AOS 801: Advanced Tropical Meteorology

Lecture 23 Spring 2023

Tropical Cyclones

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

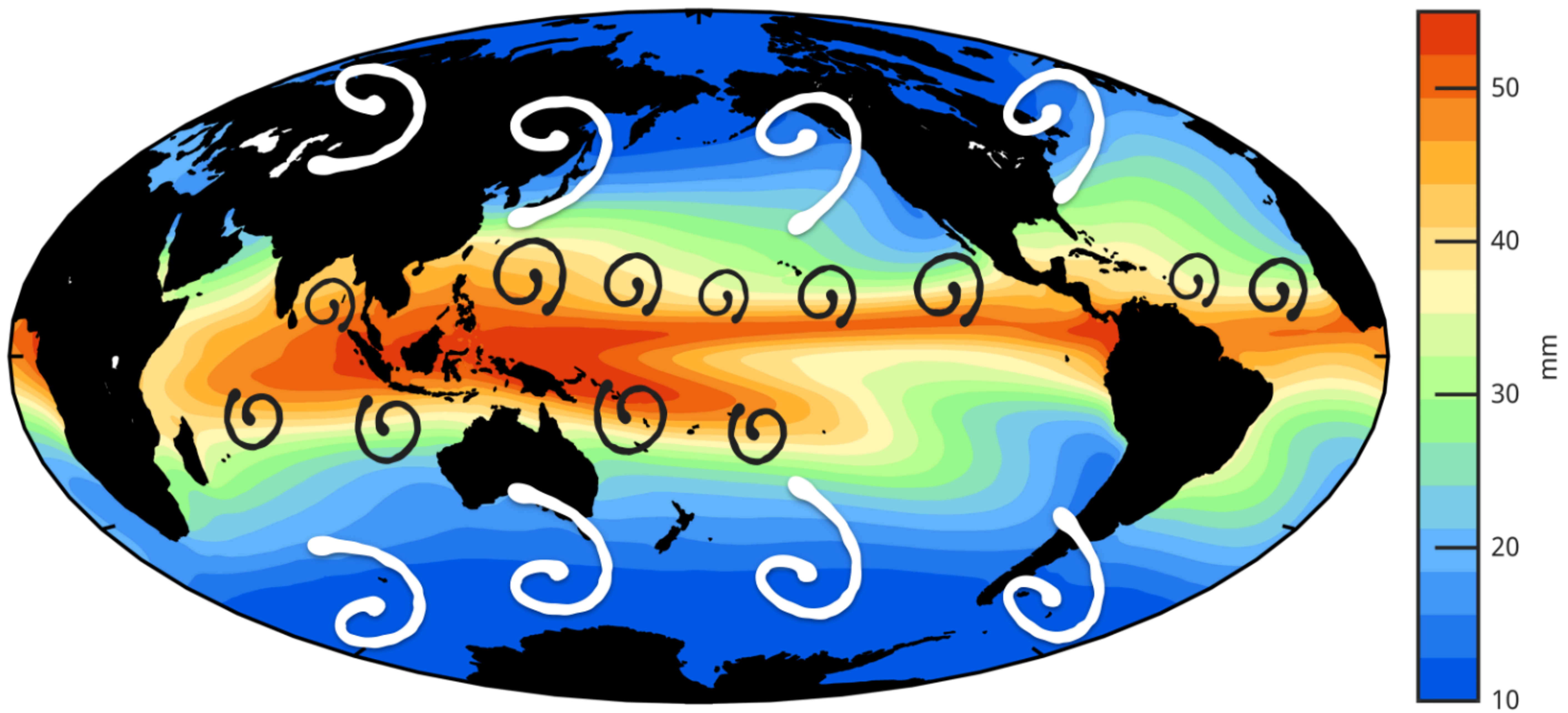
Horizontal moisture gradients are unstable

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.



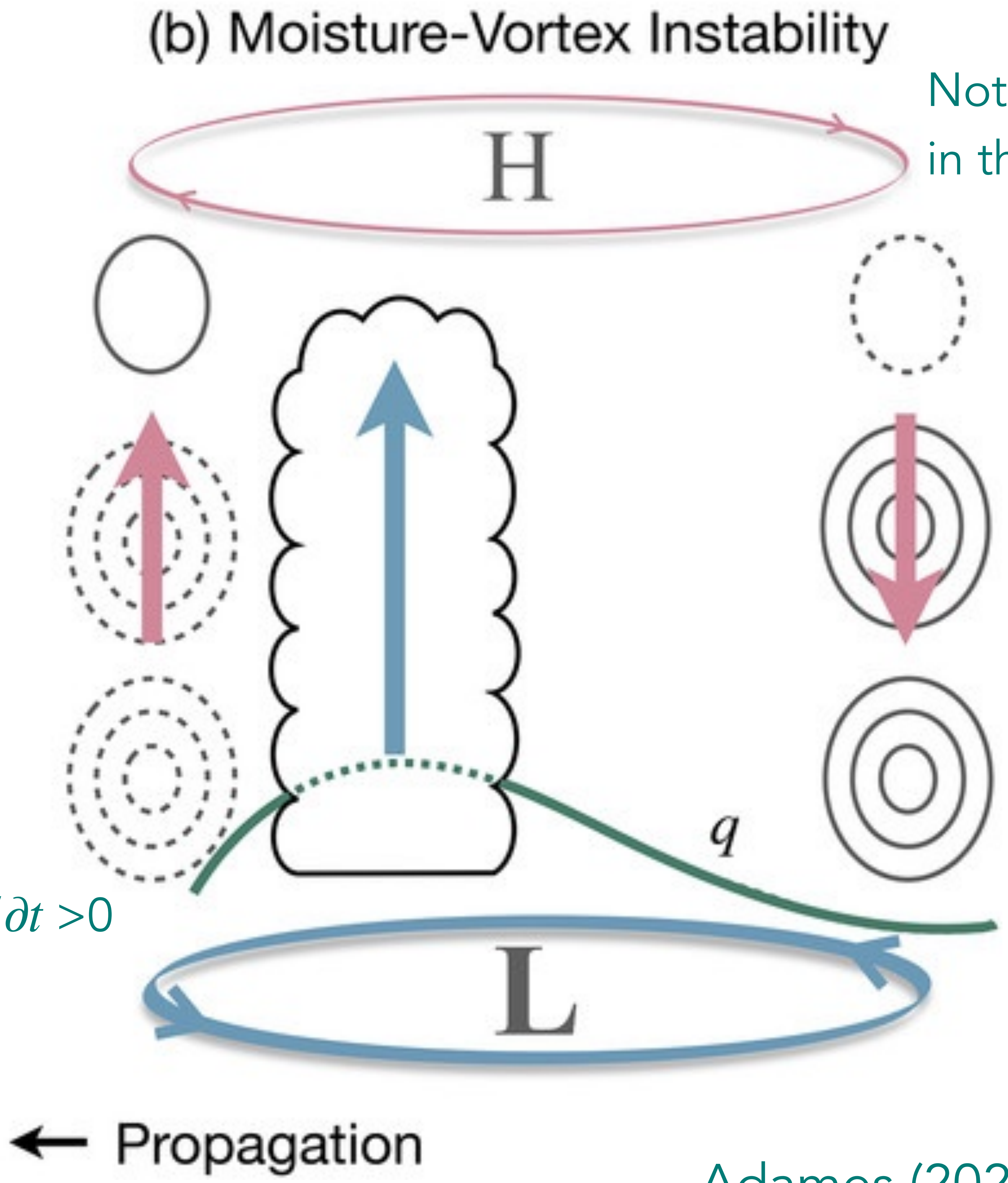
Horizontal moisture gradients are unstable

The solution to that system takes the form

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

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.



