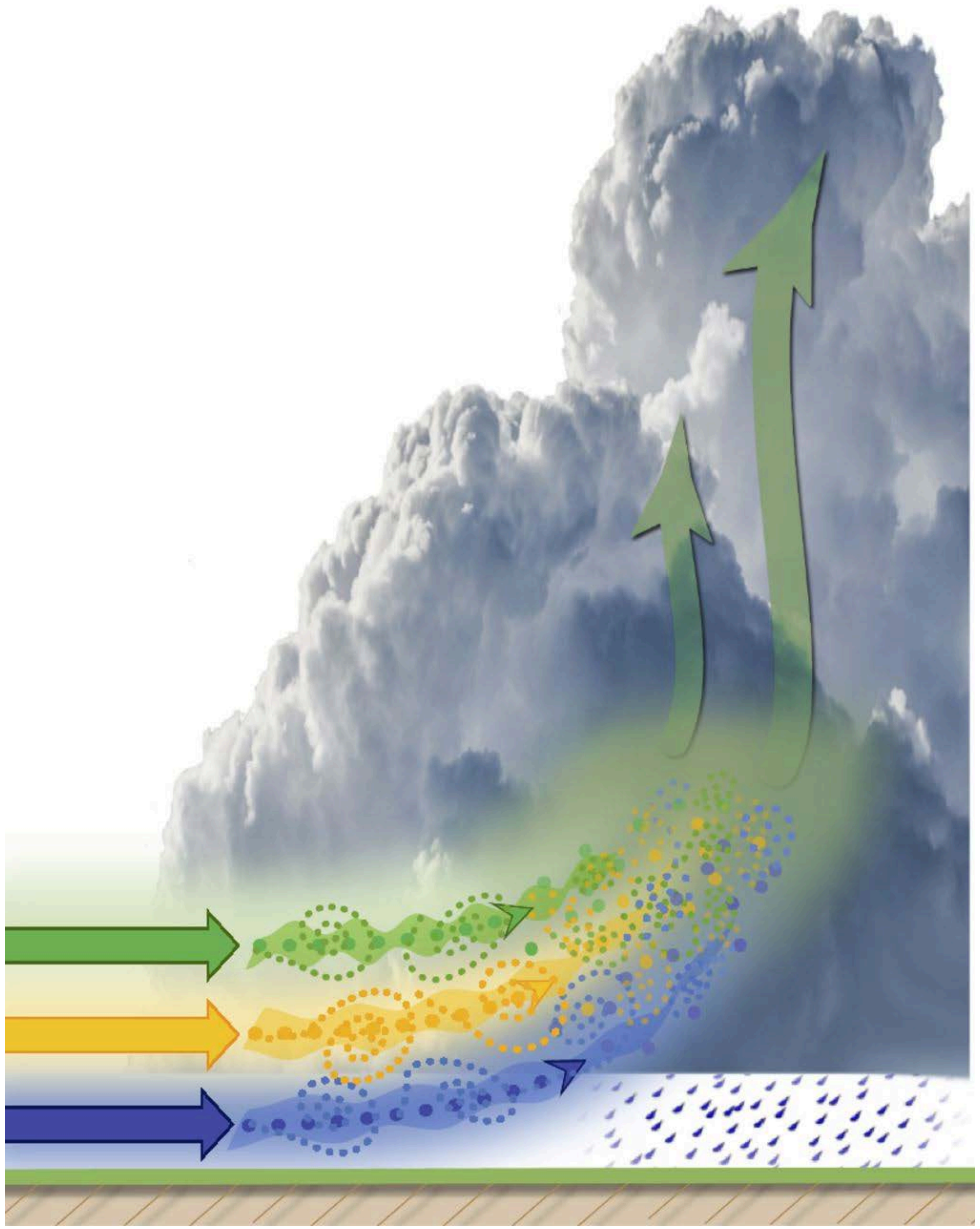
# Turbulent Entrainment

It is diffusive in nature, acting to smear out the clouds with the environment

# Dynamic entrainment

Due to winds that are associated with the convection as a whole.

Can be thought of as a larger-scale type of entrainment that is due to mesoscale dynamics.



