AOS 801: Advanced Tropical Meteorology

Lecture 22 Spring 2023

Moisture-vortex instability

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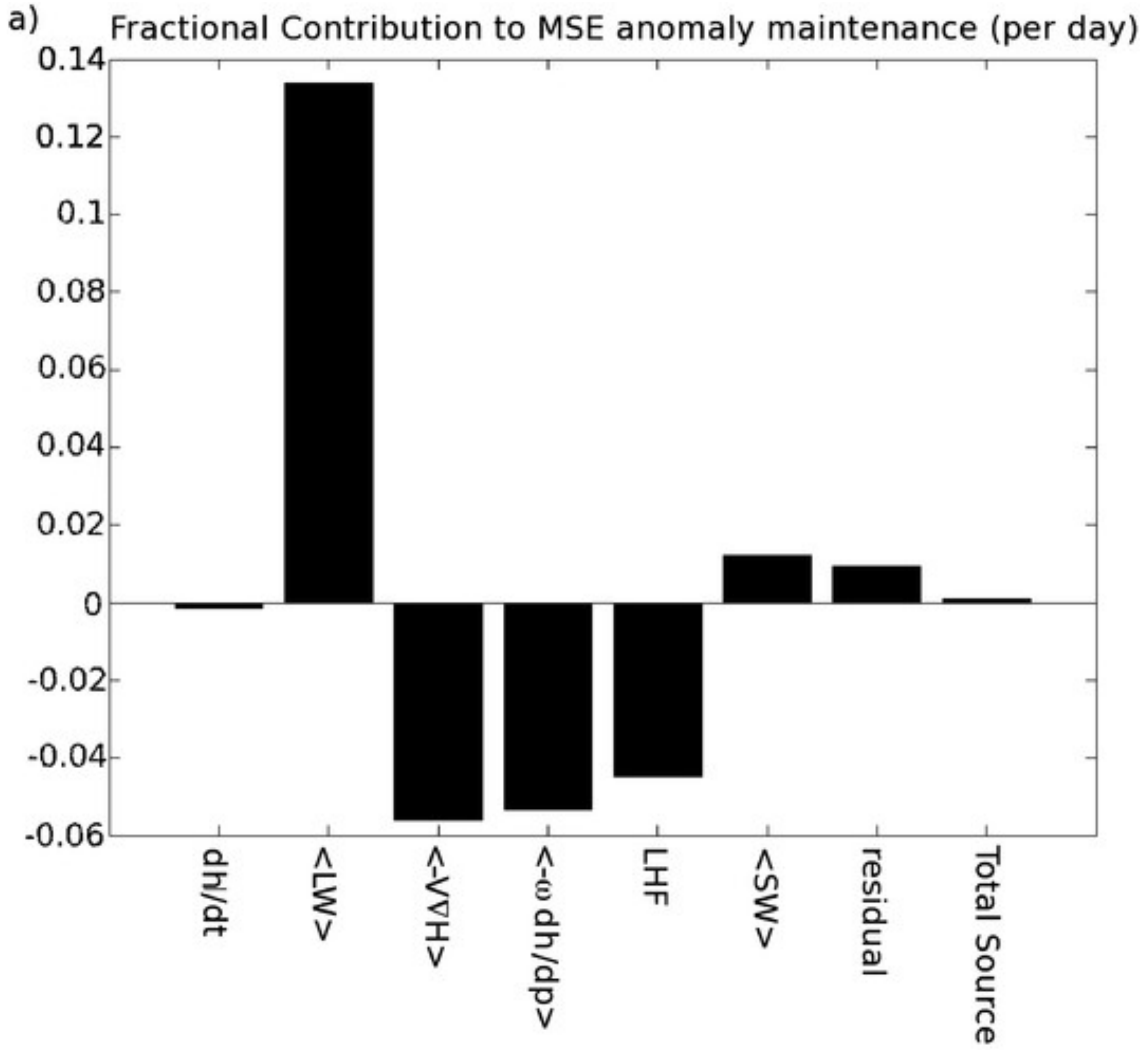
The growth of moisture modes.

The mechanism of growth can be understood as a variance budget

$$\frac{\partial L_v \langle q' \rangle^2}{\partial t} = -\langle q' \rangle \left(\langle \mathbf{v} \cdot \nabla_h L_v q \rangle' - \left\langle \omega_w \frac{\partial \mathrm{MSE}}{\partial p} \right\rangle' + \langle Q_r' \rangle + L_v E' + \mathrm{SHF}' \right)$$

