AOS 801: Advanced Tropical Meteorology

Lecture 10   Spring 2023

Vertical Velocity, Precipitation, Buoyancy and Water Vapor 2

Ángel F. Adames Corraliza
angel.adamescorraliza@wisc.edu

Announcements

Paper discussion today, let's do it 25 minutes before class ends.

HW2 is due March 6.

We are finishing our discussion about tropical convection today.

Leading Balance in Convection

We can use mass continuity to merge the two equations to obtain the following:

$$\frac{\partial^3}{\partial z^3}\left(\frac{1}{\rho}\frac{\partial \rho w}{\partial z}\right) \simeq -\frac{\rho}{\mu_c}\nabla_h^2 B$$

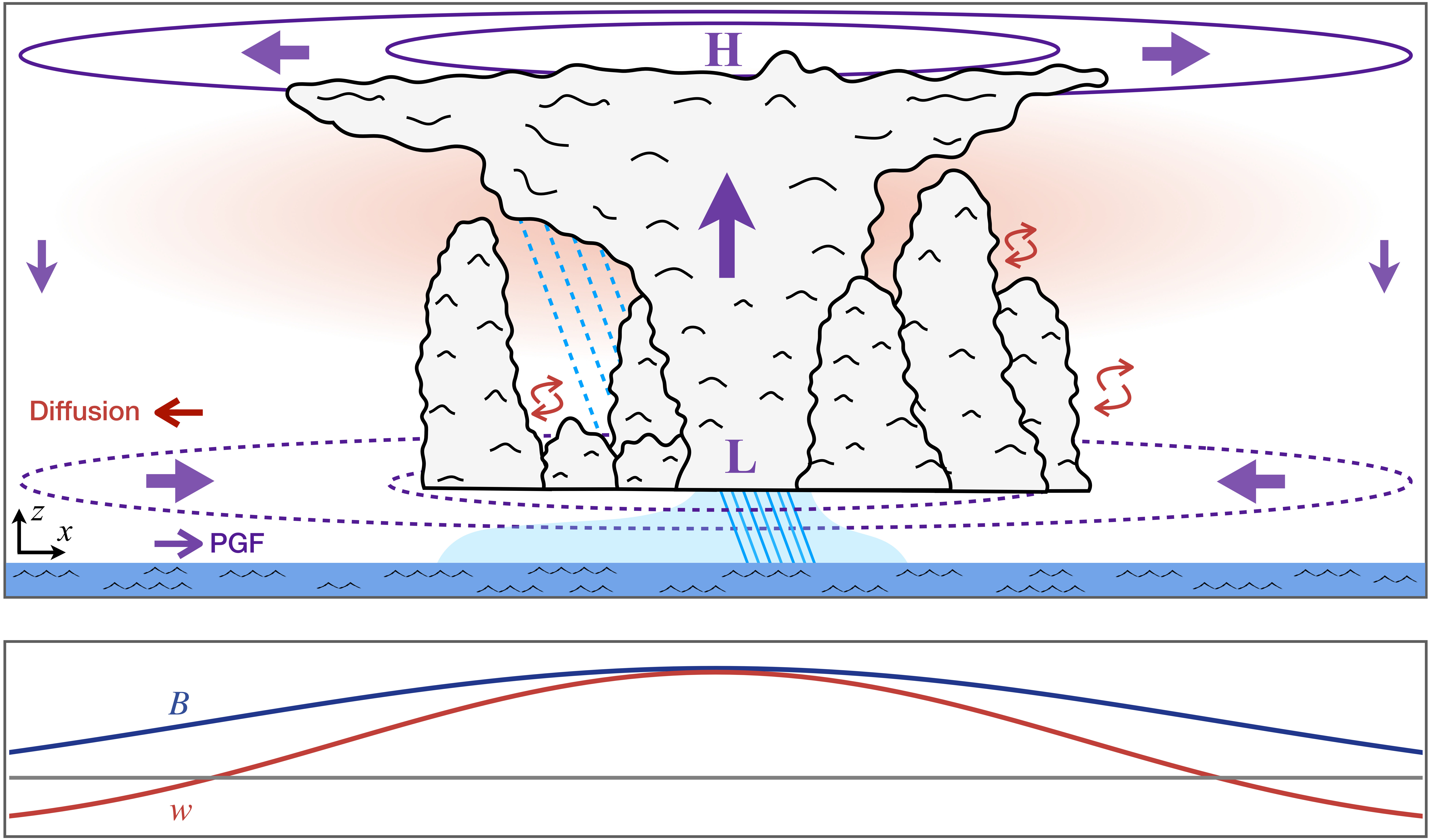
In pressure coordinates you get an even simpler relation:

$$\frac{\partial^4 \omega}{\partial p^4} = \frac{1}{\mu_c^*}\nabla_h^2 \alpha'$$

$$\alpha' = R_d T'/p \qquad T' = T_c - T_0 \qquad \mu_c^* = \omega_c p_\ell \sim g^2 \mu_c \sim 10^5$$

What does this mean?