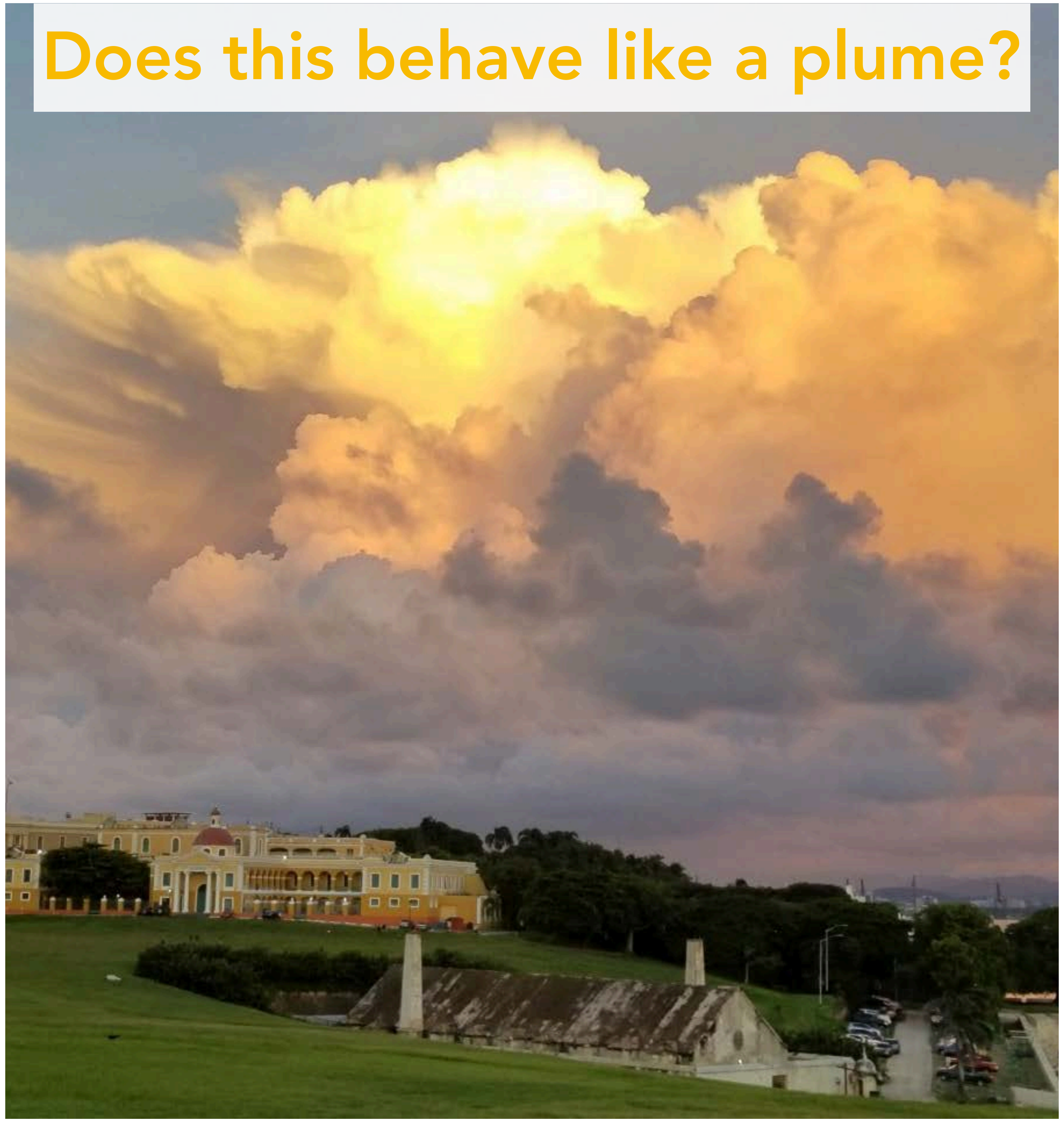
Schiro et al. (2018)

# MSE budget for entraining plume

When accounting for entrainment, the MSE budget of a cloud element becomes

$$\frac{D\mathrm{MSE}_c}{Dt} = Q_e - \boxed{\frac{1}{\mathrm{m}}\left(\frac{D\mathrm{m}}{Dt}\right)_{\varepsilon}(\mathrm{MSE}_c - \mathrm{MSE}_e)}\,.$$

**Dilution**




Courtesy of Kari Ledesma Maldonado

# The entraining plume hypothesis

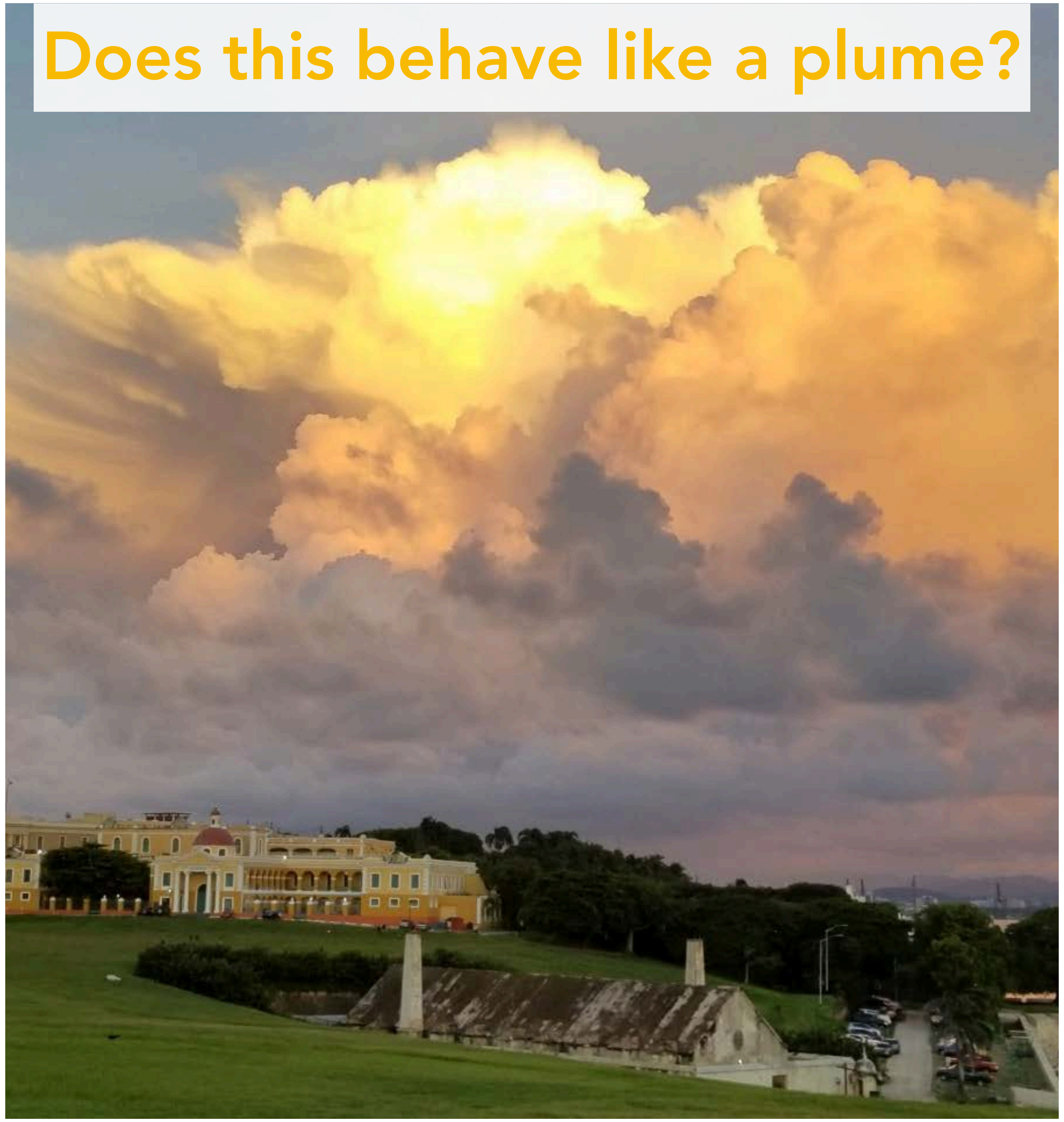
Ignoring sources and sinks of MSE, entraining plumes do not conserve their MSE because of mixing buy entrainment.