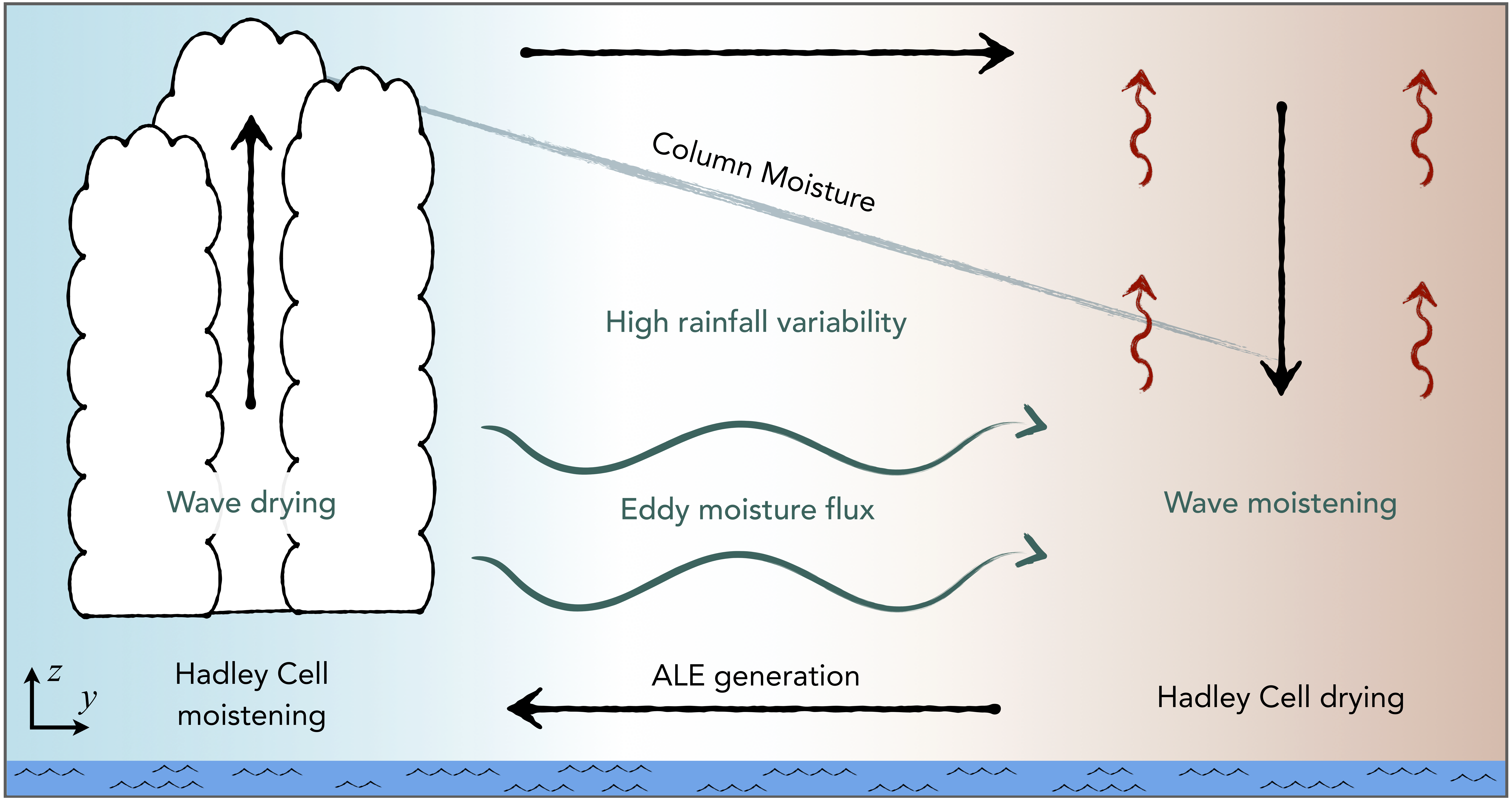
Note: β_q is flipped in the image

$\partial\langle q\rangle/\partial t > 0$

Adames (2021)

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

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

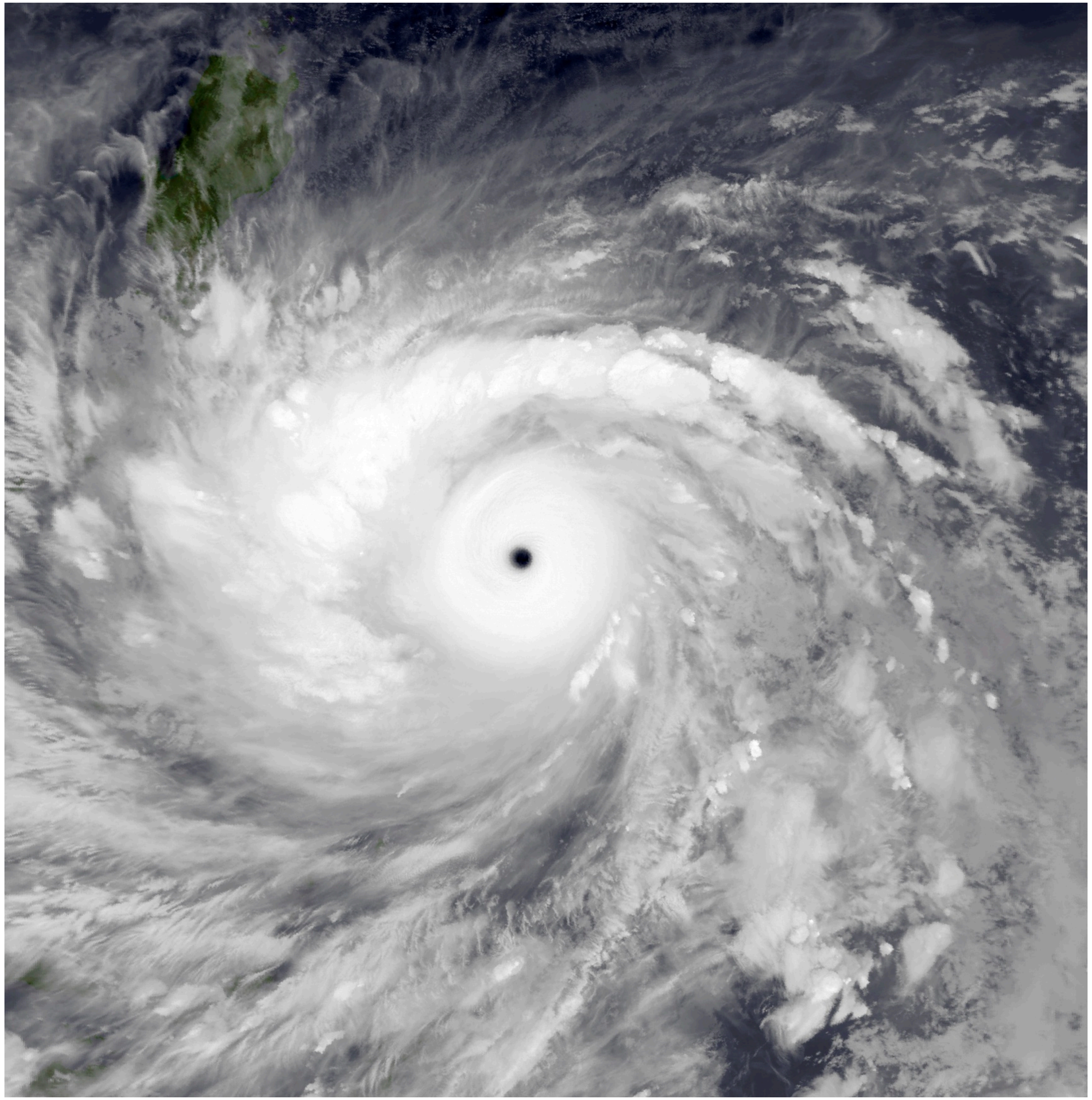
Conservation equation resembles total energy

