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Symmetric instability in cross equatorial western boundary currents

http://earth.nullshcool.net

The global conveyor

Interactions between the sub-mesoscale and global scale circulations

- Northward flowing surface current
- Southward flowing deep western boundary current
- **Global scale** current, drives cross-equatorial flow
- Can *sub-mesoscale* instability at the equator lead to a bottleneck?

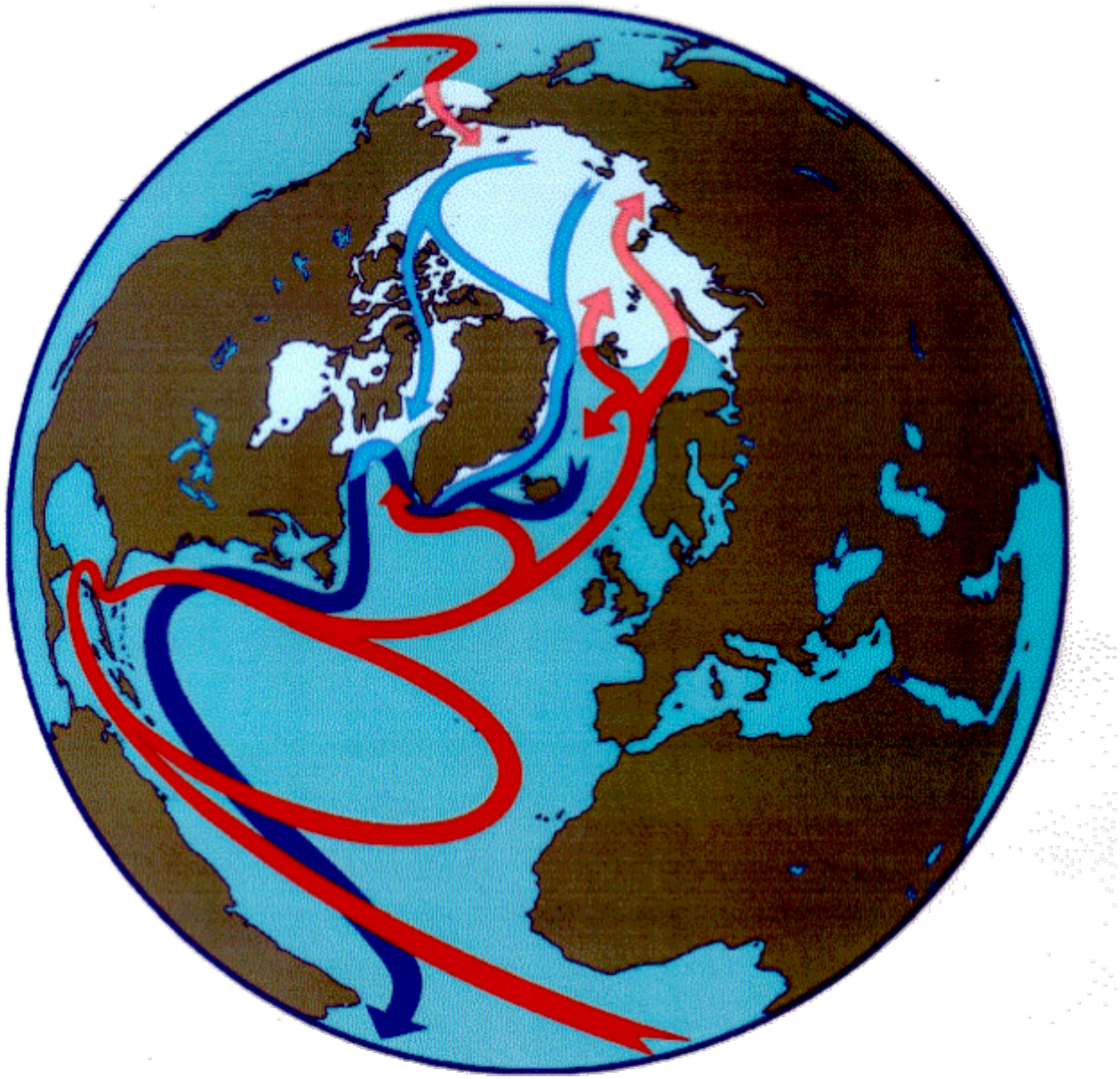
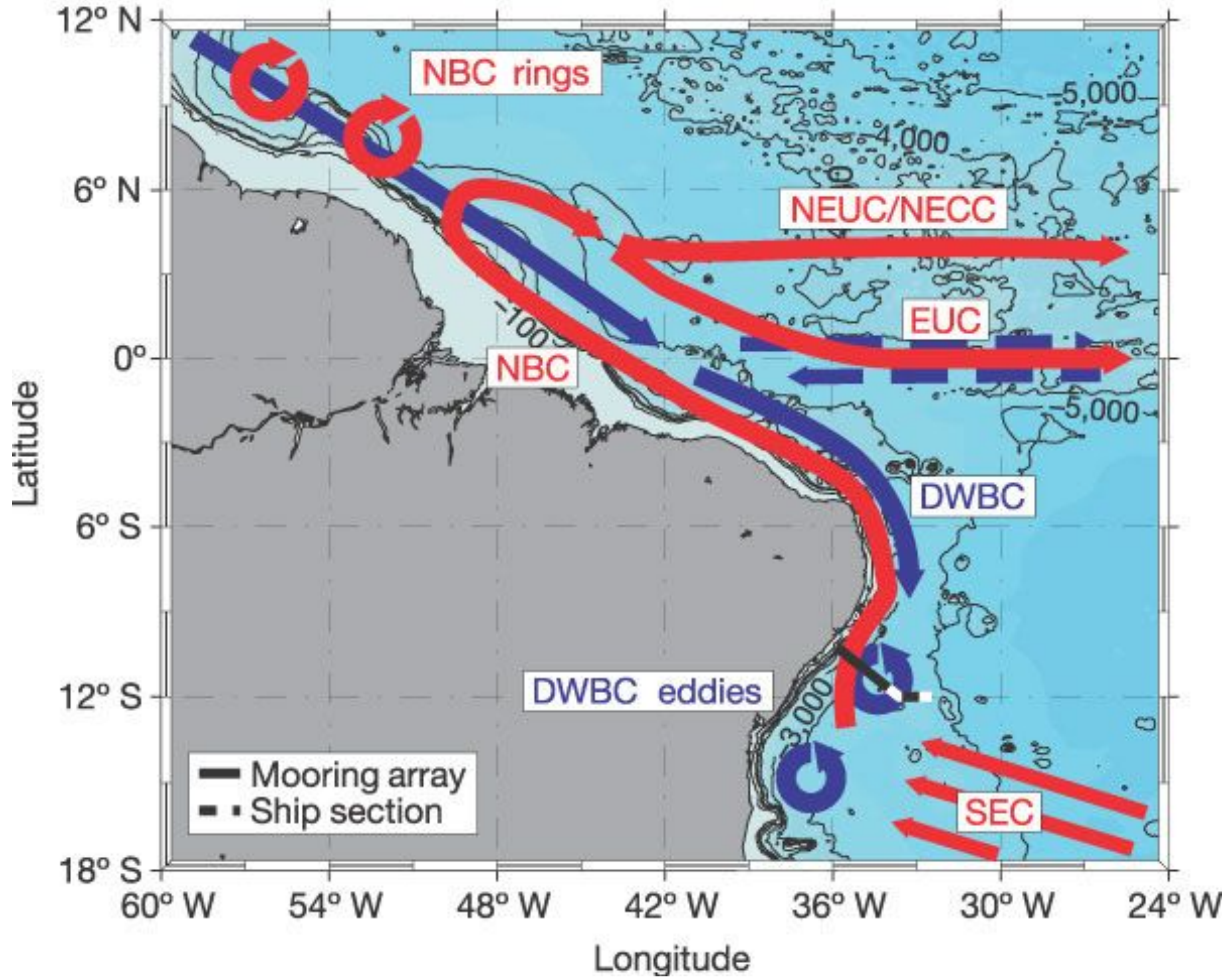


Image credit: Greg Holloway, Dan Wright

Tropical circulations

- Northward flowing surface currents
  - North Brazil Current & rings
  - Equatorial Counter Current
- Southward flowing deep western boundary current