Their budget equation can be written as:

$$\frac{\partial \mathrm{MSE}_c}{\partial z} = -\,\epsilon\left(\mathrm{MSE}_c - \mathrm{MSE}_e\right).$$

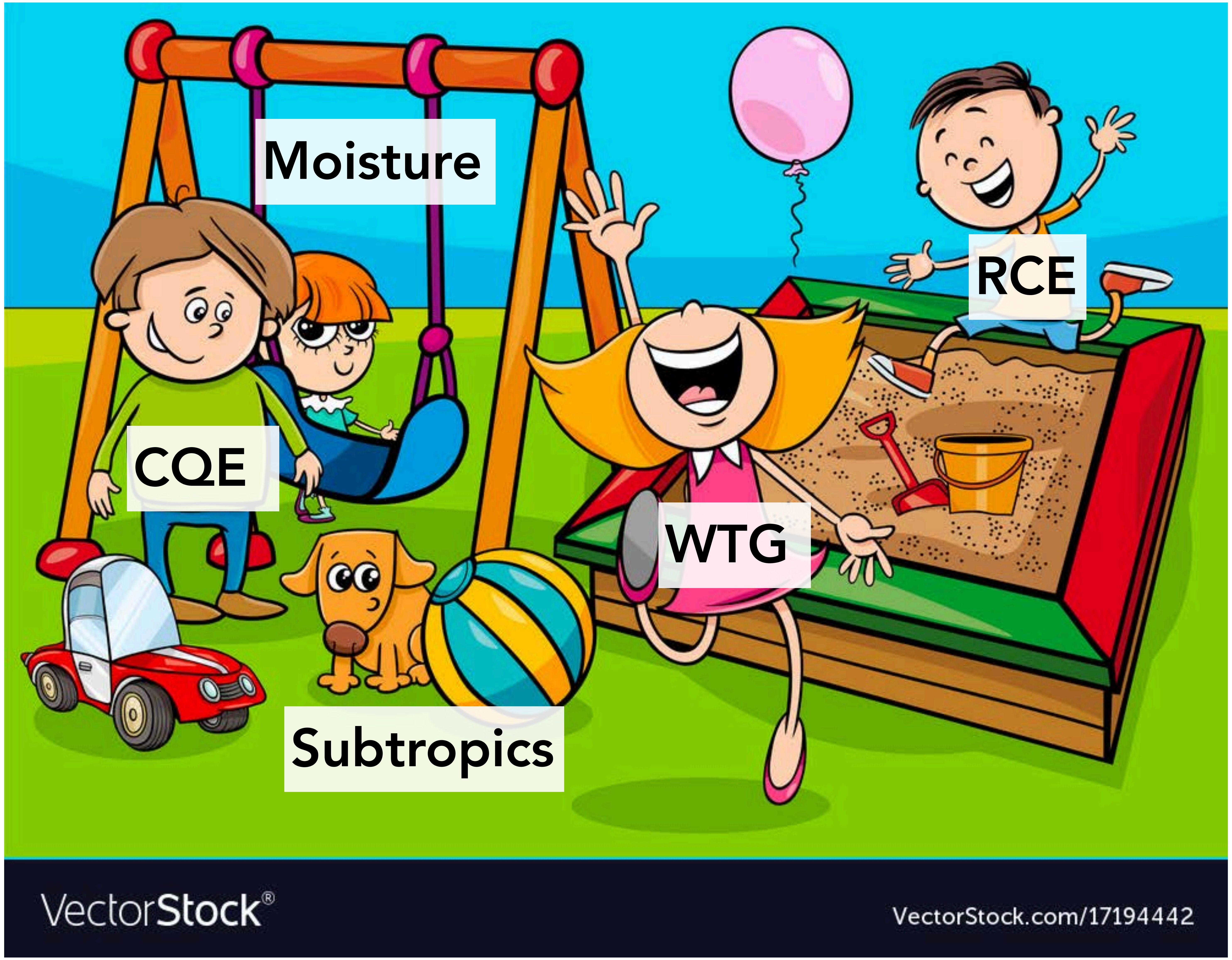
$$\epsilon = \frac{1}{\mathrm{m}}\left(\frac{\partial \mathrm{m}}{\partial z}\right)_{\epsilon}$$