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

Tropical Cyclones

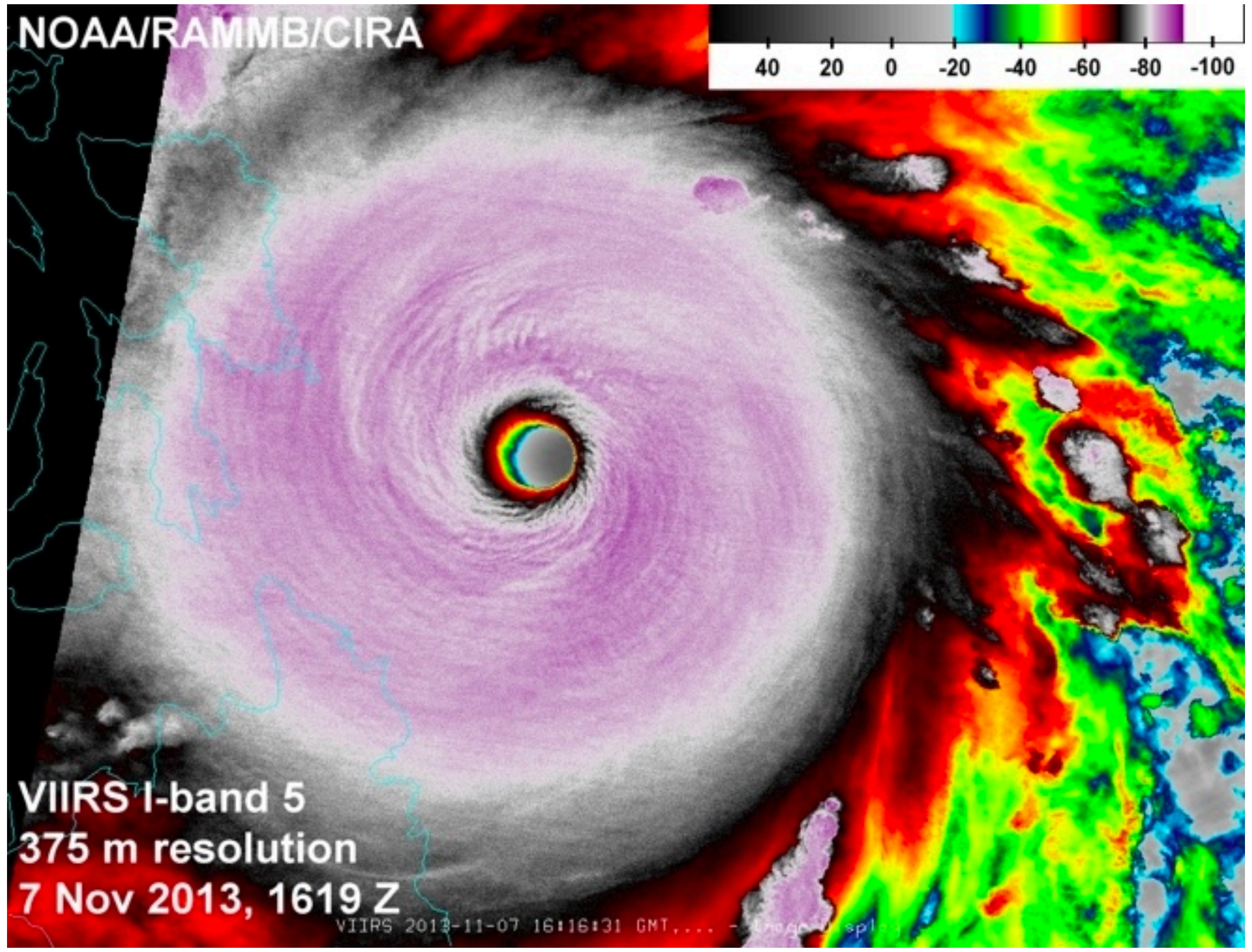
Tropical cyclones

Arguably the most well-known and distinguishable tropical phenomenon.