Dengler et al. (2004)

Potential vorticity

And a necessary condition for symmetric instability

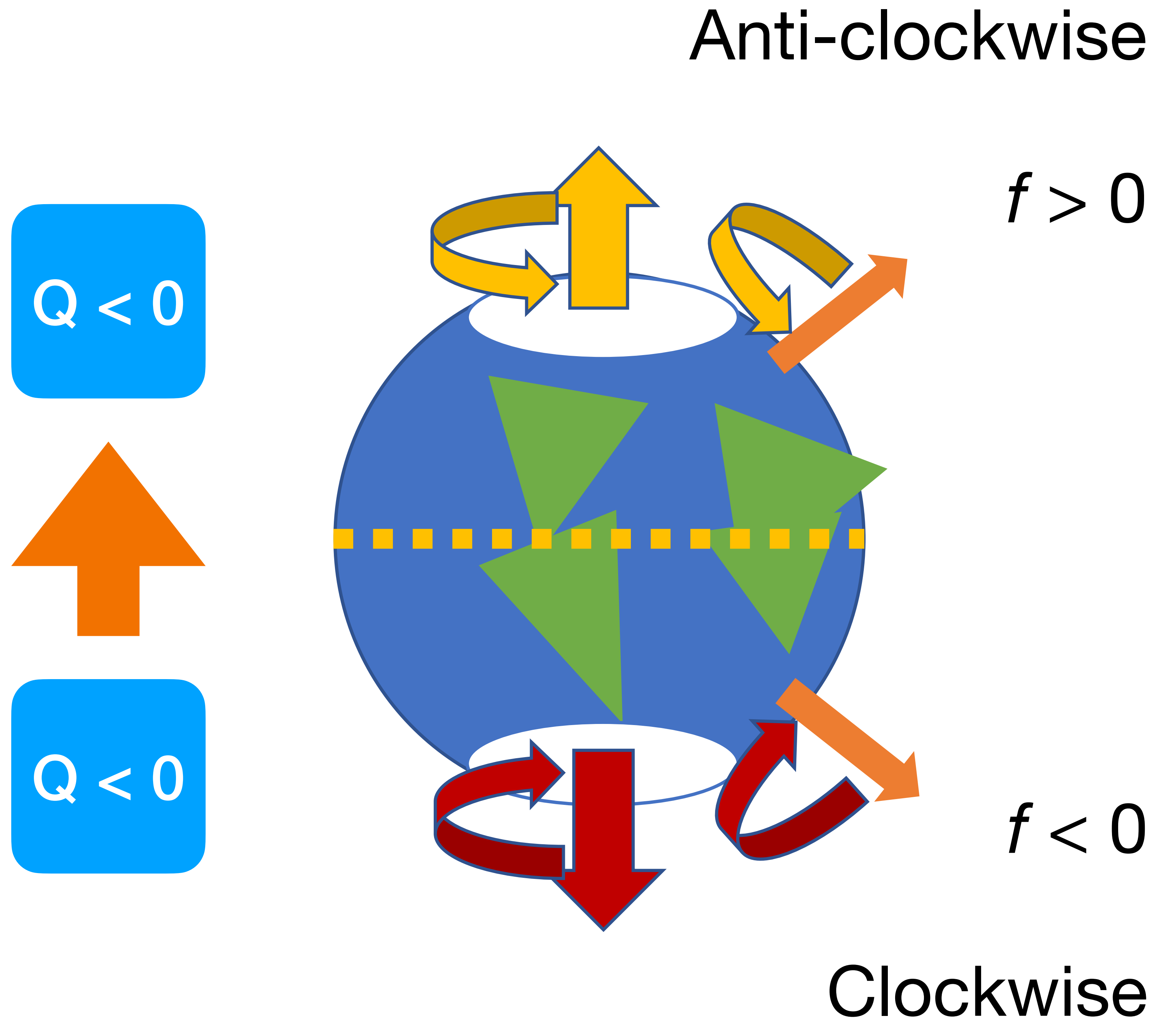
- PV is materially conserved:

Planetary — Stretching/baroclinicity

$$Q = (\mathbf{f} + \nabla \times \mathbf{u}) \cdot \nabla b$$

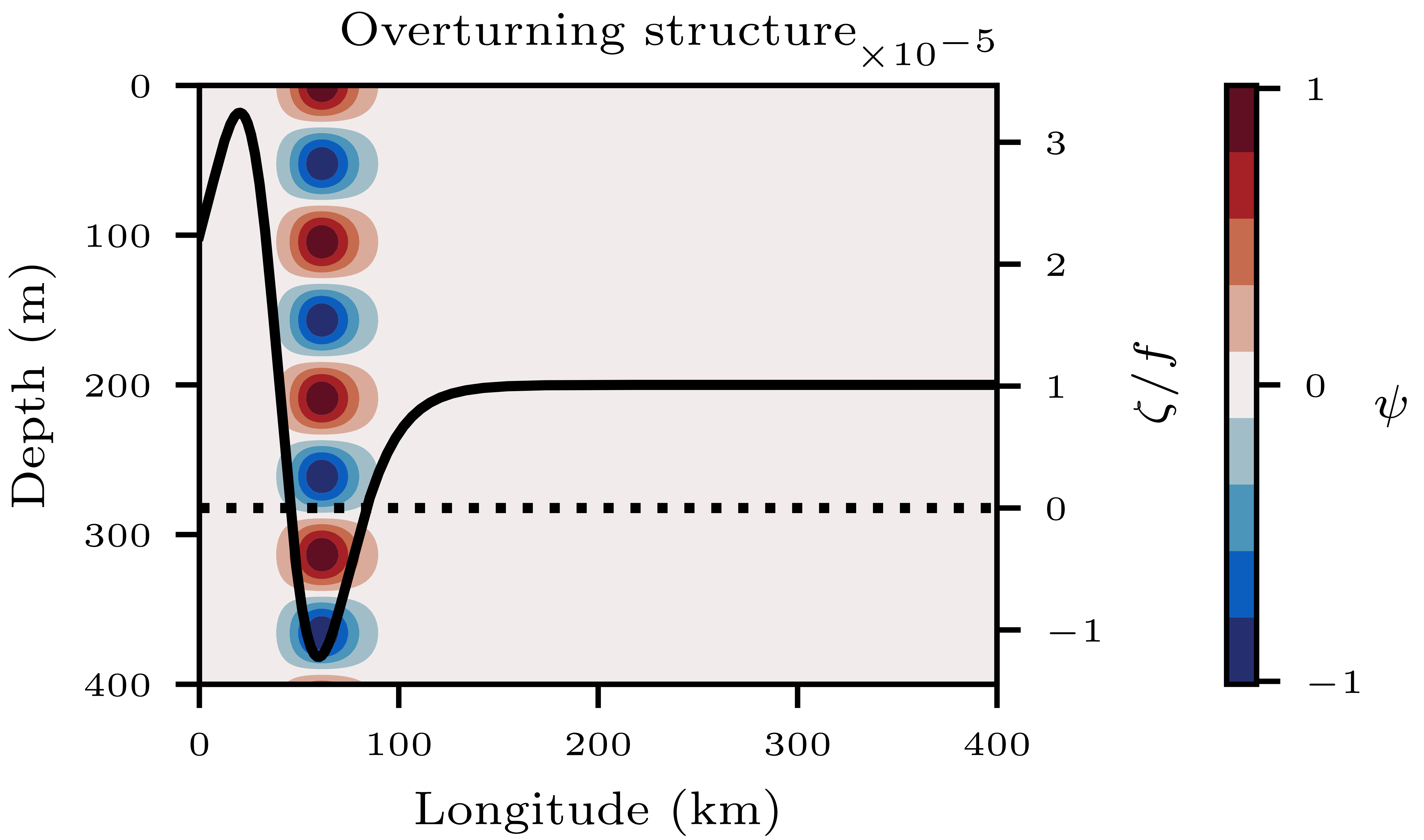
Relative

- SI if $fQ < 0$
  - If initially stable in SH, not stable in NH
- Growth rate $\sigma^2 \approx -f(f + dV/dx)$
  - Need large horizontal shear