Sticky Convection



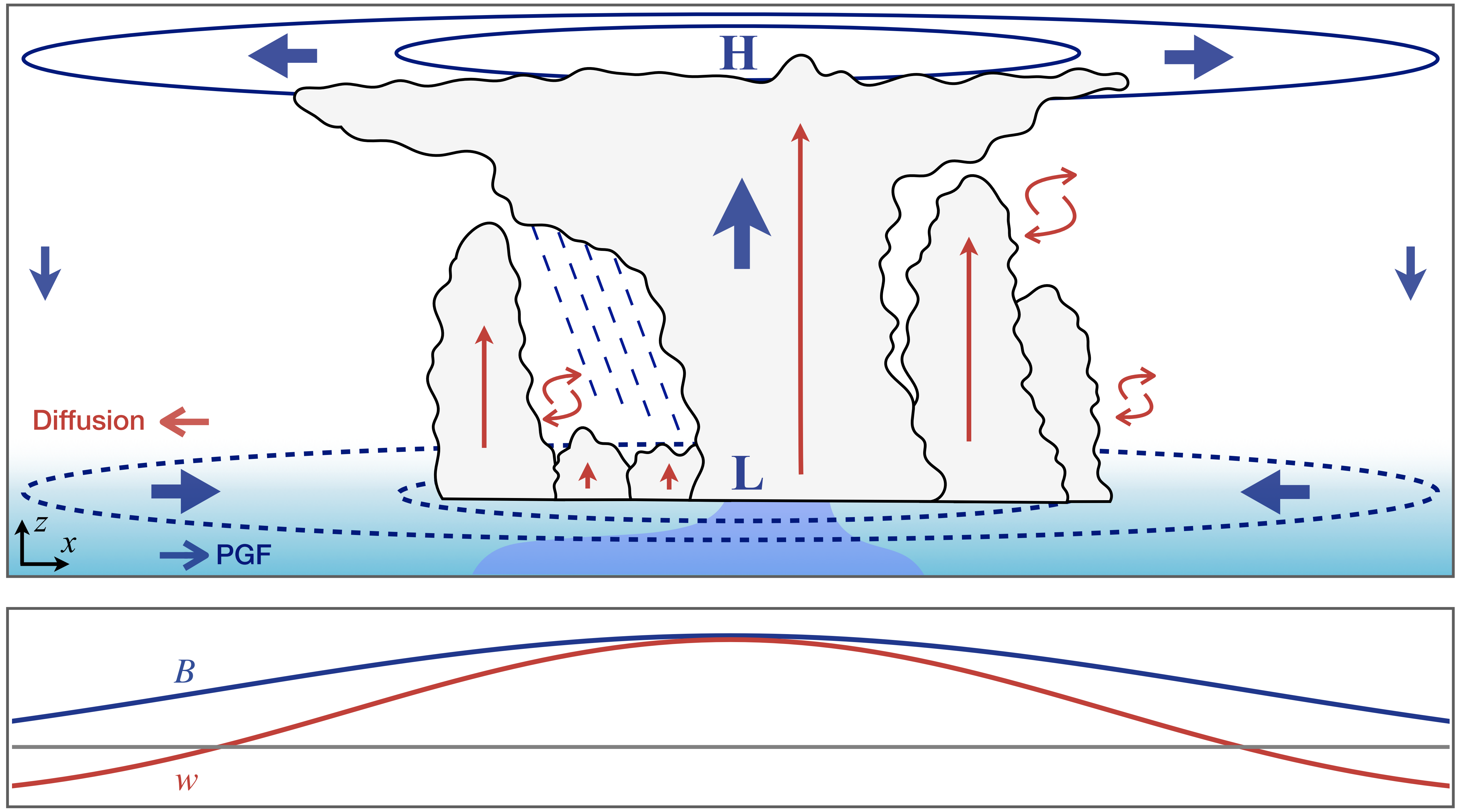
Sticky Convection

Individual Cloud elements are turbulent but their aggregate behavior is not.

Antitriptic balance implies that larger-scale flow is quasi-laminar.

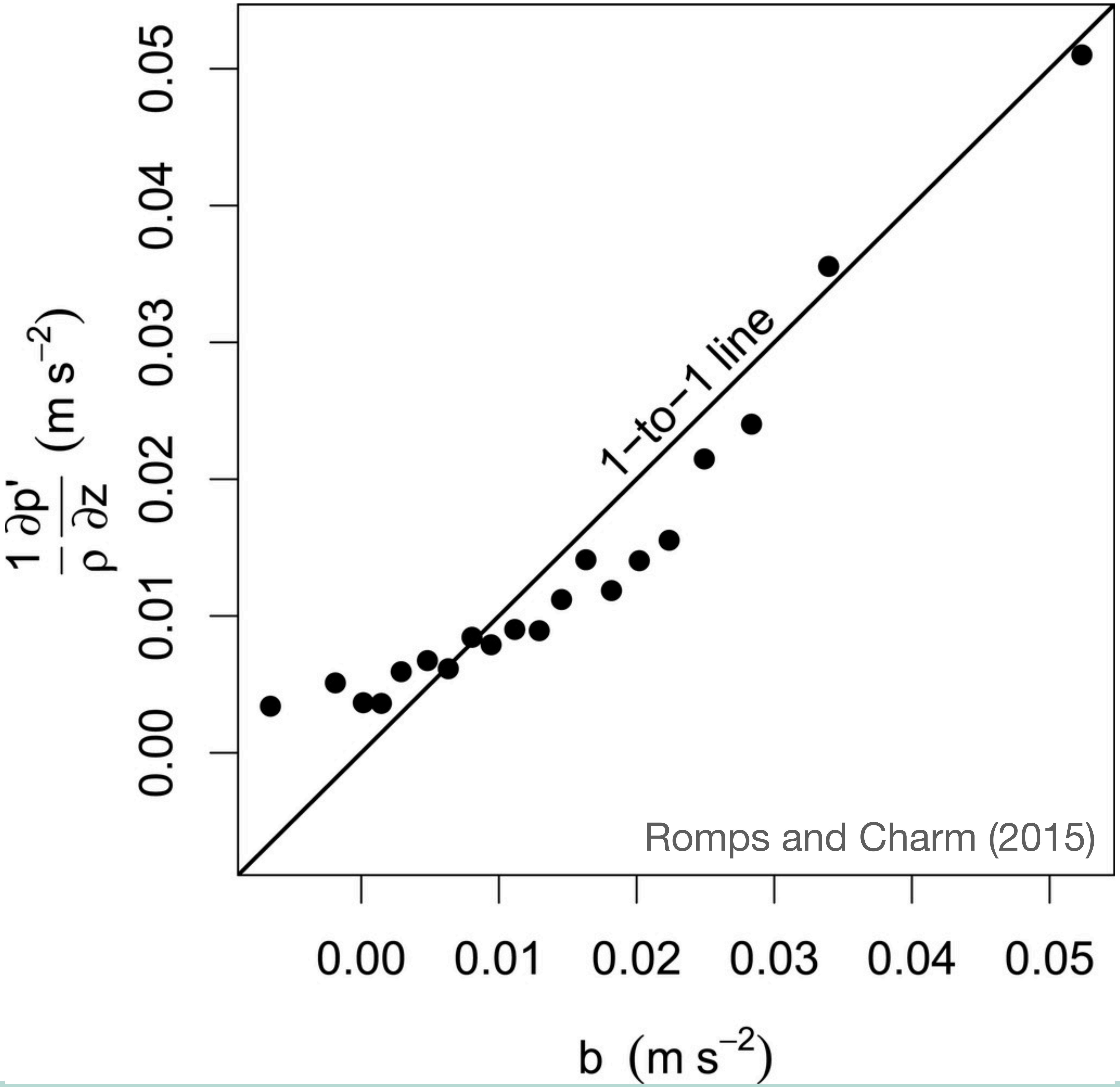
The winds flow down the pressure gradient and rise in the region of high buoyancy.

There is a direct relation between vertical velocity and buoyancy.