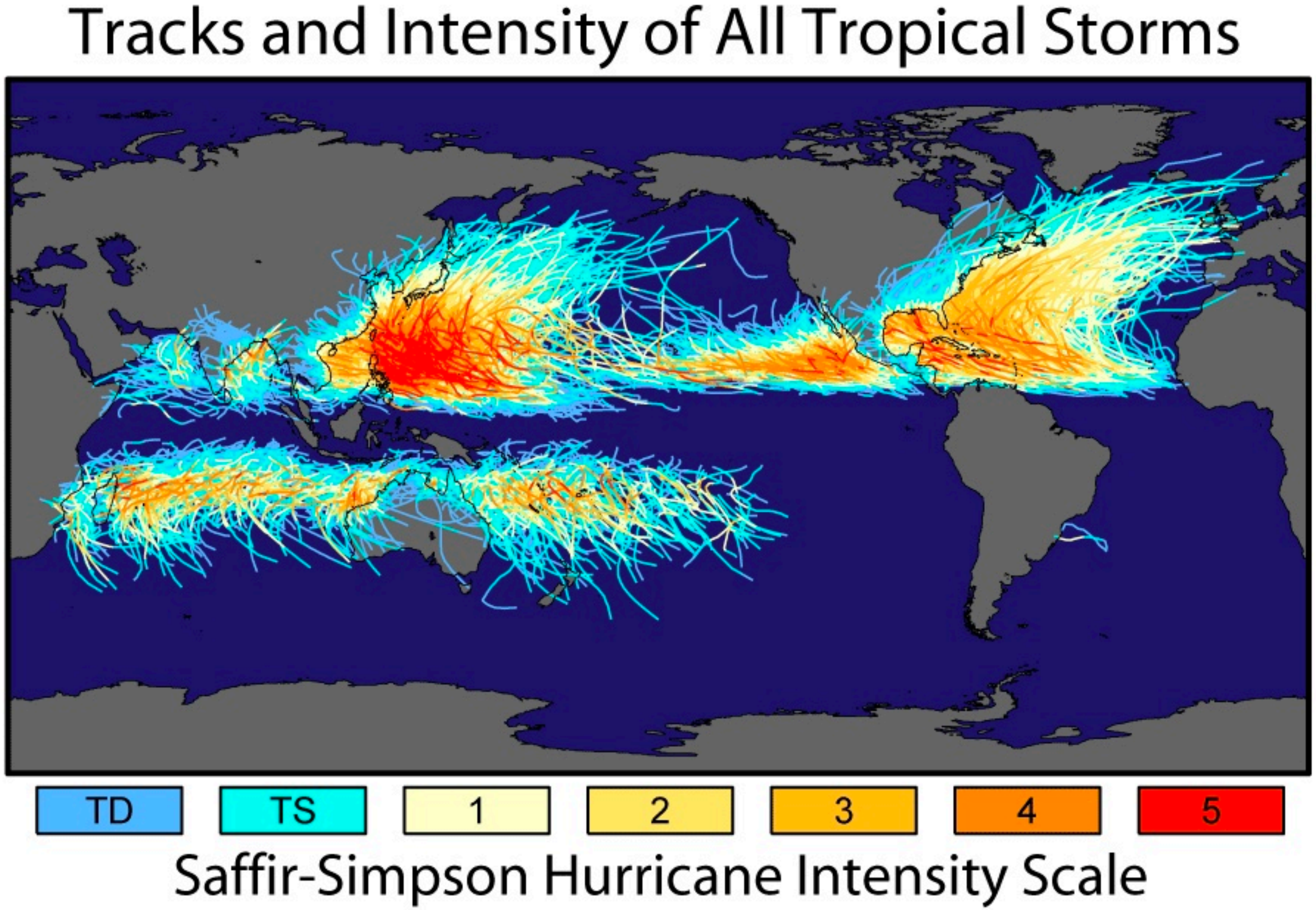


Tropical cyclones

While rare compared to other tropical phenomenon, they account for a large fraction of tropical rainfall.