$\epsilon$ is the entrainment



Courtesy of Kari Ledesma Maldonado

# The devil is in the details




$$\frac{\partial \mathrm{MSE}_c}{\partial z} = -\epsilon \left(\mathrm{MSE}_c - \mathrm{MSE}_e\right).$$

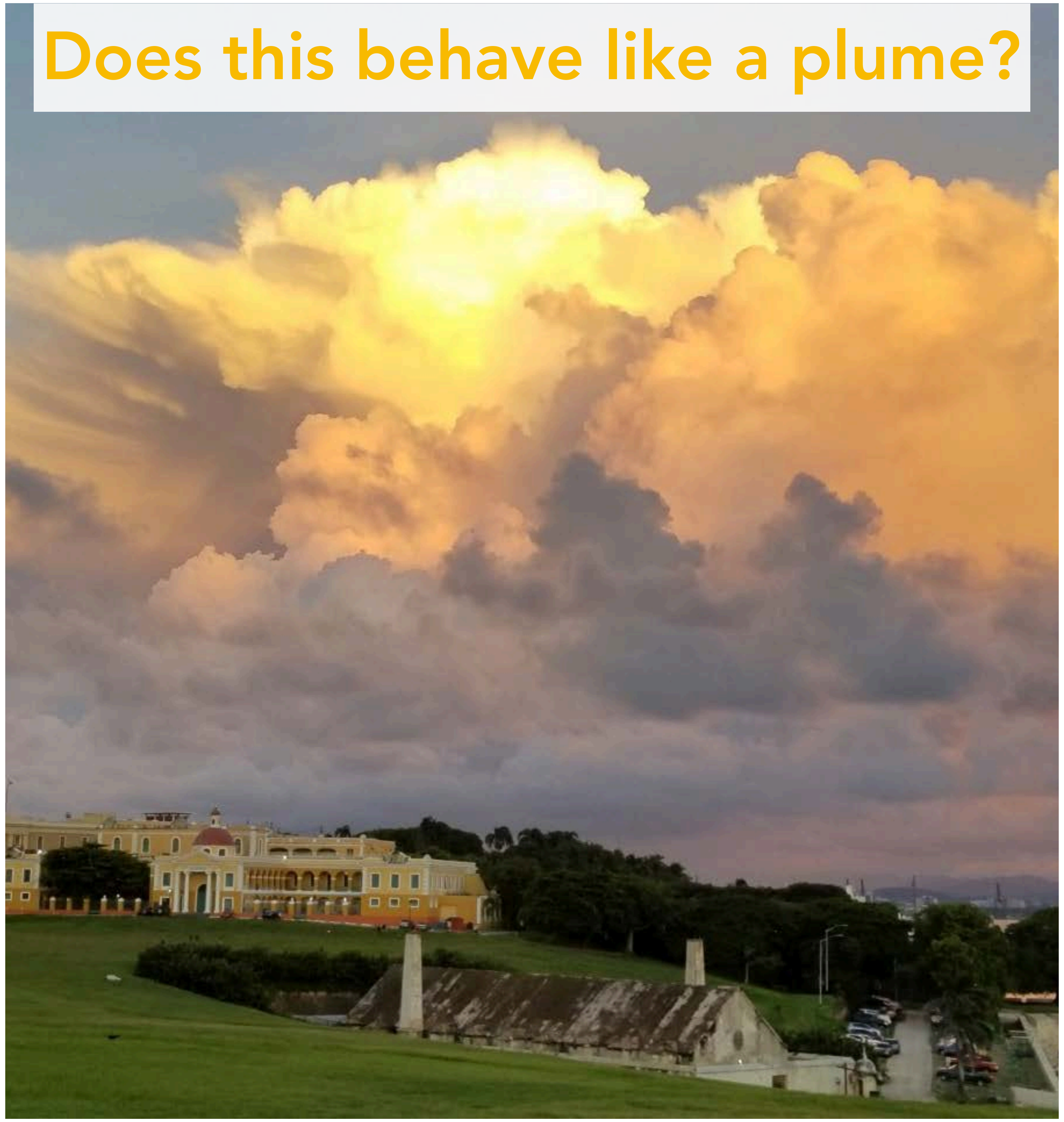
# The entraining plume hypothesis

If the plume is saturated and the right-hand side is dominated by moisture we obtain:

$$\frac{\partial \mathrm{MSE}_c^*}{\partial z} = -\,\epsilon L_v \left(q^* - q\right).$$

$$\epsilon = \frac{1}{\mathrm{m}} \left(\frac{\partial \mathrm{m}}{\partial z}\right)_\varepsilon$$

The MSE is diluted in accordance to the saturation deficit of the troposphere. The drier, the more MSE is reduced.