Sticky Thermals

This relationship applies even for shallow cumulus clouds both in and out of the tropics



Precipitation-buoyancy relation

Assuming rigid lids at the surface and tropopause, we can simplify this to

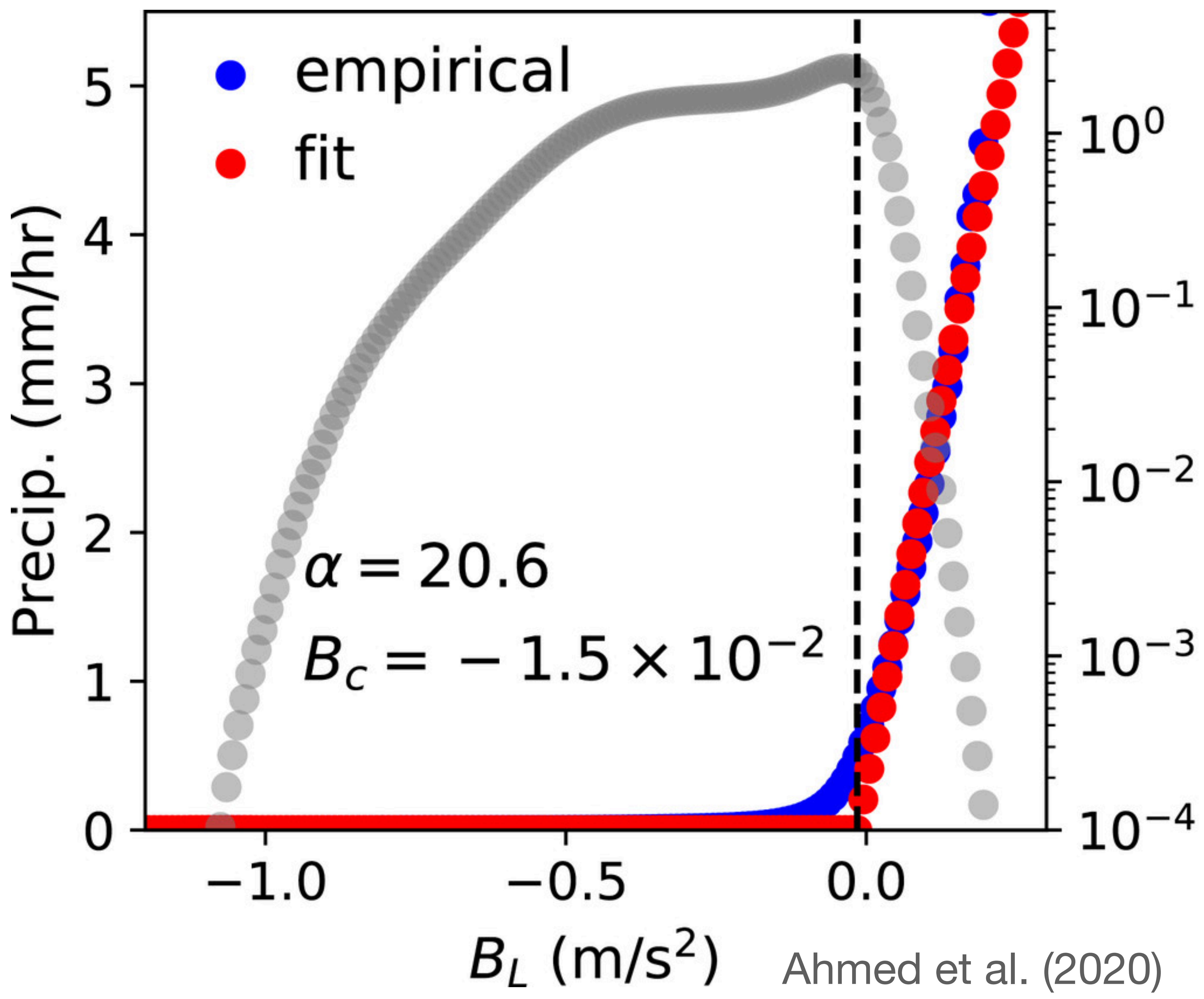
$$\mu_c^* m^4 \langle \omega \rangle = \nabla_h^2 \langle \alpha' \rangle$$

Where *m* is a vertical wavenumber. We now invoke the WTG approximation:

$$\langle \omega \rangle S_p = L_v P + \langle Q_r \rangle$$

Combining everything we have:

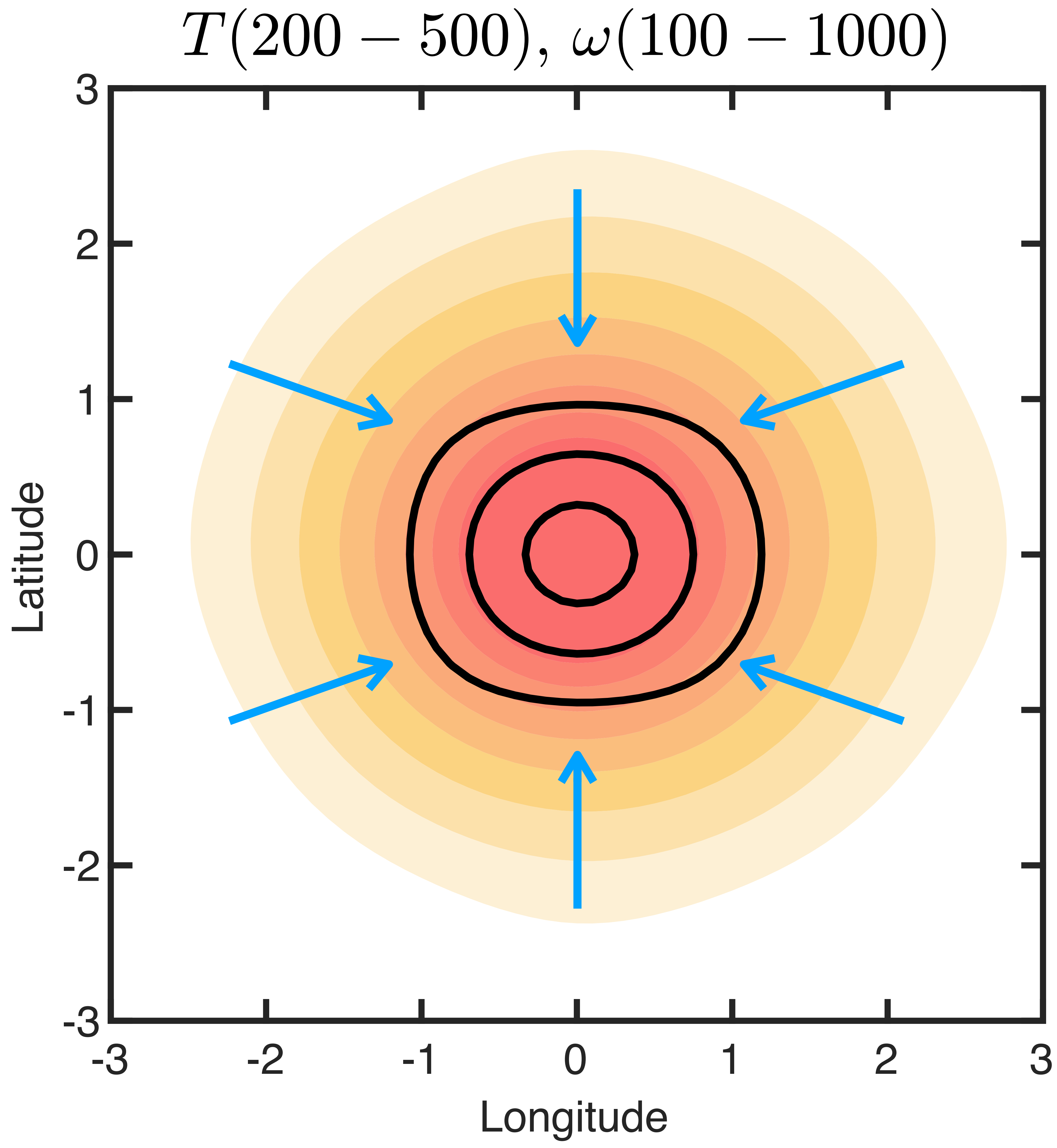
$$L_v P = \frac{S_p}{\mu_c^* m^4} \nabla_h^2 \langle \alpha' \rangle - \langle Q_r \rangle$$