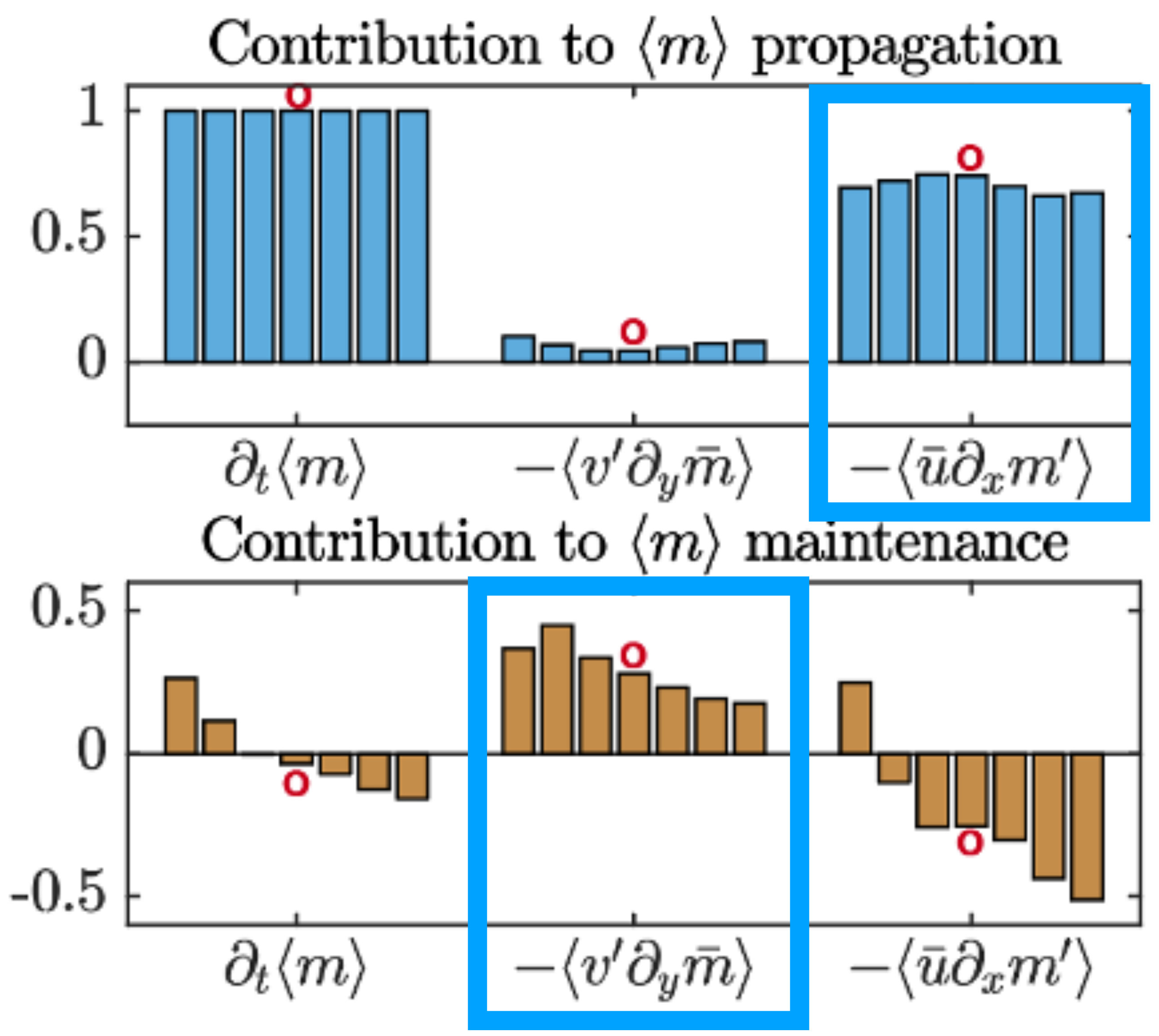


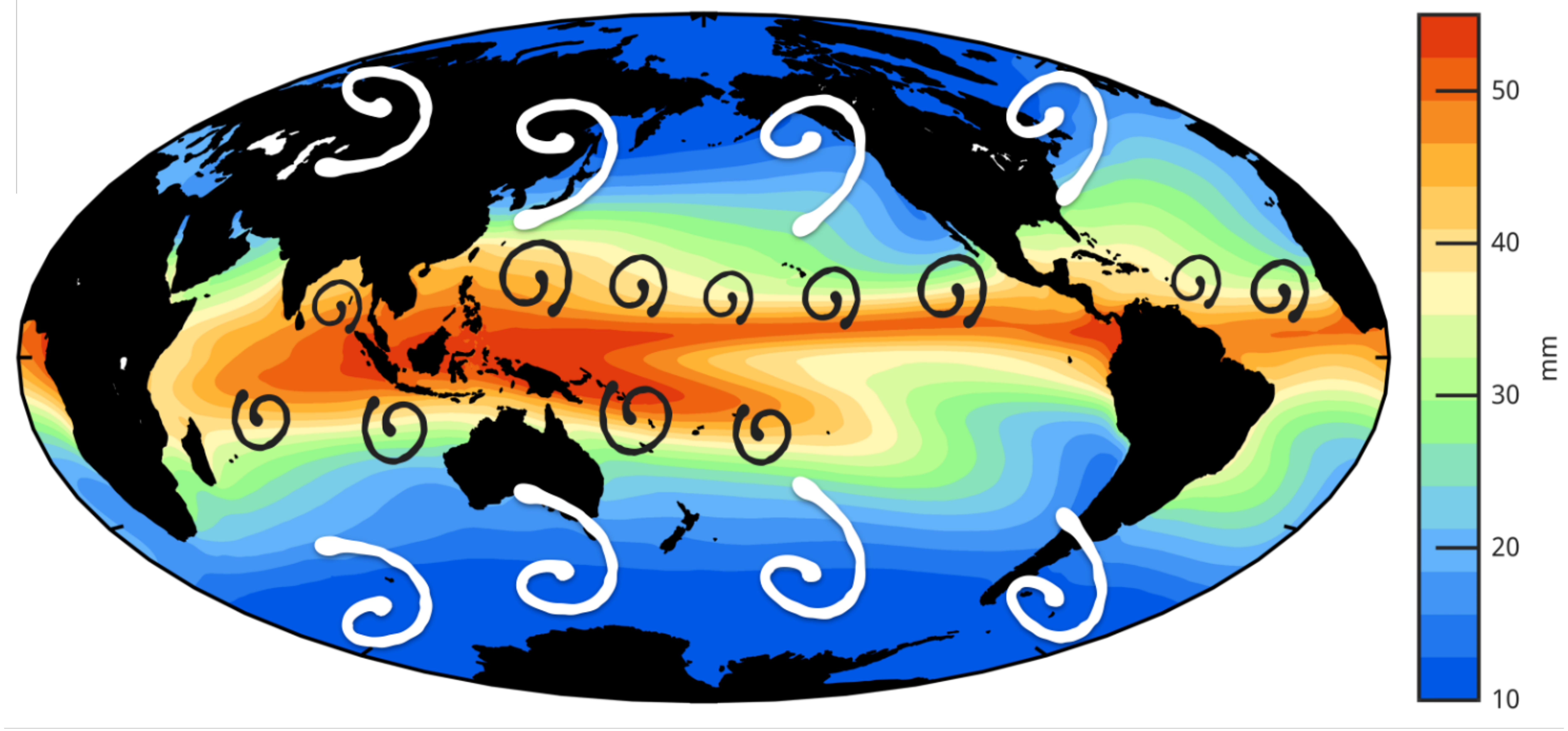
For a process to contribute to the growth of moisture anomalies, it must occur in phase with the moisture anomalies.

$$\frac{\partial L_v \langle q' \rangle^2}{\partial t} > 0 \textbf{ growth}$$

$$\frac{\partial L_v \langle q' \rangle^2}{\partial t} < 0 \textbf{ decay}$$

What about horizontal moisture advection?