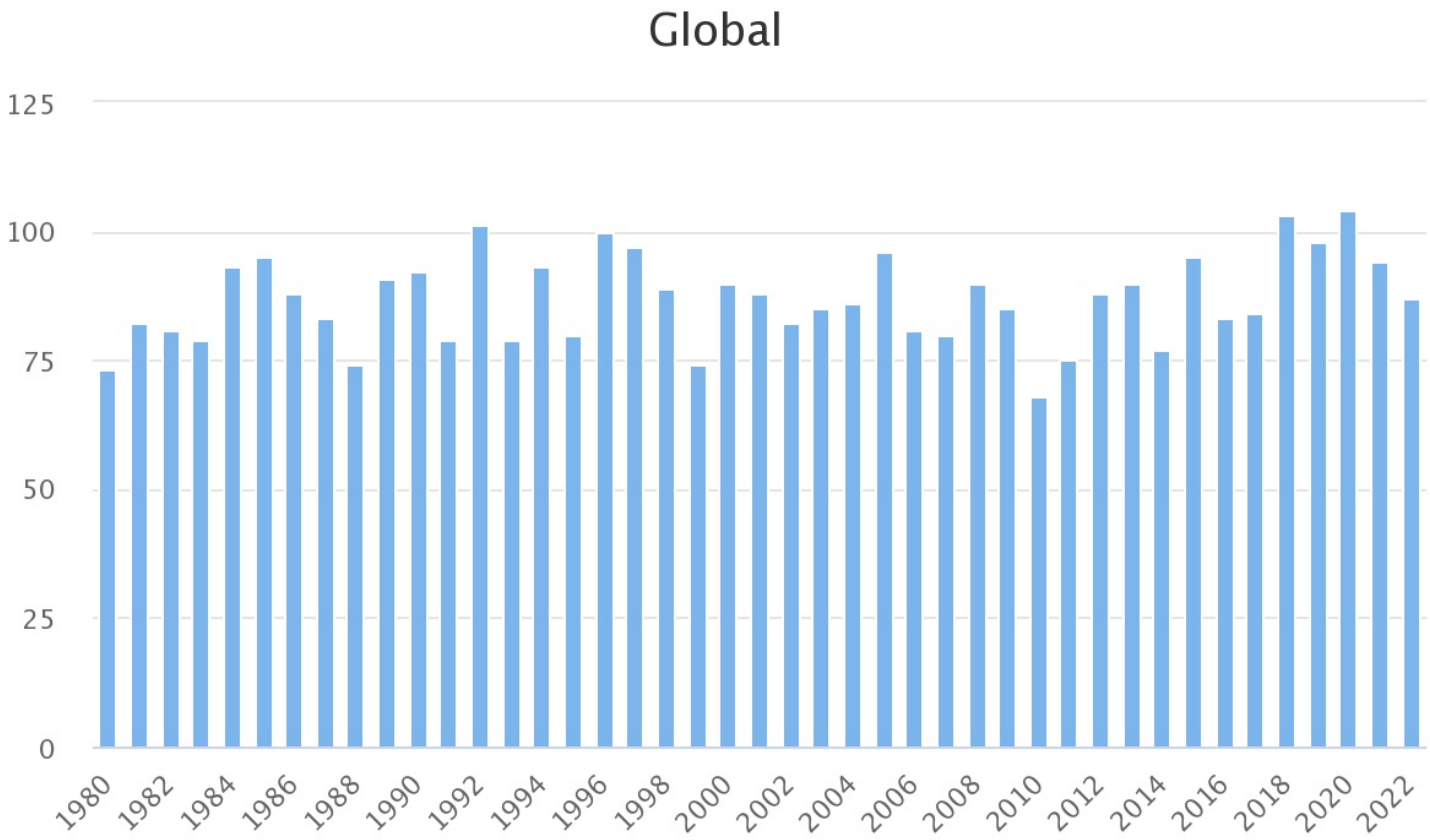


Tropical cyclones



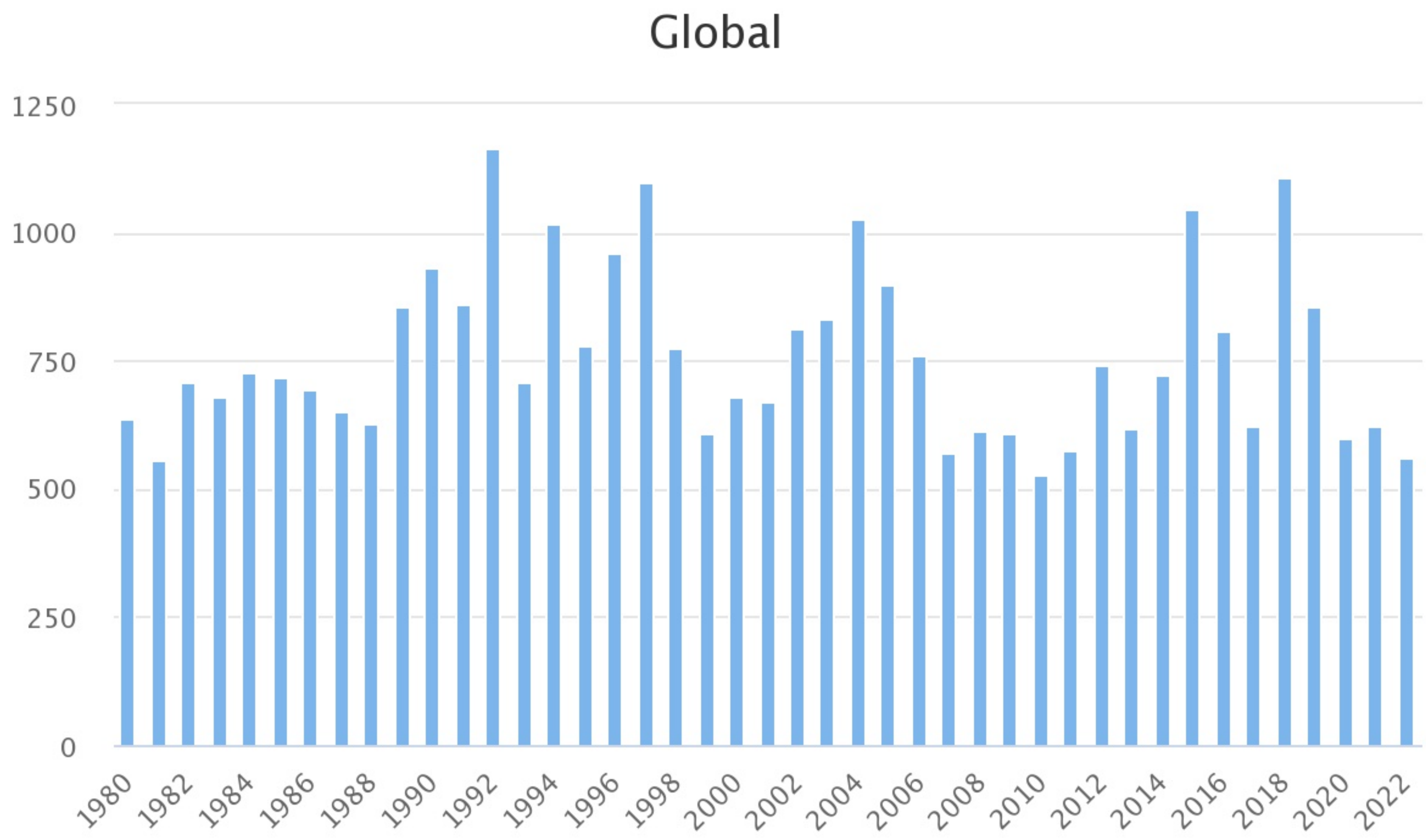
Global number of storms per year

Between 80-100 storms form globally per year. We still don't know why this is the case.

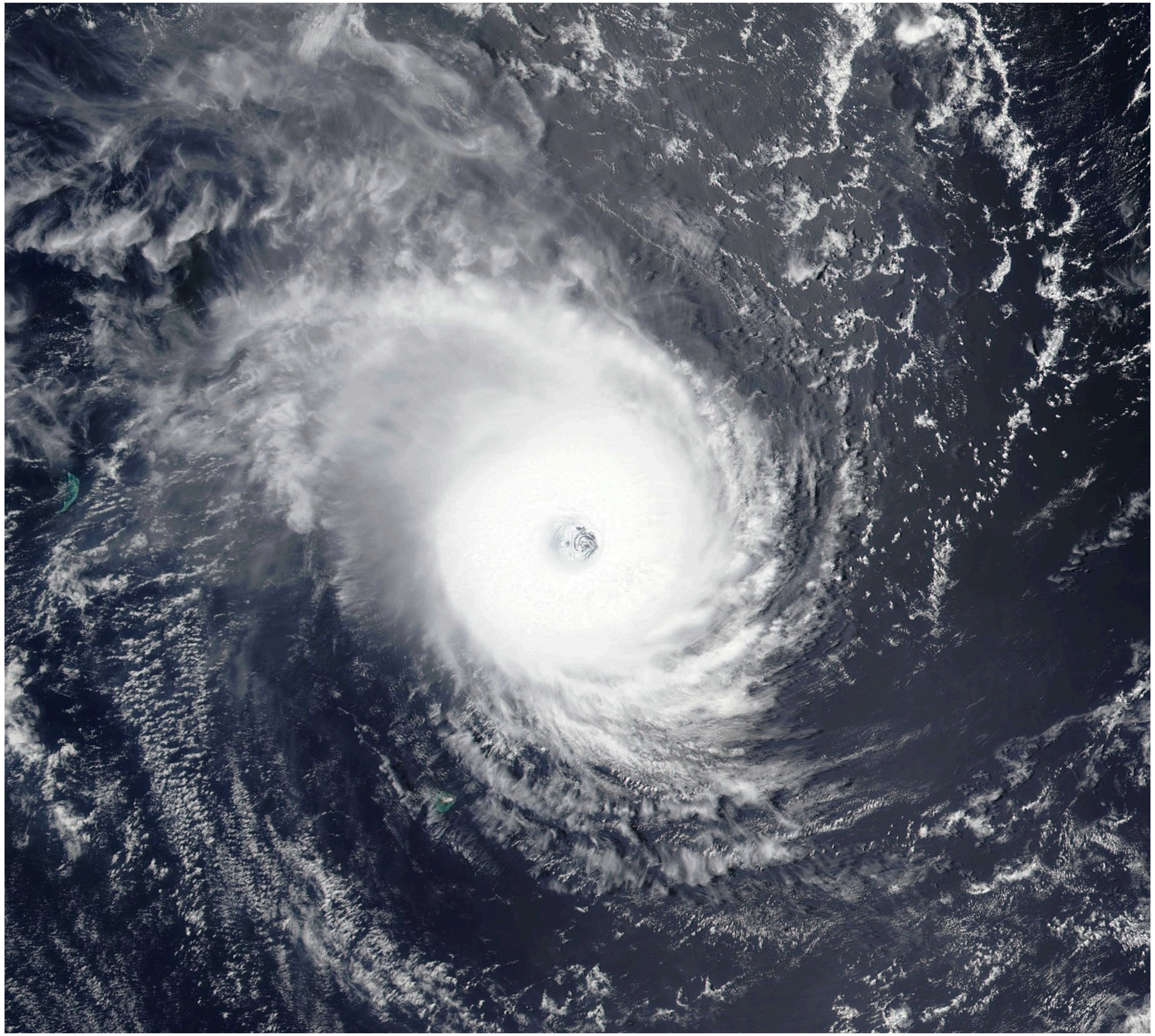


Accumulated Cyclone Energy (ACE)

The amount of TC kinetic energy integrated over a season. The number varies from 500 to 1000×10^4 knots²



ACE



ACE is dominated by a few strong and long-lasting TCs, and this varies a lot by season.