Ahmed et al. (2020)

ERA5 relation between T and w

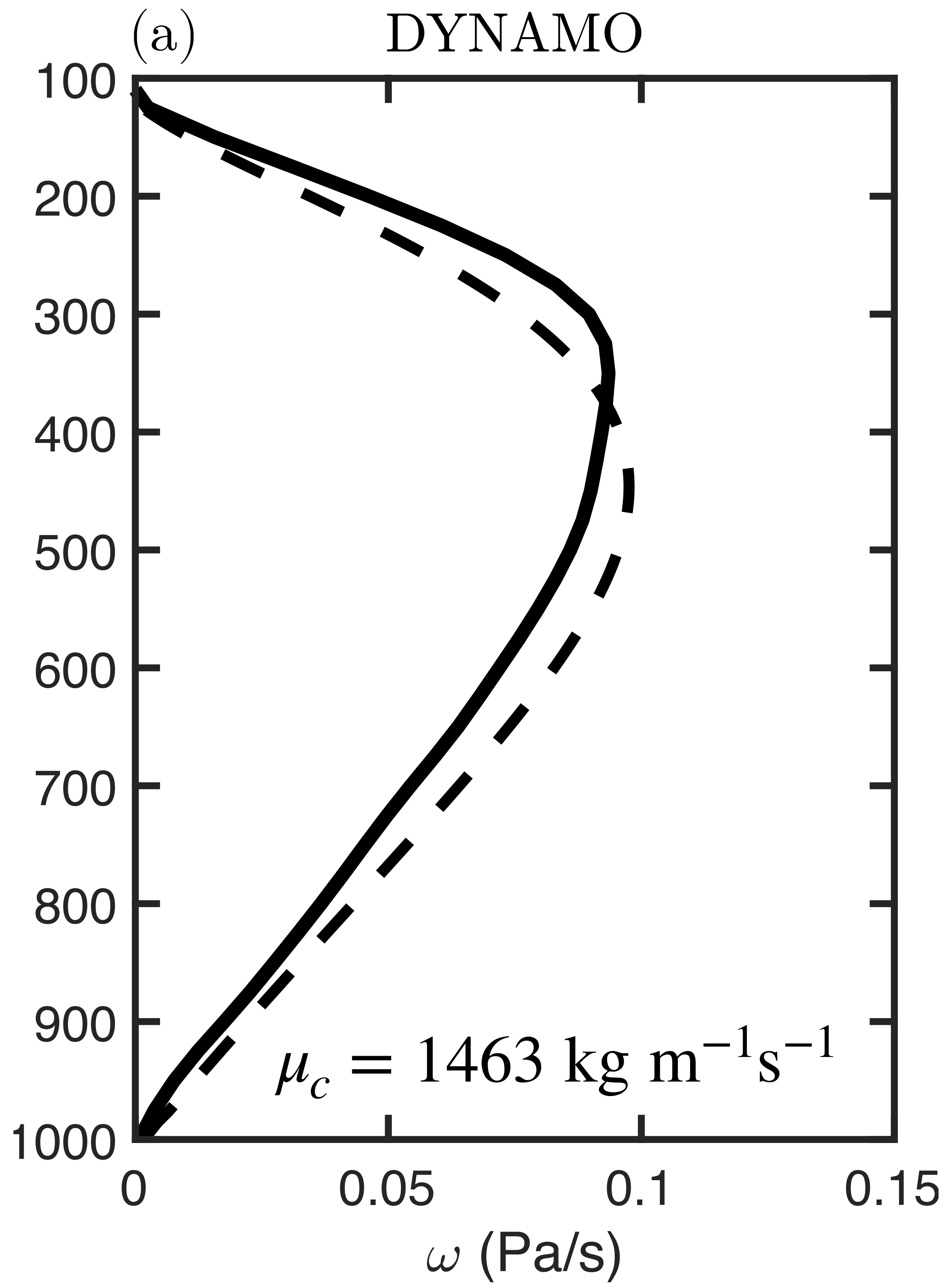
What if the individual convective elements are diffusive and entrain turbulently, but the entire region of ascent behaves like a plume that entrains dynamically ?