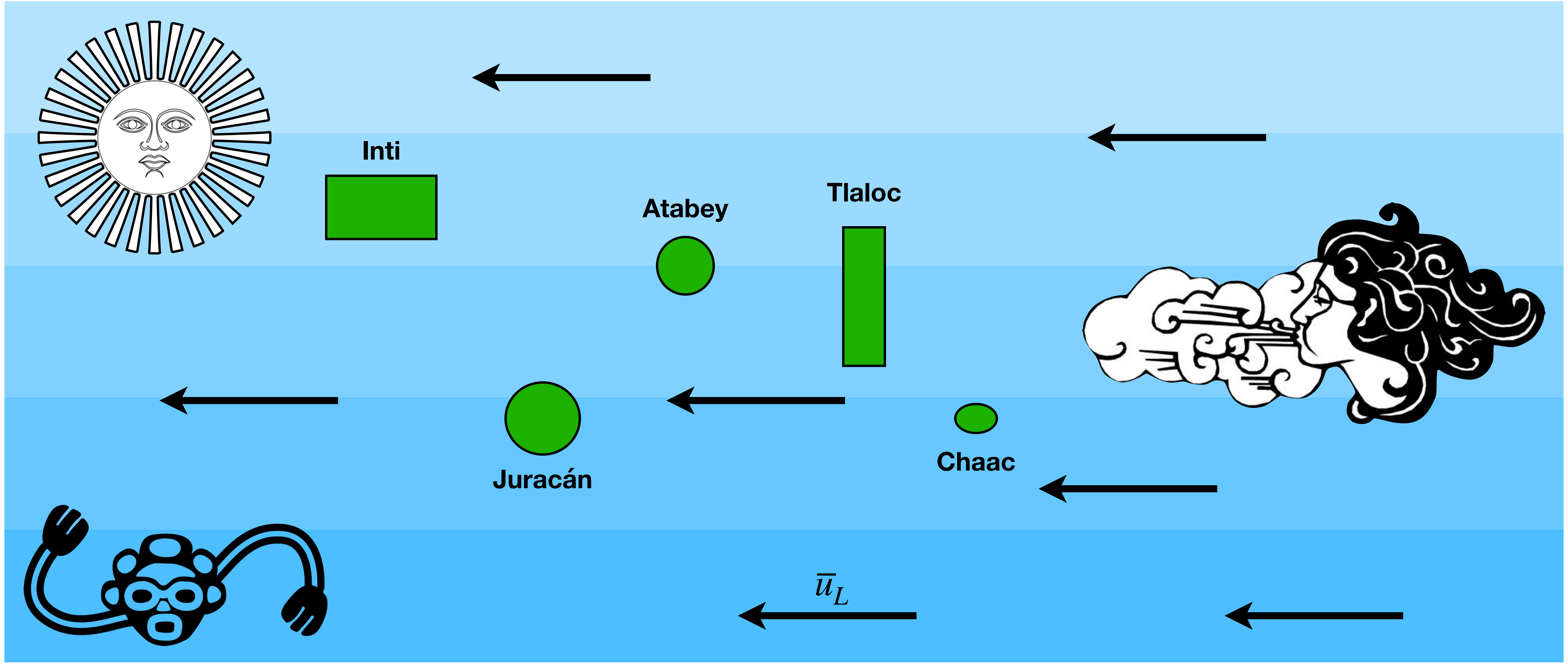
What about horizontal moisture advection?

In HW4 you obtain this set of equations to describe the evolution fluctuations in rainfall. These fluctuations are actually tropical depression-like waves that are moisture modes:

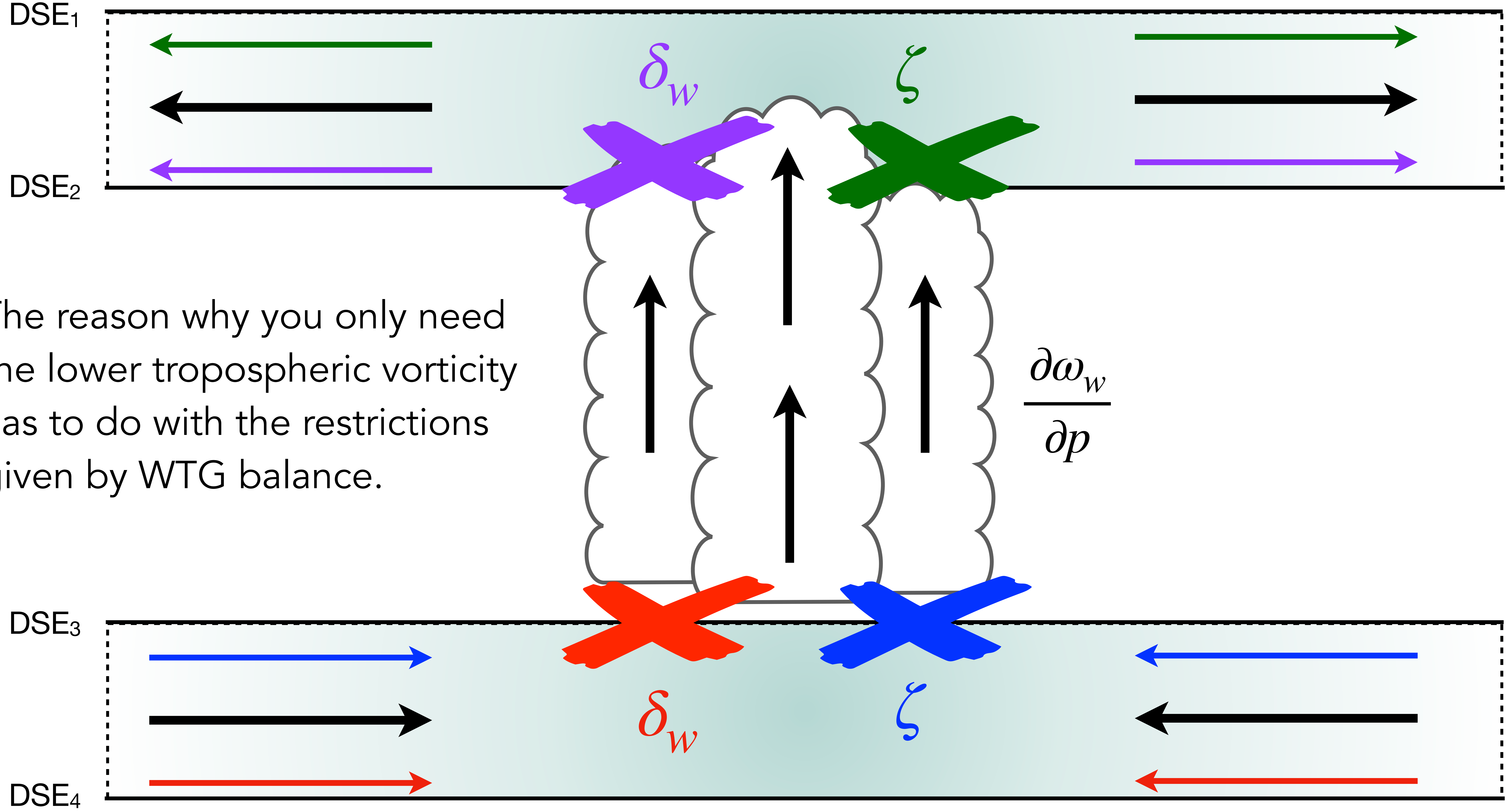
$$\frac{\partial \zeta_L'}{\partial t} \simeq -\overline{u}_L \frac{\partial \zeta_L'}{\partial x} + \frac{f_0 L_v \langle q' \rangle}{S \tau_c}$$