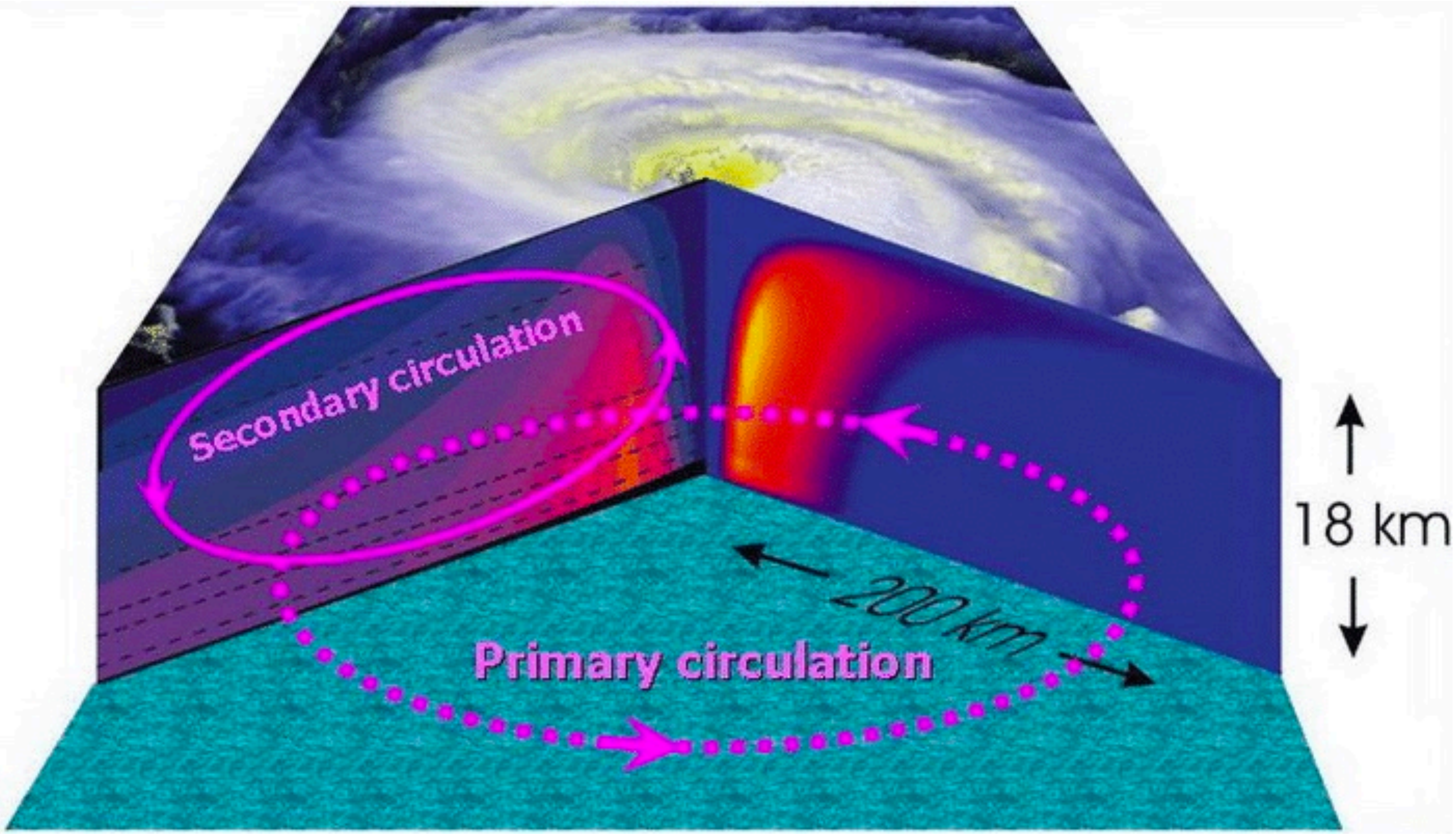
E.g. Cyclone Freddy alone produced 87 units of ACE

TC structure

TCs can be decomposed into two circulations:

1. The **primary** tangential circulation
2. The **secondary** transverse circulation.

While much weaker, the secondary circulation maintains the primary circulation.



Emanuel (2003)