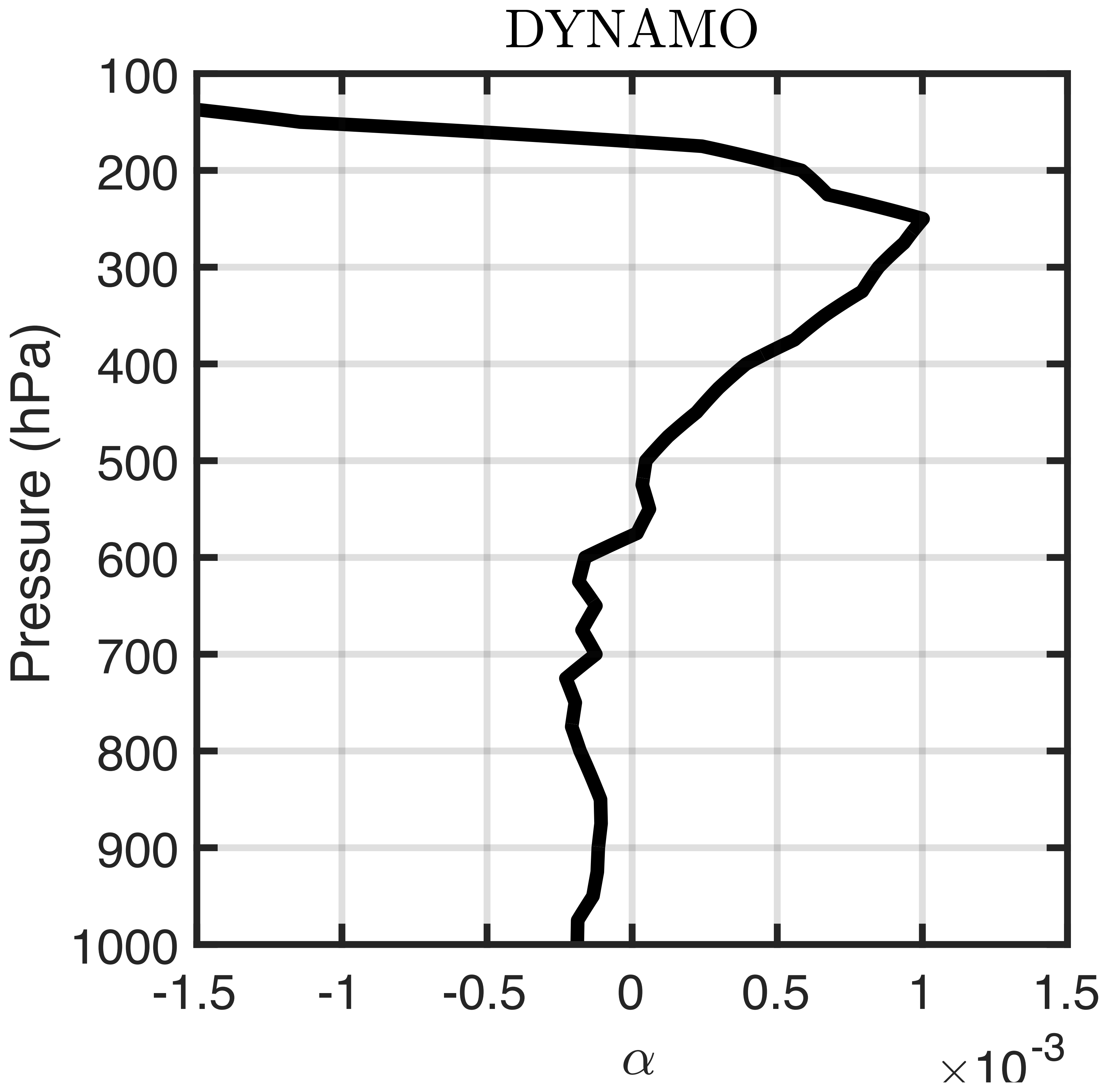


Relationship between alpha and omega

What if we assume vertical wave solutions (m is a vertical wavenumber) with rigid lids at the surface and tropopause:

$$\mu_c^* m^4 \omega = \nabla_h^2 \alpha'$$

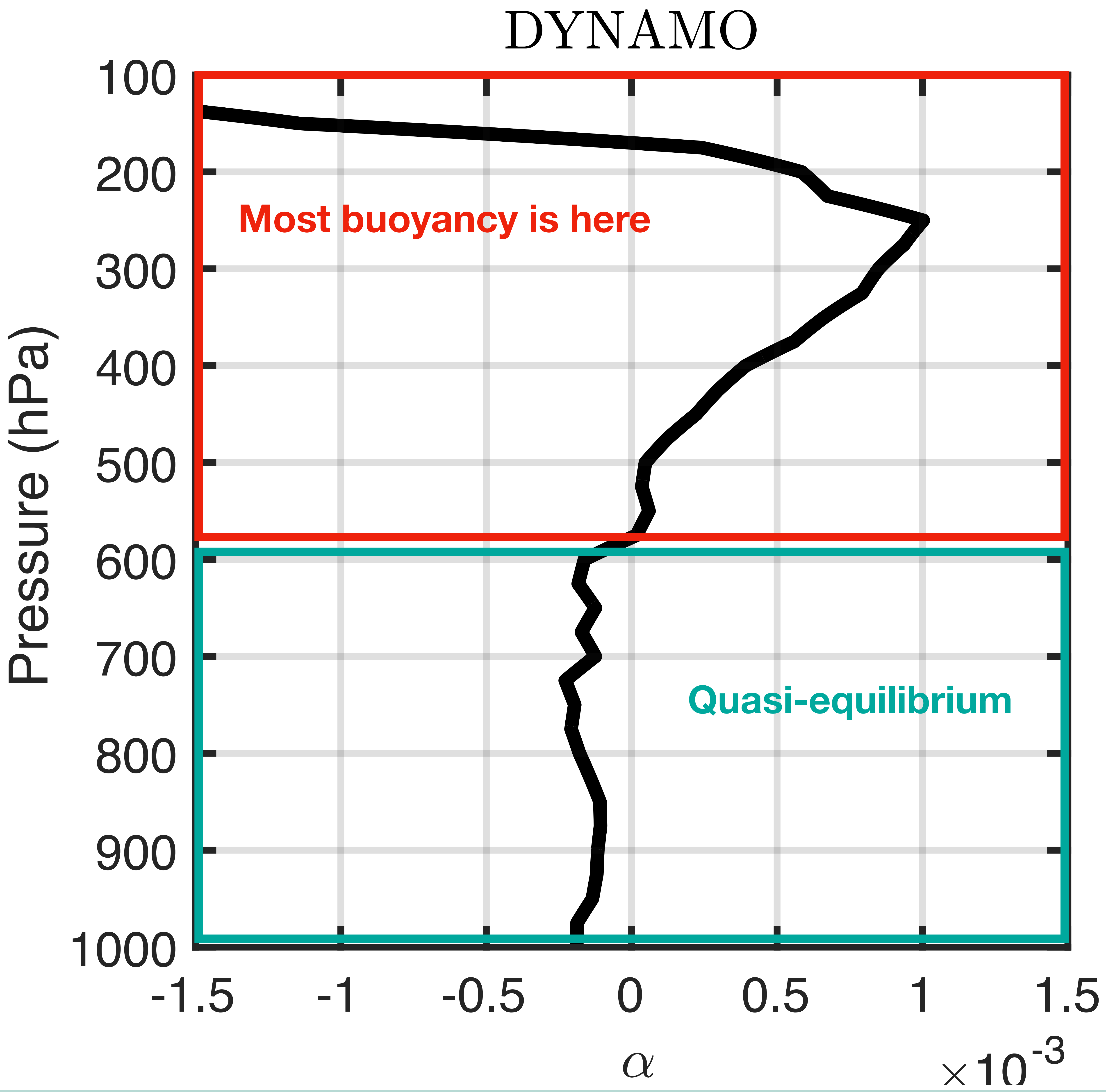




Relationship between alpha and omega

$$\mu_c^* m^4 \omega = \nabla_h^2 \alpha'$$

Let's try dividing α' into two regions: a lower troposphere with small values, and an upper troposphere with large values.