$$\frac{\partial \langle q' \rangle}{\partial t} \simeq -\overline{u}_L \frac{\partial \langle q' \rangle}{\partial x} - v_L' \frac{\partial \langle \overline{q} \rangle}{\partial y}$$

Archipelago of Clarity



Tropical motions under WTG balance are severely restricted



The reason why you only need the lower tropospheric vorticity has to do with the restrictions given by WTG balance.

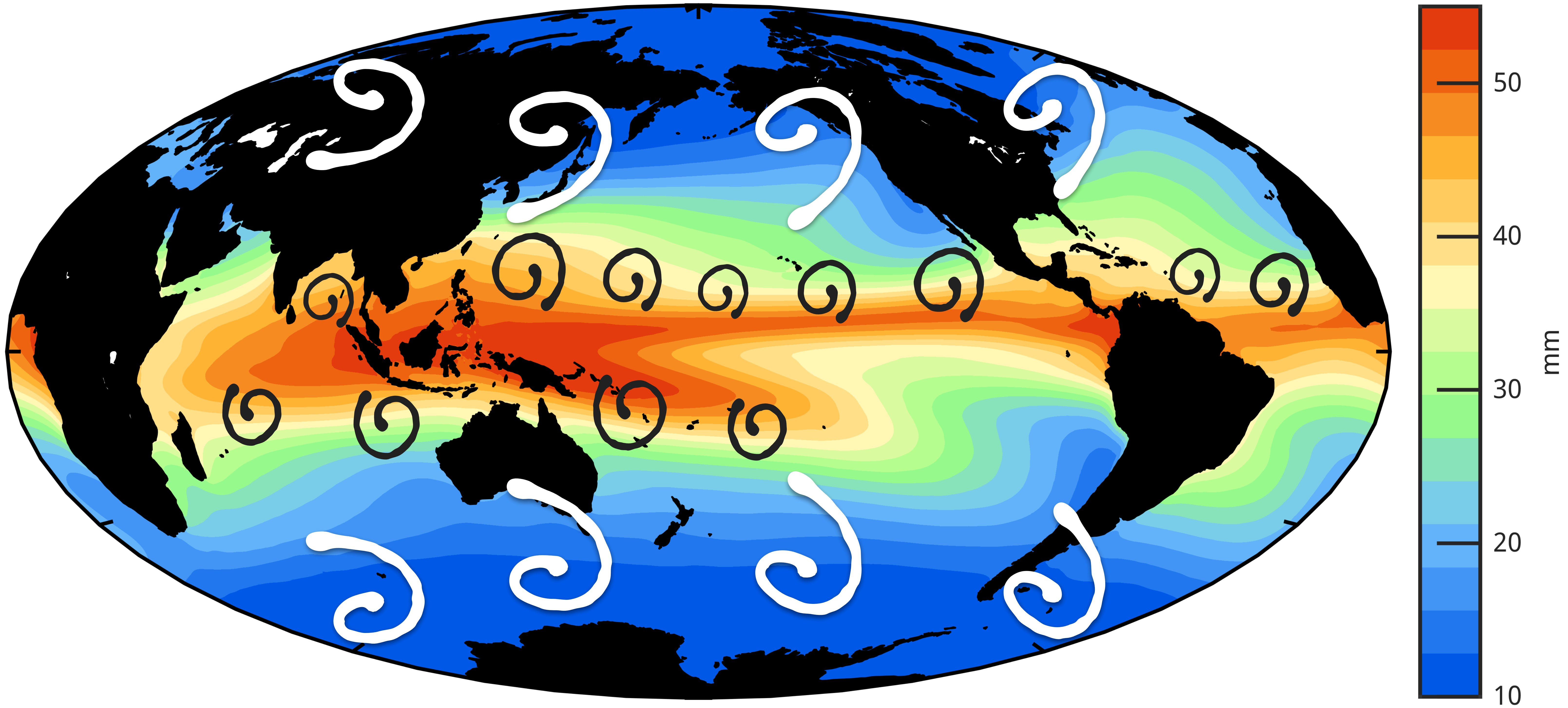
Horizontal moisture gradients are unstable

The solution to that system takes the form

$$\varpi = [\overline{u}_3]k \pm \sqrt{\frac{i\beta_q k}{\tau_c K^2}}$$

Where $\beta_q = -\frac{f_0}{S}\frac{\partial L_v \overline{W}}{\partial y}$ is a moist beta effect.