Courtesy of Kari Ledesma Maldonado

# The entraining plume hypothesis

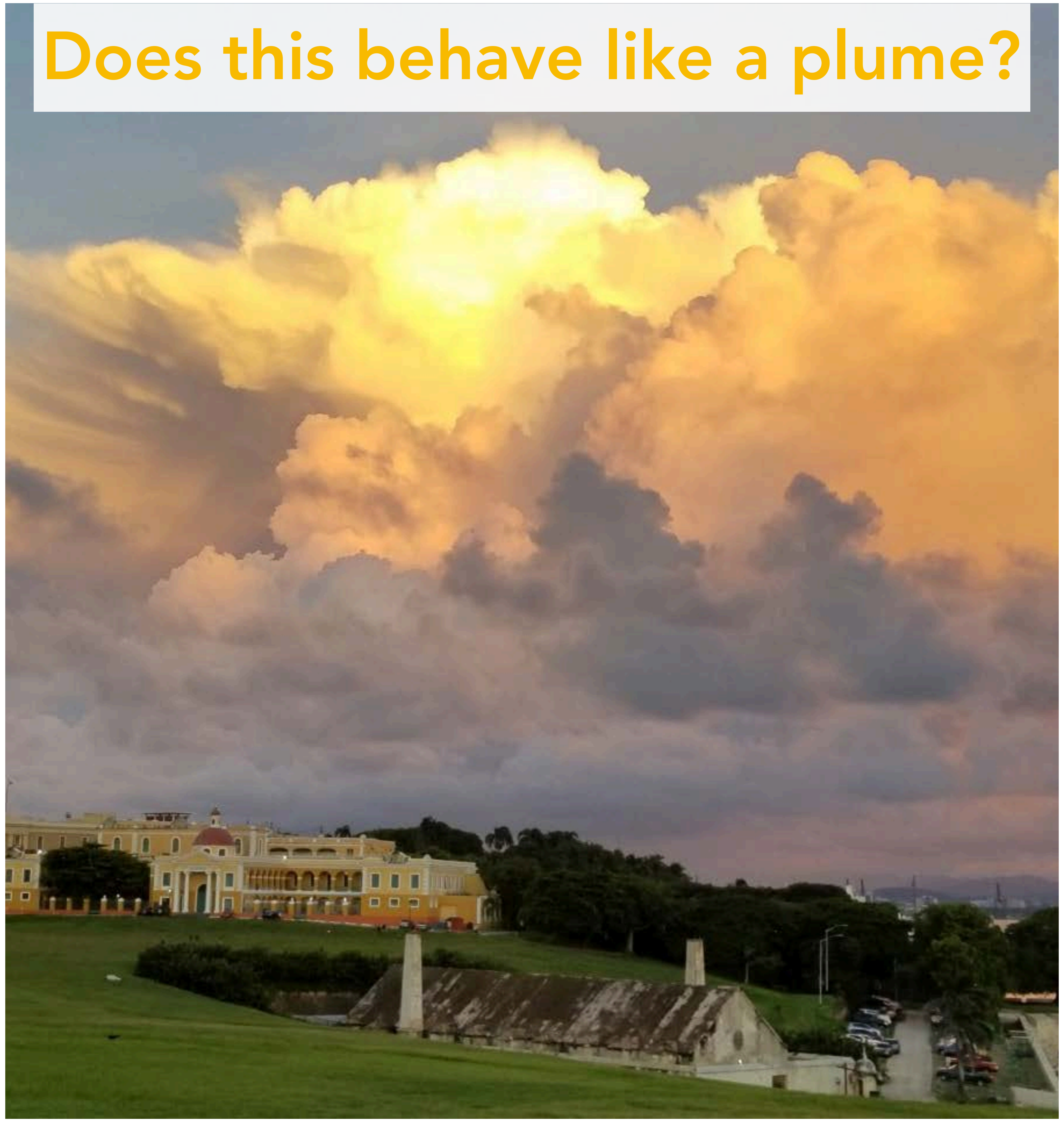
The buoyancy of the plume is the same of a parcel

$$B = g\frac{T_c - T_e}{T_e}$$

Which we can use the chain rule to express in terms of saturation MSE.

$$B = g\frac{\mathrm{MSE}_c^* - \mathrm{MSE}_e^*}{\kappa C_p T_e}$$

But we know that $\mathrm{MSE}_c^*$ changes if the plume is entraining dry air. Moisture must then be important for determining $B$.