Primary and secondary circulations

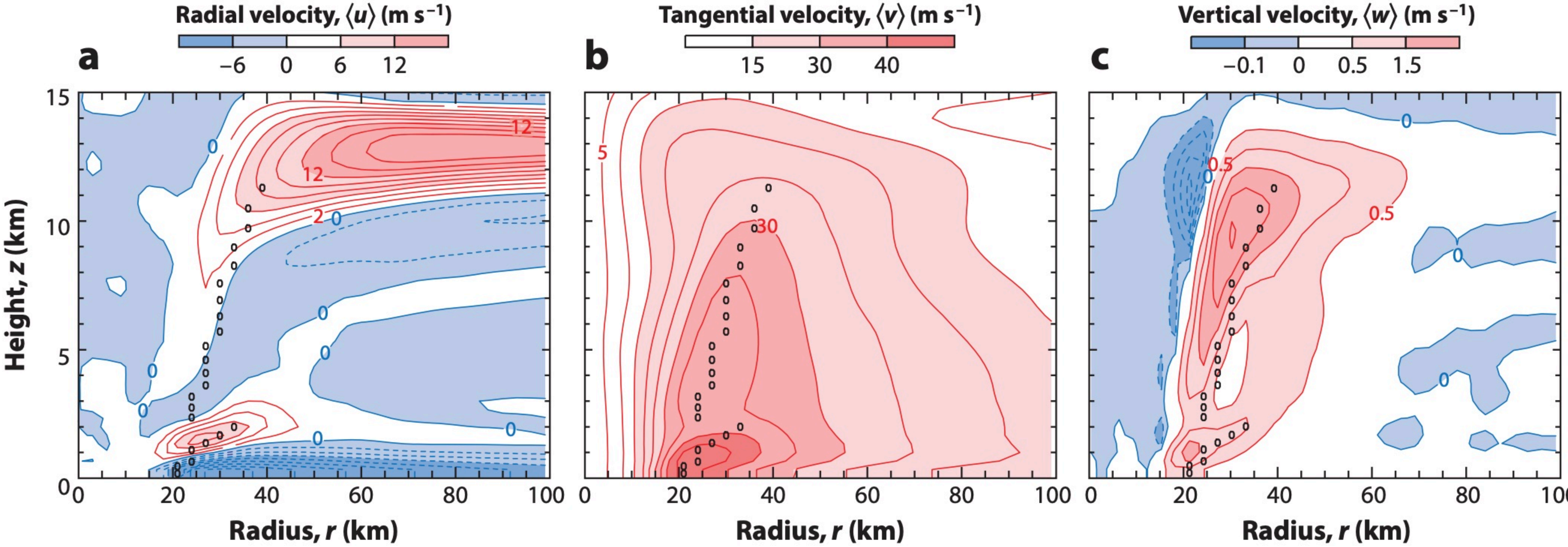
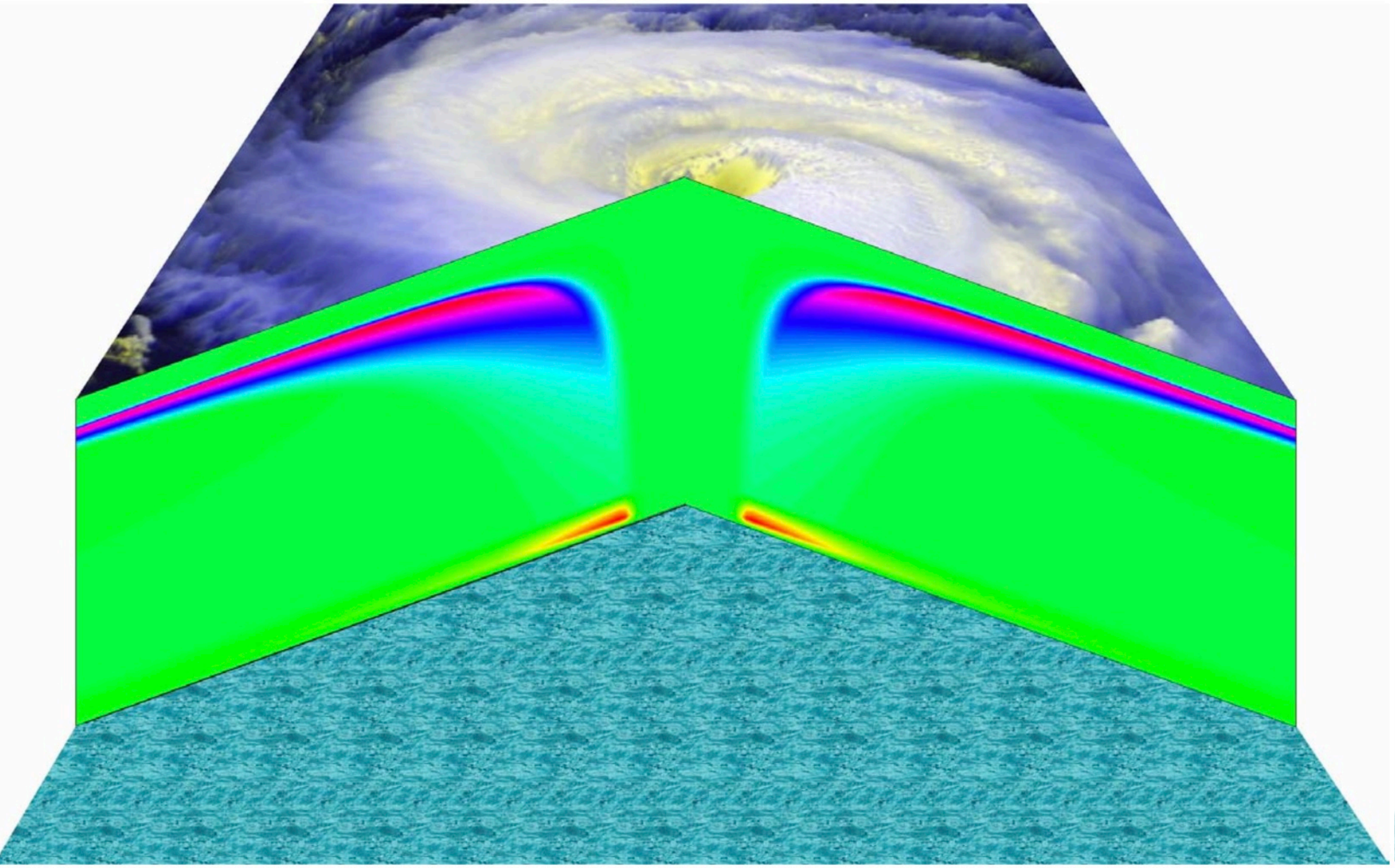


Figure 2

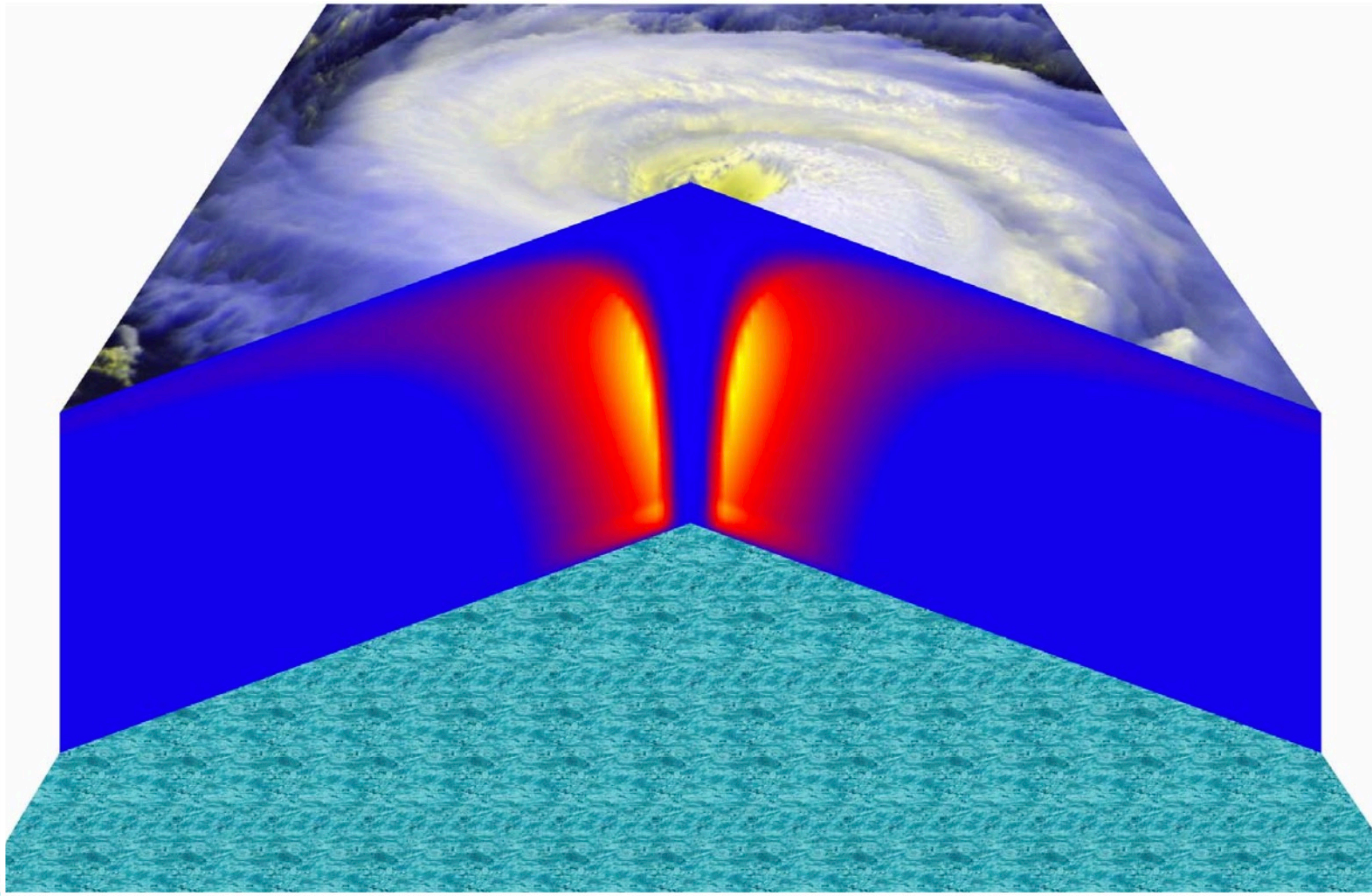
Radius-height cross sections of the azimuthally averaged velocity components in the simulation described by Persing et al. (2013), time averaged during an intensification phase (144–148 h) of the 3D calculation: (*a*) radial velocity (contour interval 2 m s^{-1}), (*b*) tangential velocity (contour interval 5 m s^{-1}), and (*c*) vertical velocity (contour interval 0.5 m s^{-1} for positive values and 0.1 m s^{-1} for negative values). Positive values are represented in red and by solid lines, and negative values are represented in blue and by dashed lines. The black dotted circles in each plot show the location of the maximum tangential wind speed at each height. Figure adapted with permission from Persing et al. (2013).