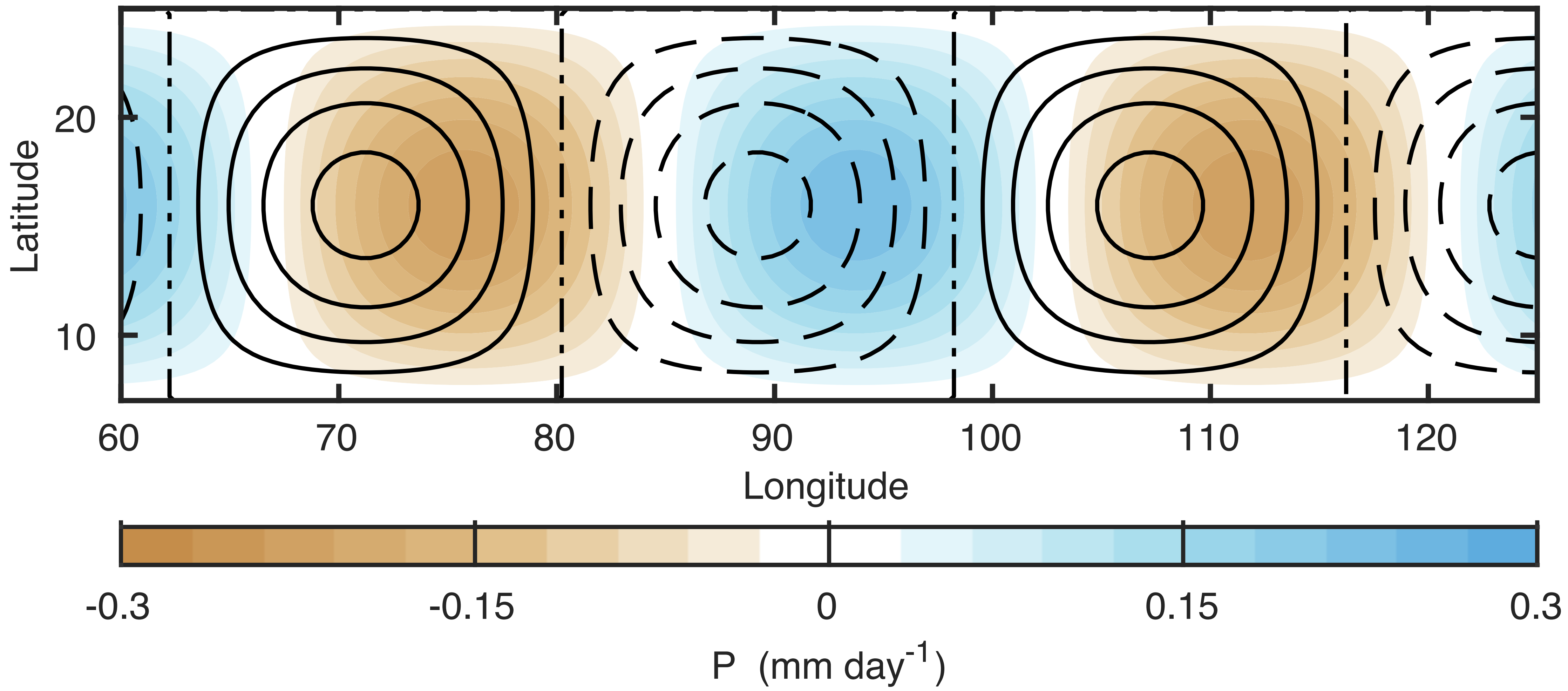
Since the solution has the ± sign, one of the solution is always unstable.