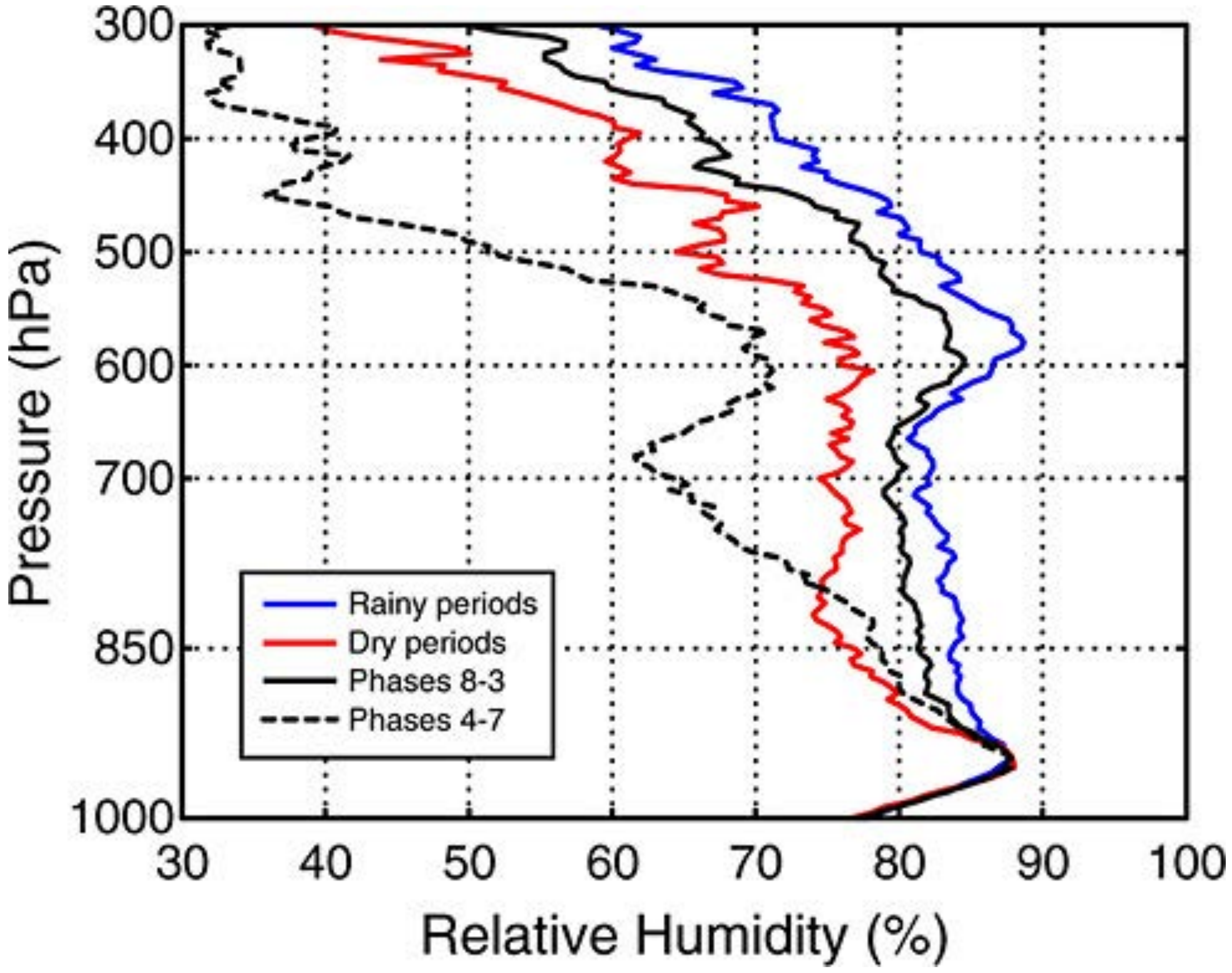
Courtesy of Kari Ledesma Maldonado

# The entraining plume hypothesis

Integrating from the top of the boundary layer we find

$$B = g\frac{\mathrm{MSE}_B - \mathrm{MSE}_e^*}{\kappa C_p T_e} - \frac{g}{\kappa C_p T_e}\int_{z_B}^{z} \epsilon L_v q^* (1 - \mathrm{RH})\, dz'$$

**Undilute component ($B_U$)** **Dilution ($D_B$)**




Powell and Houze (2013)

So we can write the buoyancy as

$$B = B_U - D_B$$

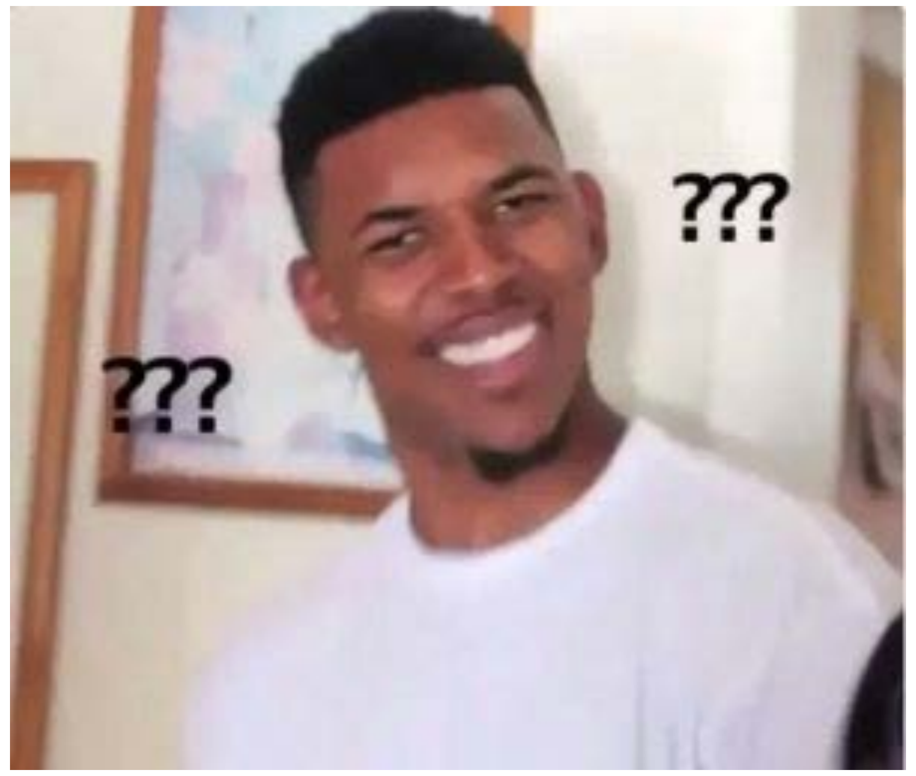
# Dilution and Convective Quasi-equilibrium