Dynamic entrainment

The mesoscale plume entrains dynamically:

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

Assuming that the plume is saturated we have:

$$\mathrm{MSE}_c(p_{fl})^* = -\frac{1}{\omega_c(p_{fl})}\int_{p_{fl}}^{p_s} \frac{\partial \omega_c}{\partial p}\mathrm{MSE}_e dp\,.$$

If the mass flux is assumed linear beneath the freezing layer we have

$$\mathrm{MSE}_c^*(p_{fl}) \simeq \mathrm{MSE}_{eL}\,.$$

The MSE that makes it to the top of the troposphere is the average MSE beneath the freezing layer

Special case

Assuming latent energy dominates changes in lower troposphere MSE, and a super small BL we get:

$$\langle \omega \rangle = \frac{L_v}{\mu_c^* m^4 \Delta p} \ln \left(\frac{T_{fl}}{T_{lnb}} \right) \nabla_h^2 \langle q \rangle$$

Vertical velocity is determined by the laplacian of column moisture. Using the WTG approximation we have

$$\langle \omega \rangle S_p = L_v P + \langle Q_r \rangle$$

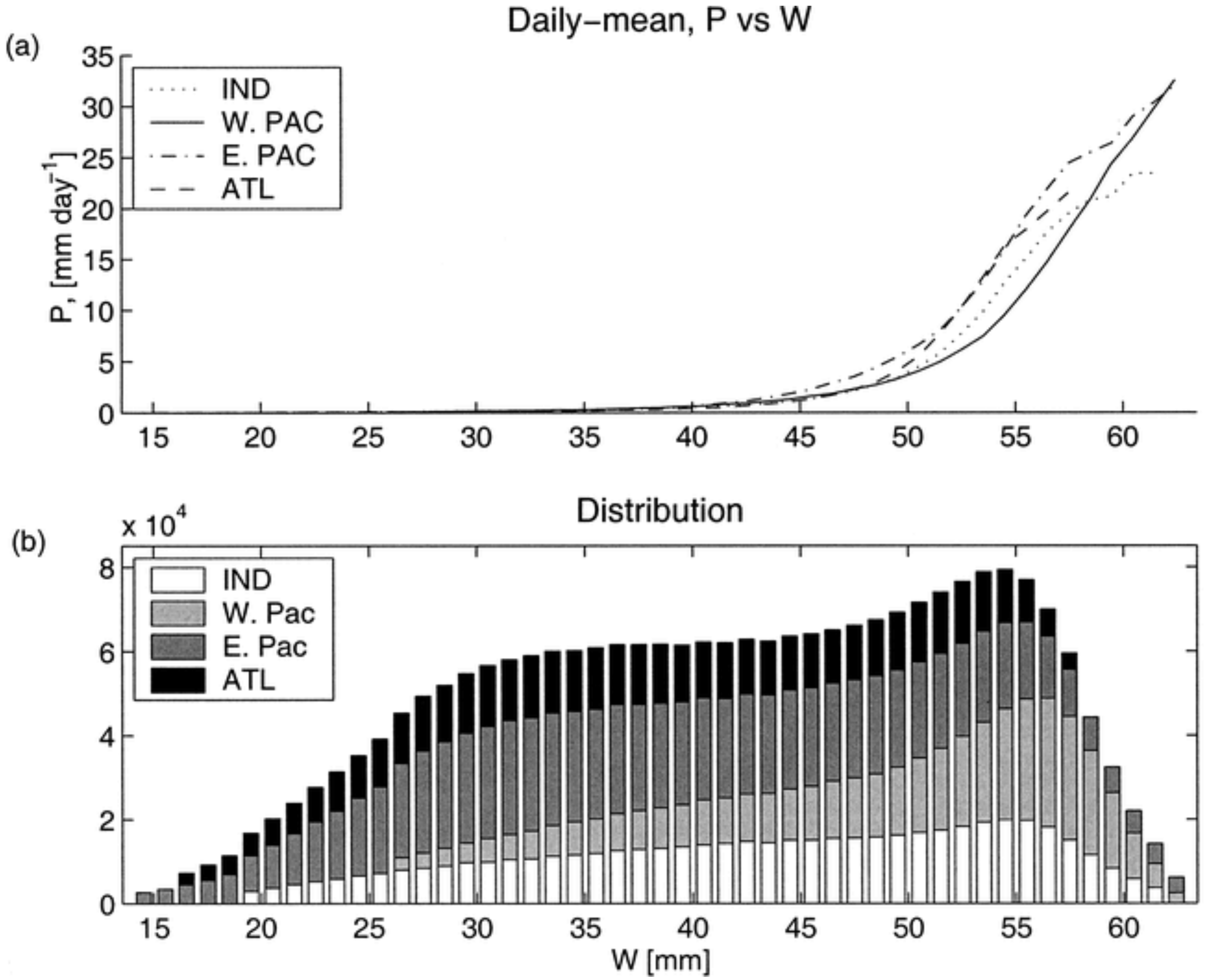
So we get

$$L_v P = \frac{S_p L_v}{\mu_c^* m^4 \Delta p} \ln \left(\frac{T_{fl}}{T_{lnb}} \right) \nabla_h^2 \langle q \rangle - \langle Q_r \rangle$$

Precipitation-moisture relation

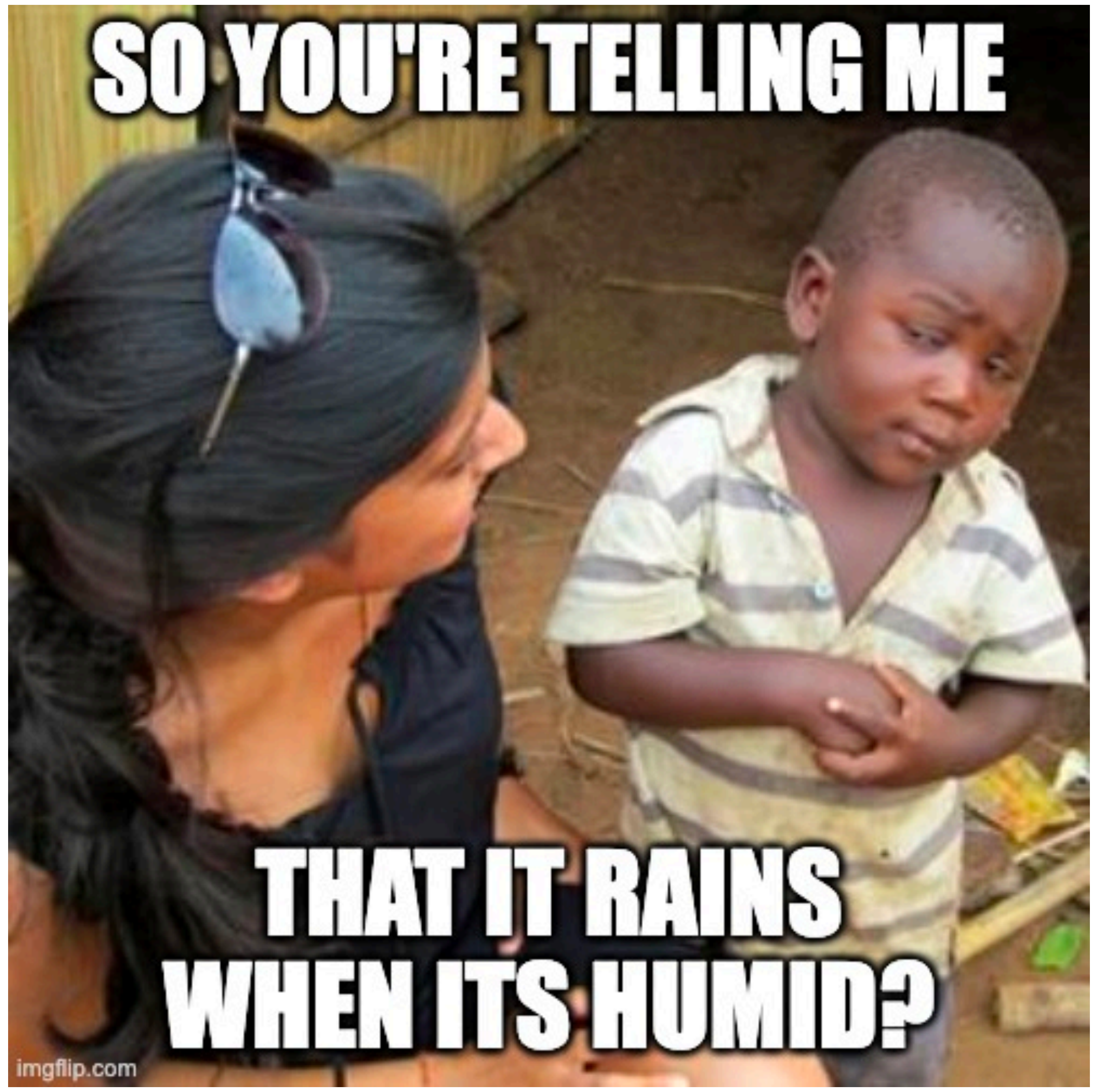
$$L_v P = \frac{S_p L_v}{\mu_c^* m^4 \Delta p} \ln\left(\frac{T_{fl}}{T_{lnb}}\right) \nabla_h^2 \langle q \rangle - \langle Q_r \rangle$$