The secondary circulation

Radial wind



Vertical velocity



TC momentum equations

TCs are best understood in cylindrical coordinates. Two of the three momentum equations are in balance.

Gradient balance

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial r} + \frac{v}{r}\frac{\partial u}{\partial \lambda} + w\frac{\partial u}{\partial z} - \frac{v^2}{r} - fv = -\frac{1}{\rho}\frac{\partial p}{\partial r} + F_r,$$

Radial wind

Centrifugal, Coriolis and PGF

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial r} + \frac{v}{r}\frac{\partial v}{\partial \lambda} + w\frac{\partial v}{\partial z} + \frac{uv}{r} + fu = -\frac{1}{\rho r}\frac{\partial p}{\partial \lambda} + F_\lambda,$$

Tangential wind

Hydrostatic balance

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial r} + \frac{v}{r}\frac{\partial w}{\partial \lambda} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g + F_z,$$

Vertical wind

Gradient Balance

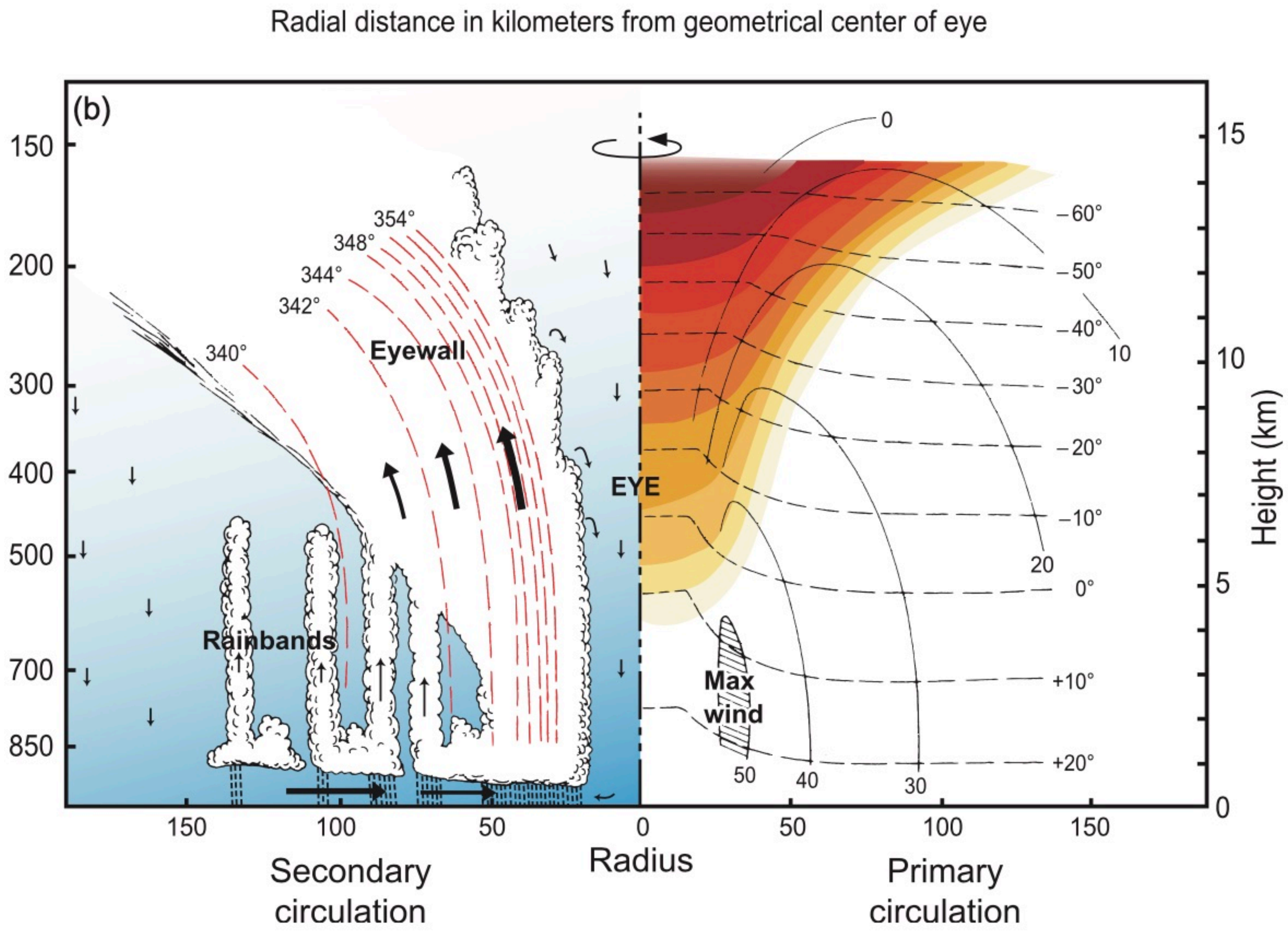
The tangential circulation is in gradient balance:

$$\frac{v^2}{r} + fv = \frac{\partial \Phi}{\partial r}$$

Using hydrostatic balance we can obtain the TC thermal wind:

$$\left(\frac{2v}{r} + f\right)\frac{\partial v}{\partial p} = -\frac{R_d}{p}\frac{\partial T}{\partial r}$$

Plugging some reasonable numbers yields $\delta T \sim 6K$. Hurricanes are major departures from WTG balance.



Houze (2014)