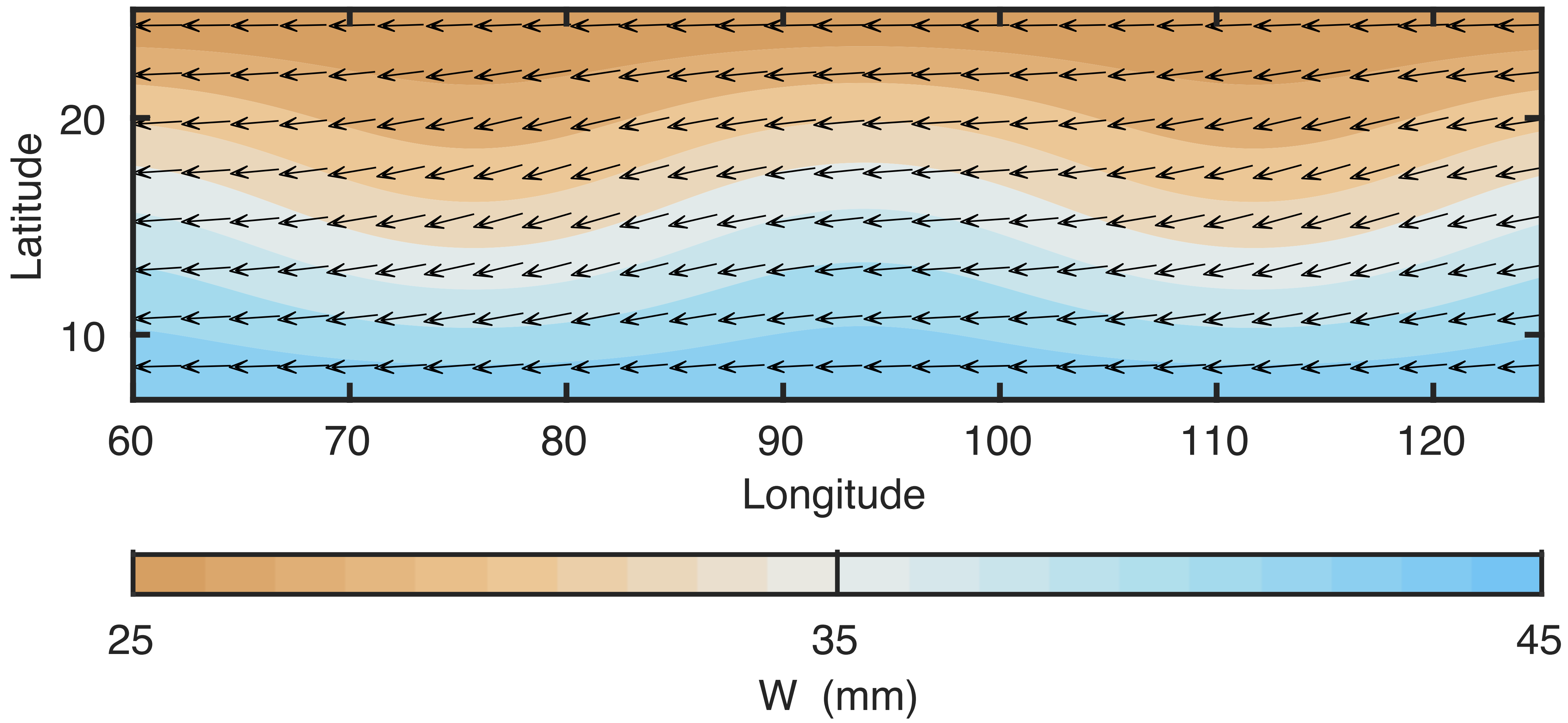


Moisture-vortex instability

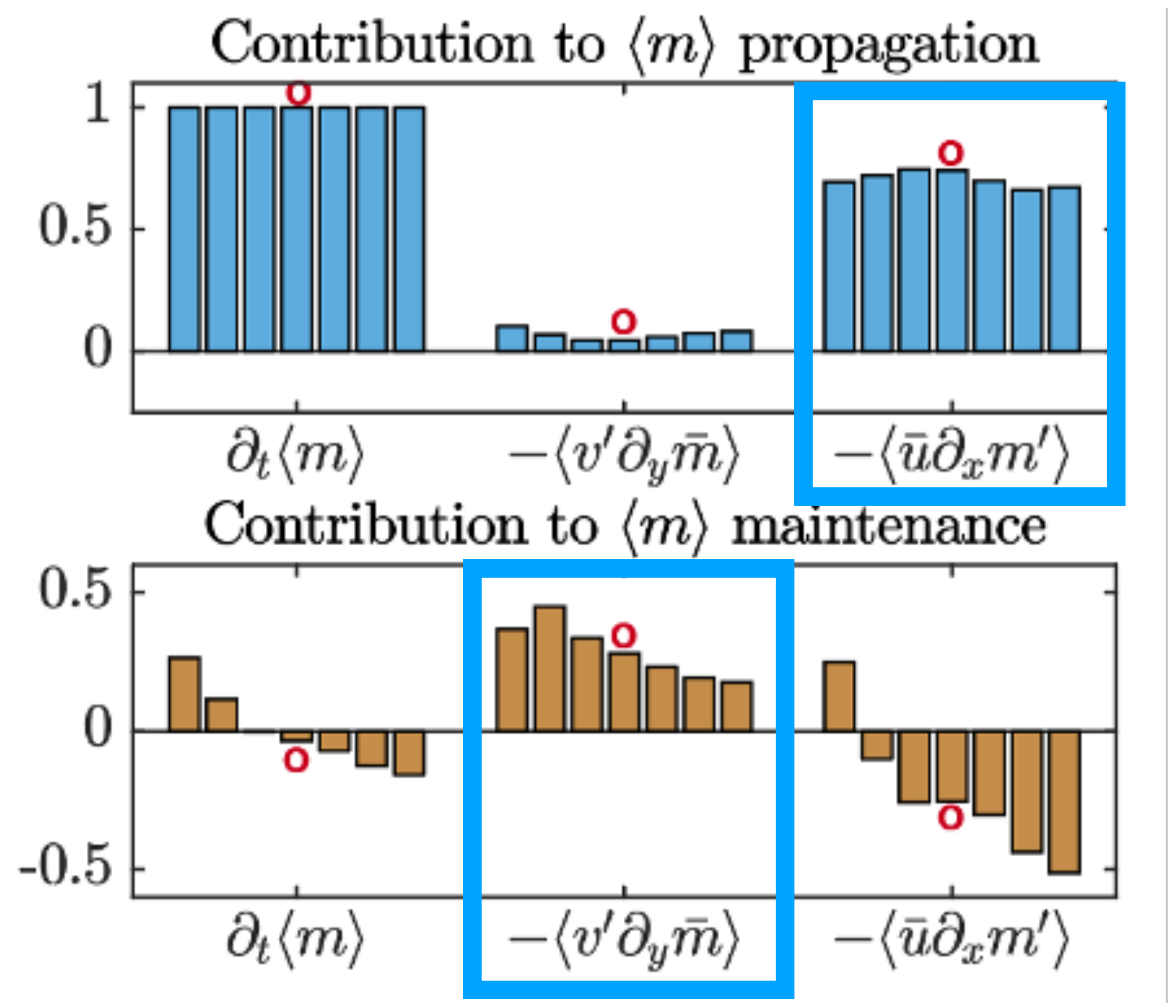
Since the solution has the ± sign, one of the solution is always unstable. Thus, **horizontal moisture gradients** in the presence of rotation **are unstable.**

This instability is referred (by some people) as **moisture-vortex instability.**