Precipitation is a function of the Laplacian of column water vapor

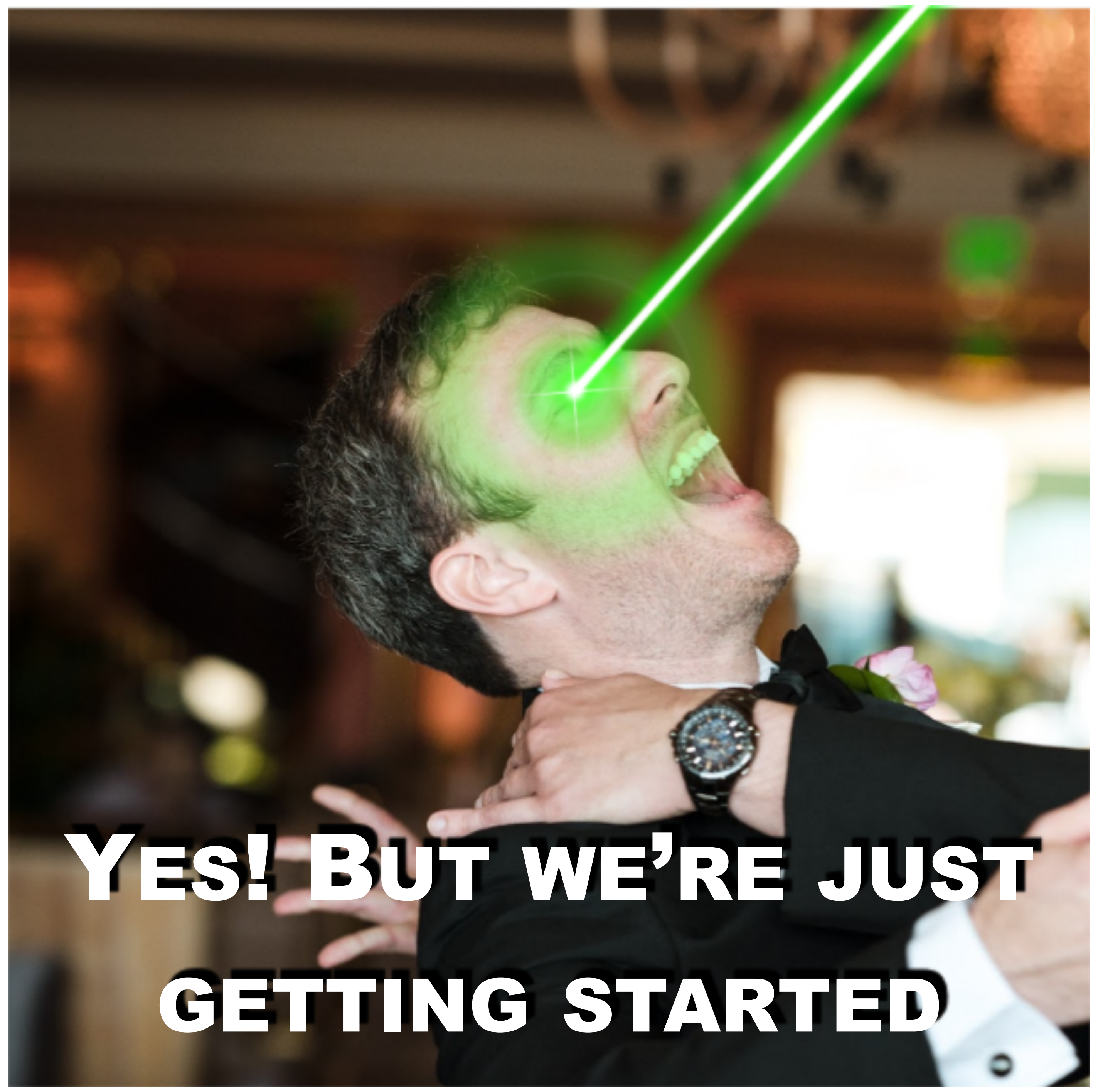


Bretherton, Peters, and Back (2004)