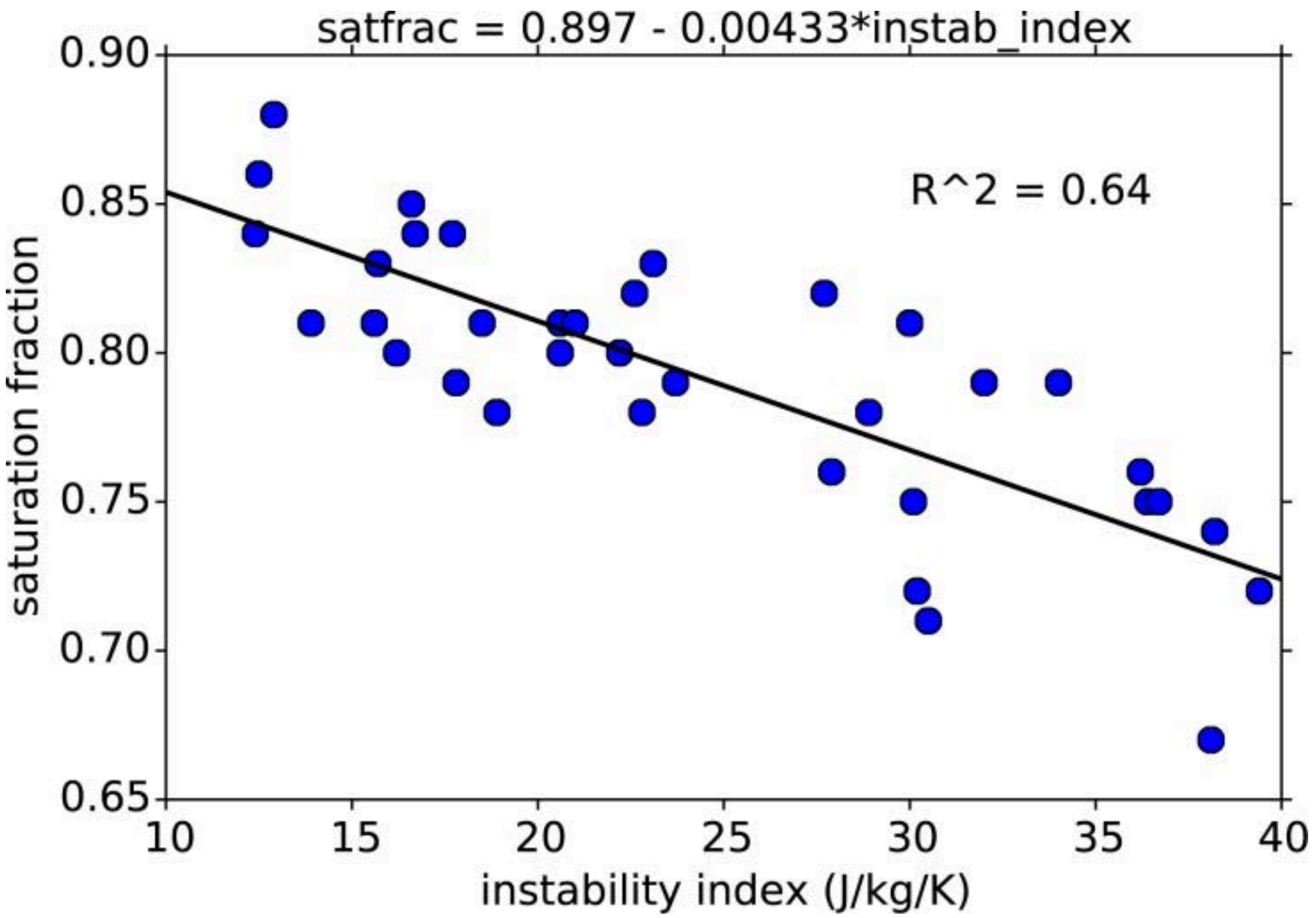
If we still assume that B ~ 0 in the tropics overall we find that