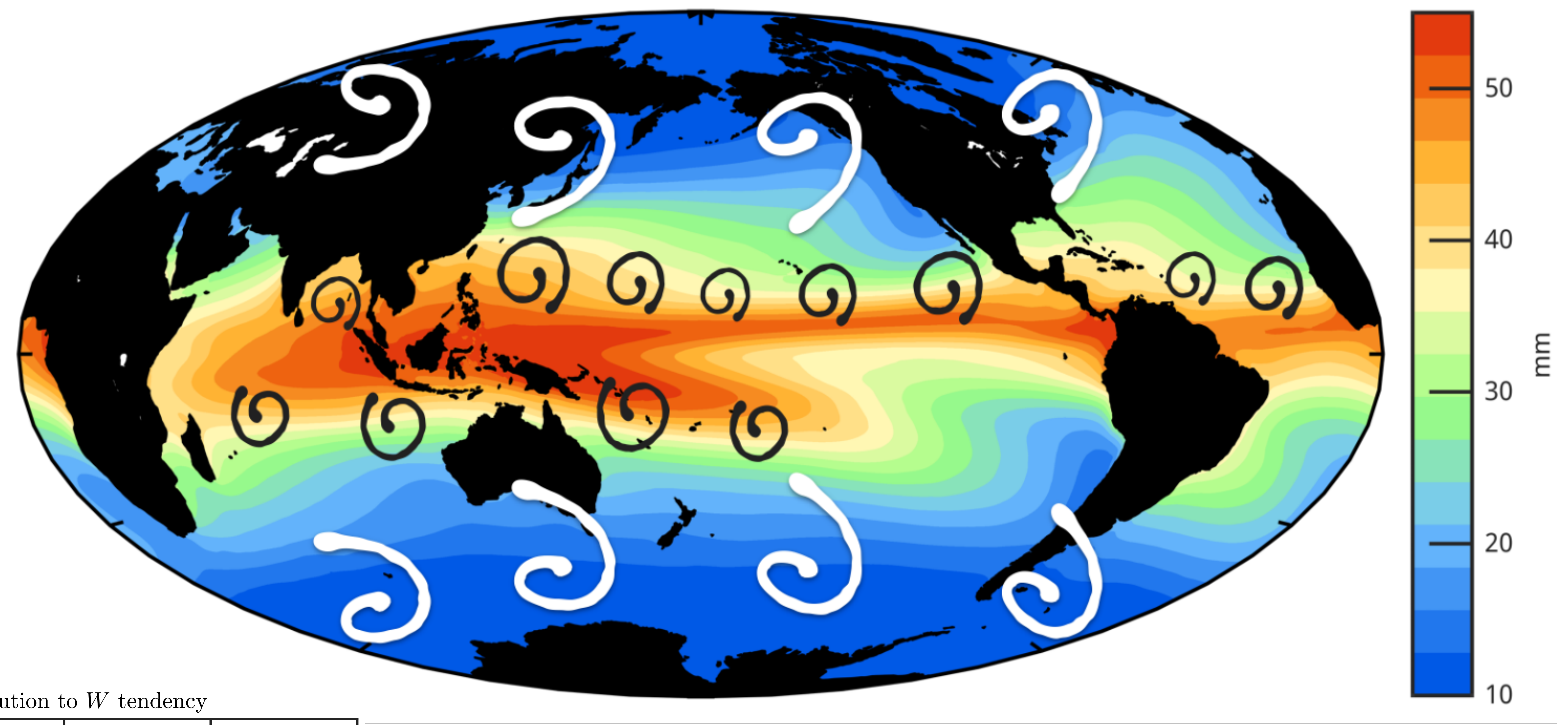




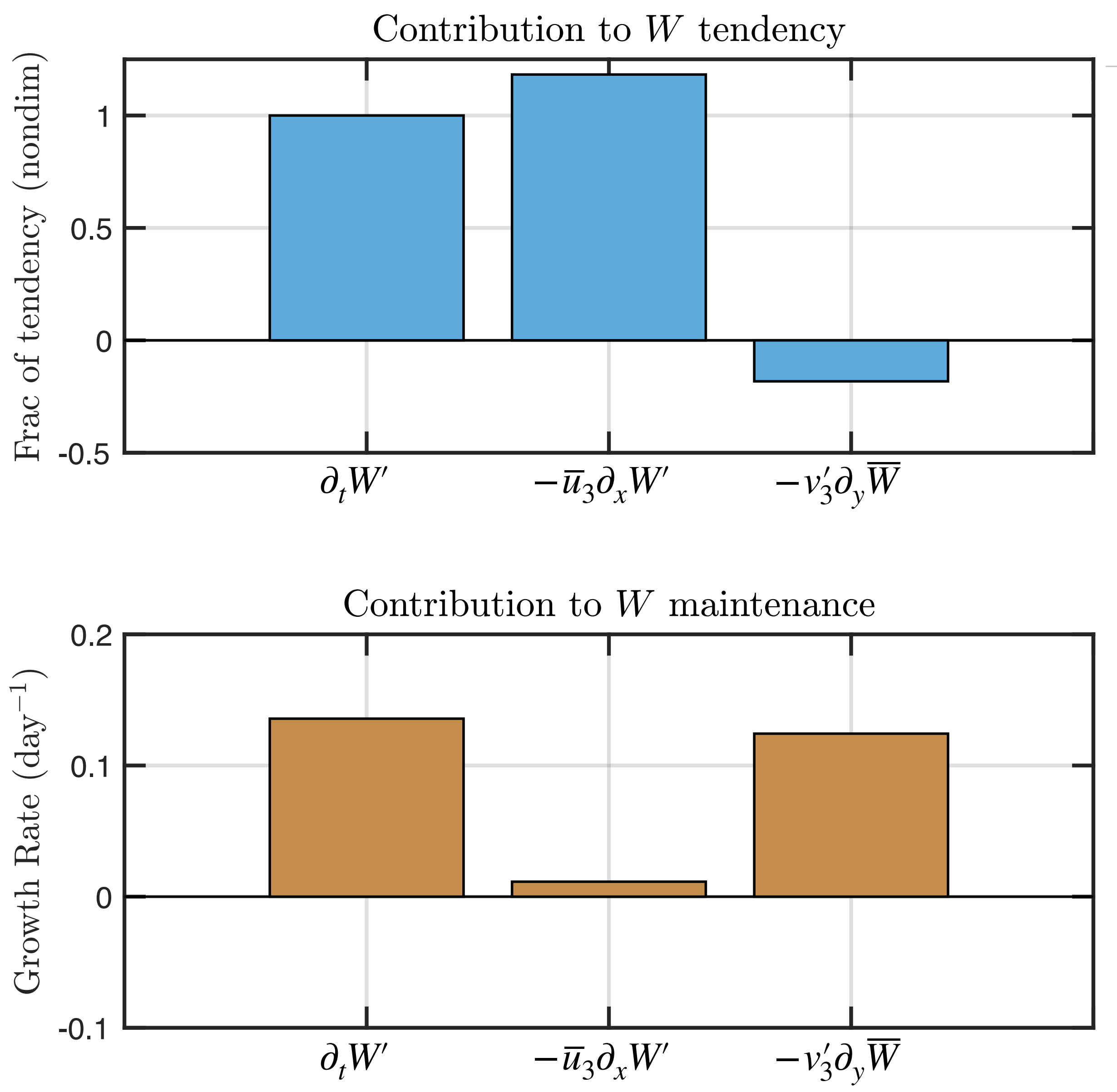
Moisture-vortex instability



Reanalysis



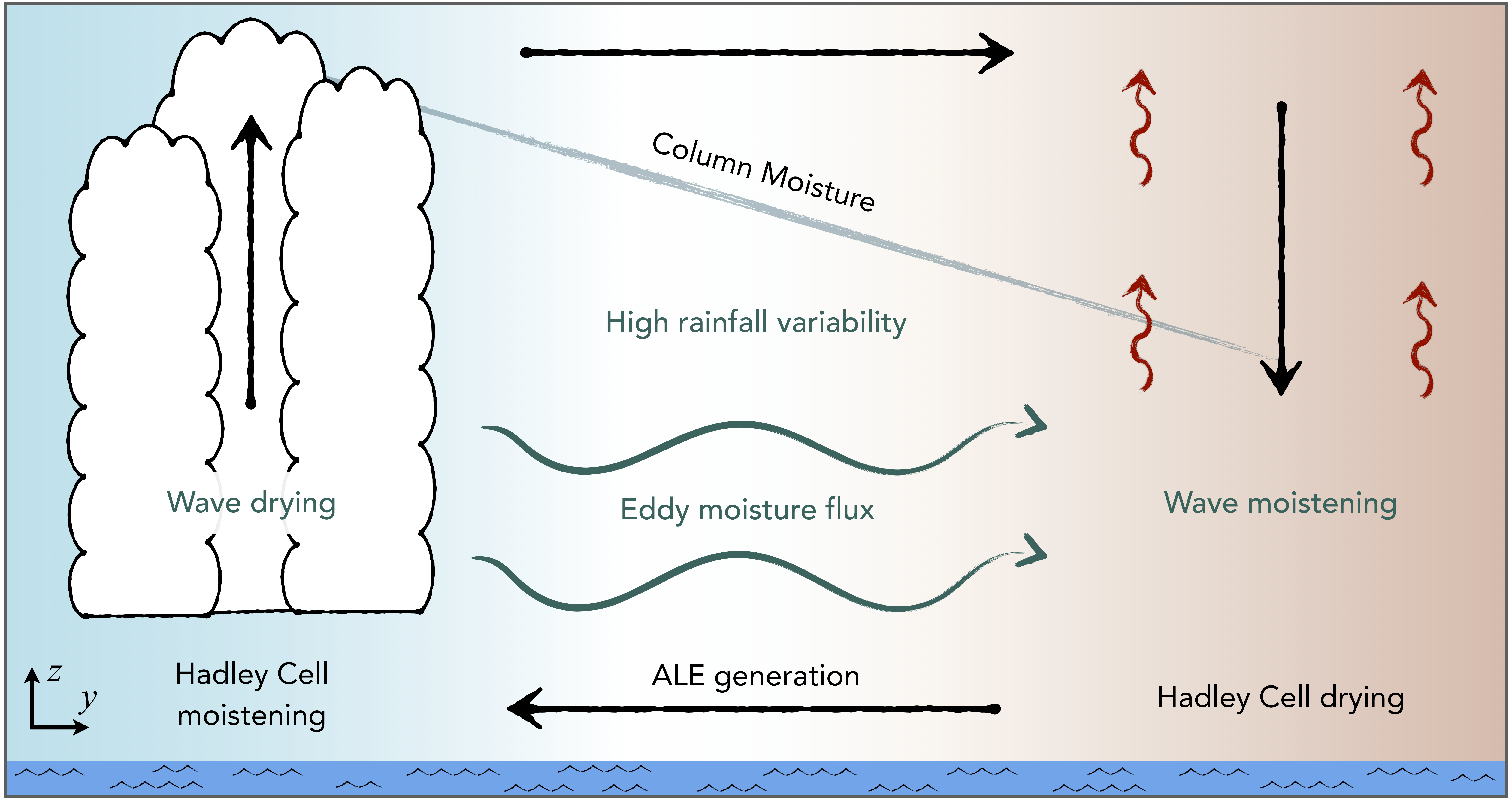
Linear wave solution



What is the mechanism?

What if the moisture advection affects the background state?

Hypothetical Hadley Cell-Moisture Mode Interactions



Wave mean flow interactions in the presence of moisture gradients

Let's look at the eddy moisture variance and the mean state

$$\frac{\partial \mathcal{A}}{\partial t} = \overline{v'W'} \qquad \mathcal{A} = -\frac{\overline{W'^2}}{2}\left(\frac{\partial \overline{W}}{\partial y}\right)^{-1}$$

Wave Activity

$$\frac{\partial \mathrm{ALE}}{\partial t} = -\overline{v'W'} \qquad \mathrm{ALE} = -\frac{L_H}{2}\frac{\partial L_v \overline{W}}{\partial y}$$

Available Latent Energy

$$\frac{\partial}{\partial t}\left(\mathrm{ALE} + \mathcal{A}\right) = 0.$$

Conservation equation resembles total energy

Eddies grow at the expense of the mean moisture gradient, therefore weakening the Hadley Cell.