Precipitation-moisture relation

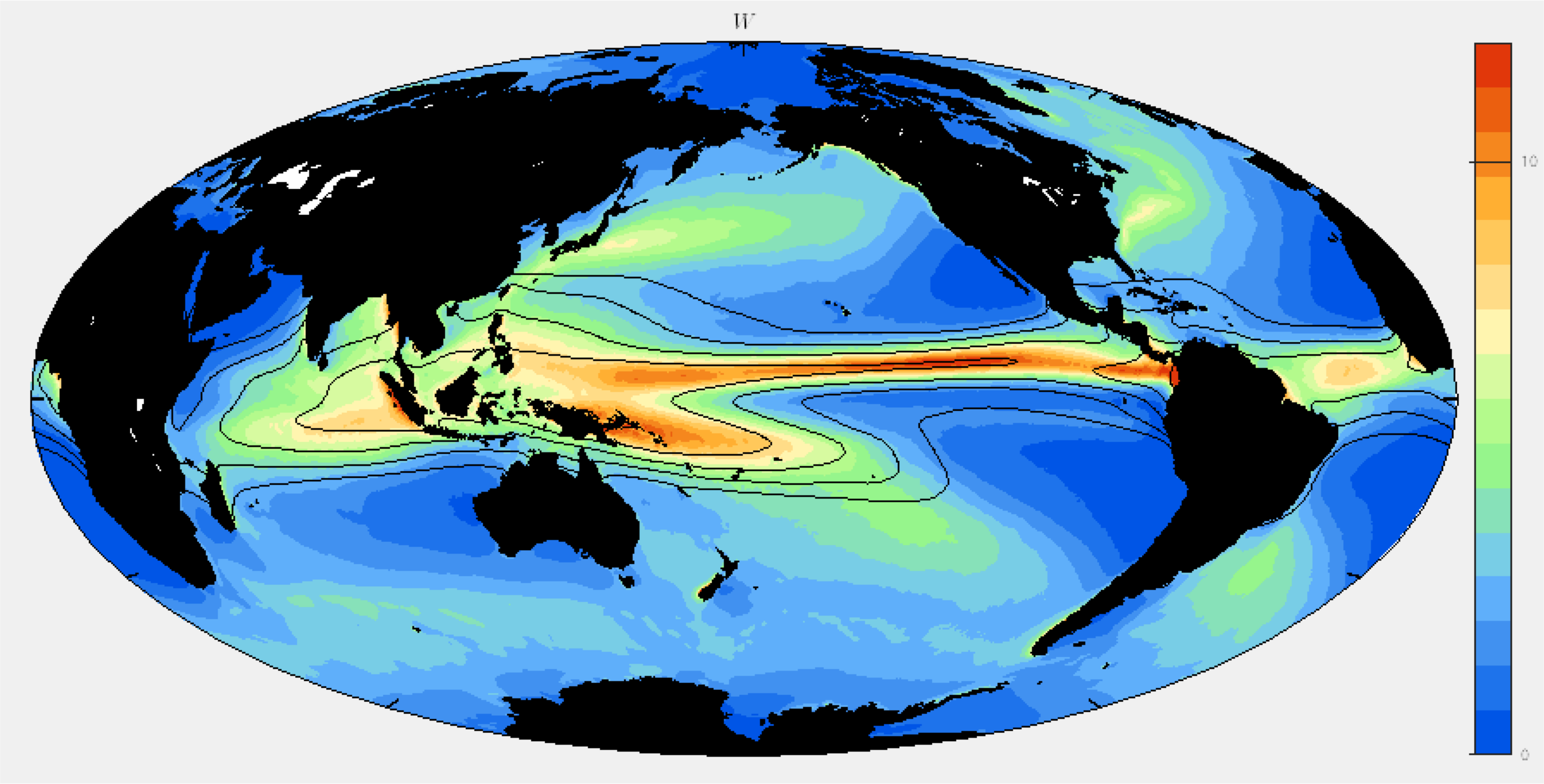


On the surface this seems like an obvious result.



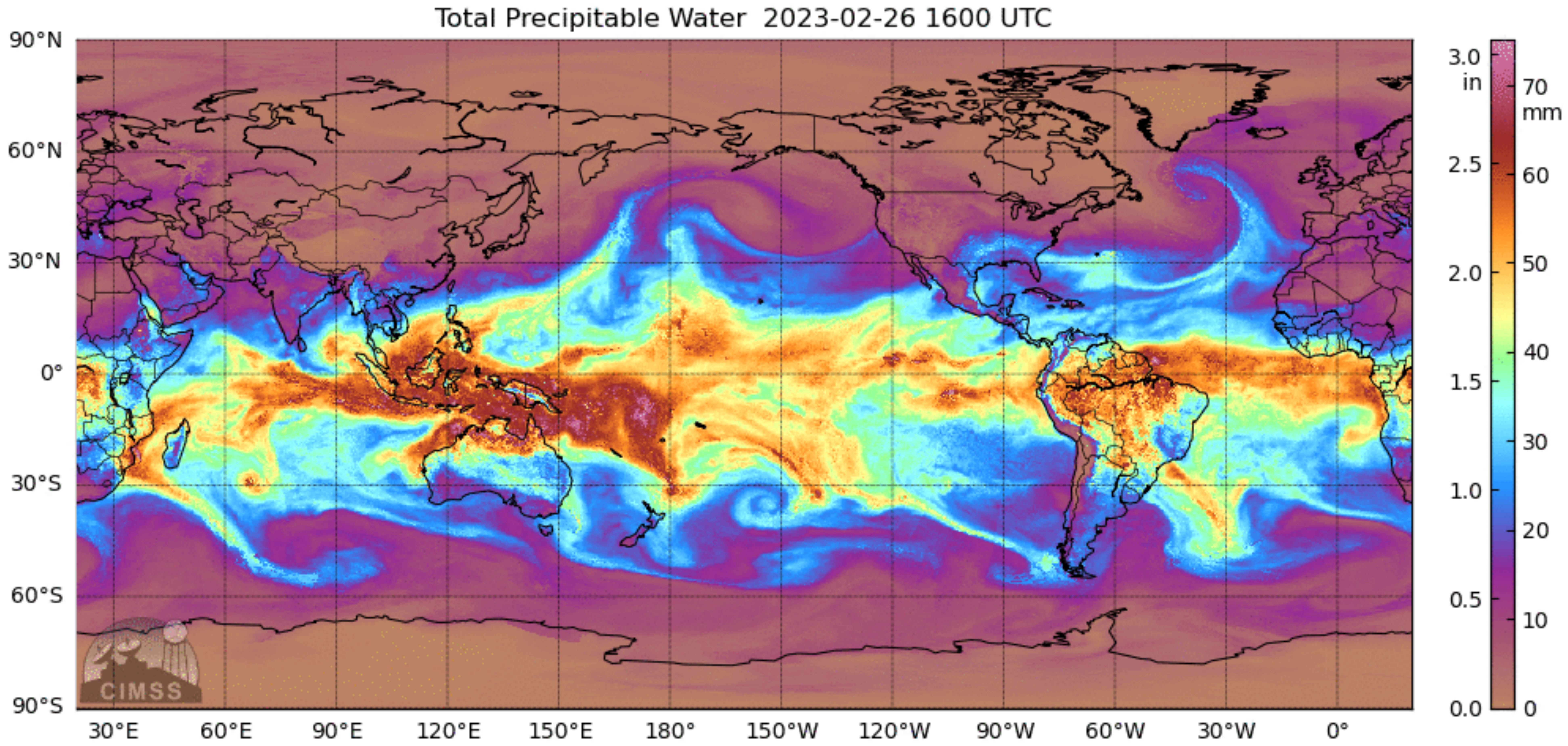
But the fact that it's a Laplacian is interesting. The fact that moisture has a strong control over deep convection under WTG balance will have major implications down the road.

Precipitation-moisture relation



Precipitation-moisture relation

A massive consequence is that moving moisture around implies moving rainfall around too.



Wolding et al. (2022)

Draw a schematic of a convective life cycle and point out the main findings of Wolding et al. (2022)

How do the results compare to what you have learned in class?