$$B_U = D_B$$

**Dry regions are unstable.**

**Humid regions are stable.**

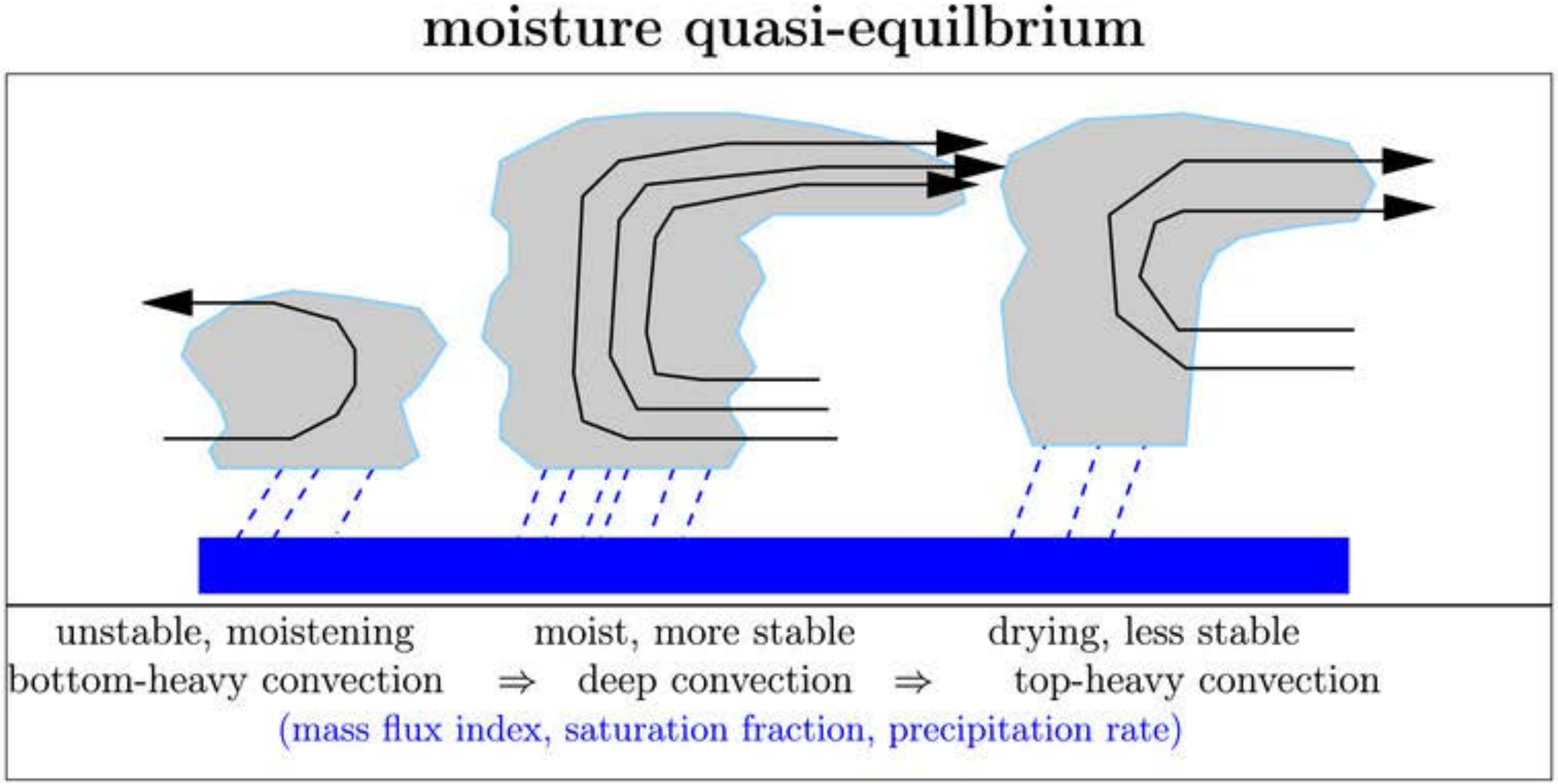


# Moisture Quasi-equilibrium

**Dry regions are unstable.**
**Humid regions are stable.**

When dilution is considered **Convective QE becomes the more modern moisture QE**

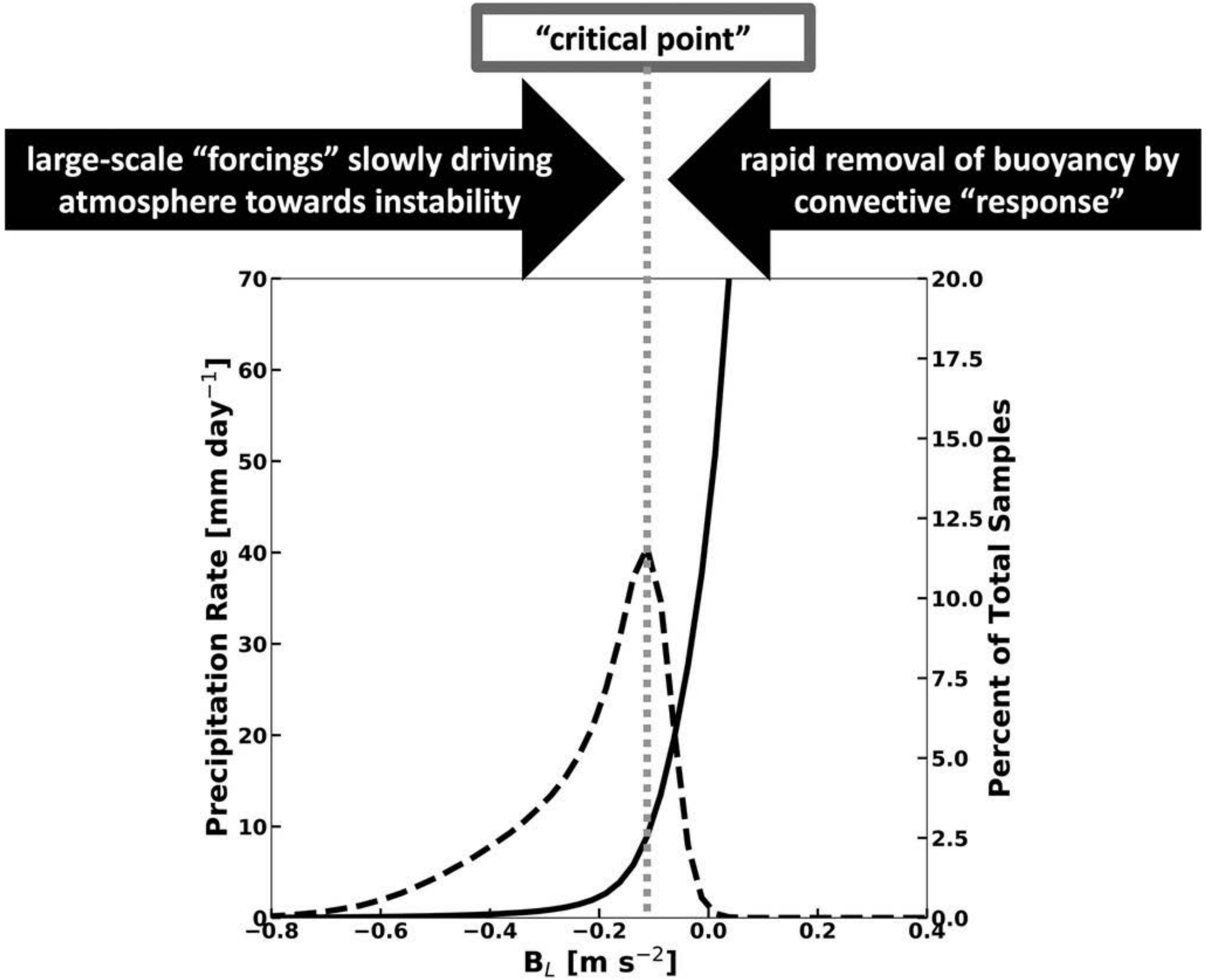



Sessions et al. (2019)

# Generalized Quasi-Equilibrium

Climatologically-speaking, areas of rainfall tend to hover around a near zero buoyancy value, irrespective of how humid it is.

But small deviations from this stable point is what drives rapid changes in rainfall.




Wolding et al. (2022)

# Welcome to advanced tropical meteorology