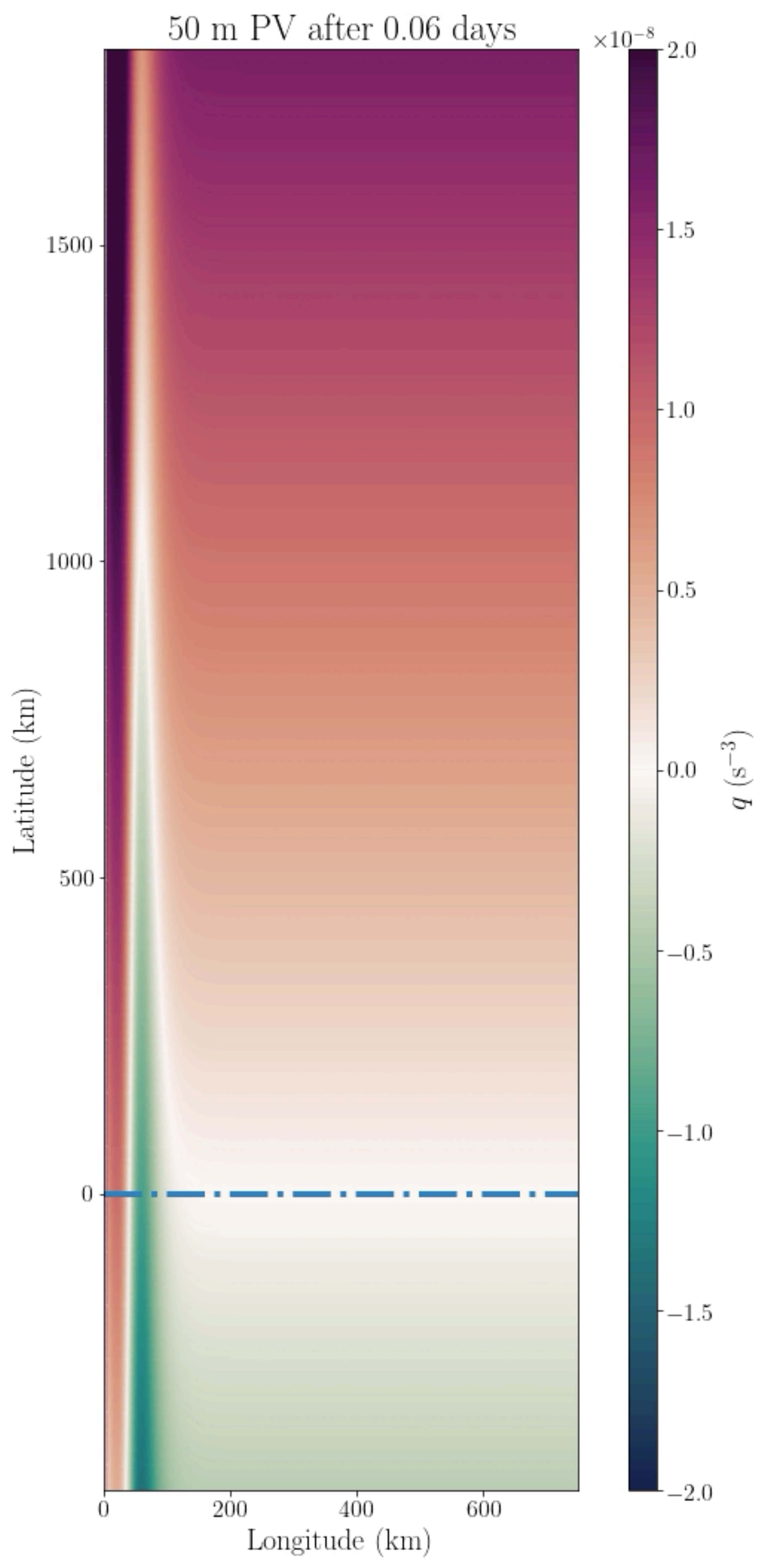
What does symmetric instability look like?

- Predictions from a linear stability analysis
- Stacked overturning cells
- Localised in regions of negative PV
- Could be an important mixing mechanism



An idealised model

- Simplifications made:
  - Brazil is a straight line
  - No topography
  - Open boundaries (sponged)
- Unstable regions have negative PV in the northern hemisphere

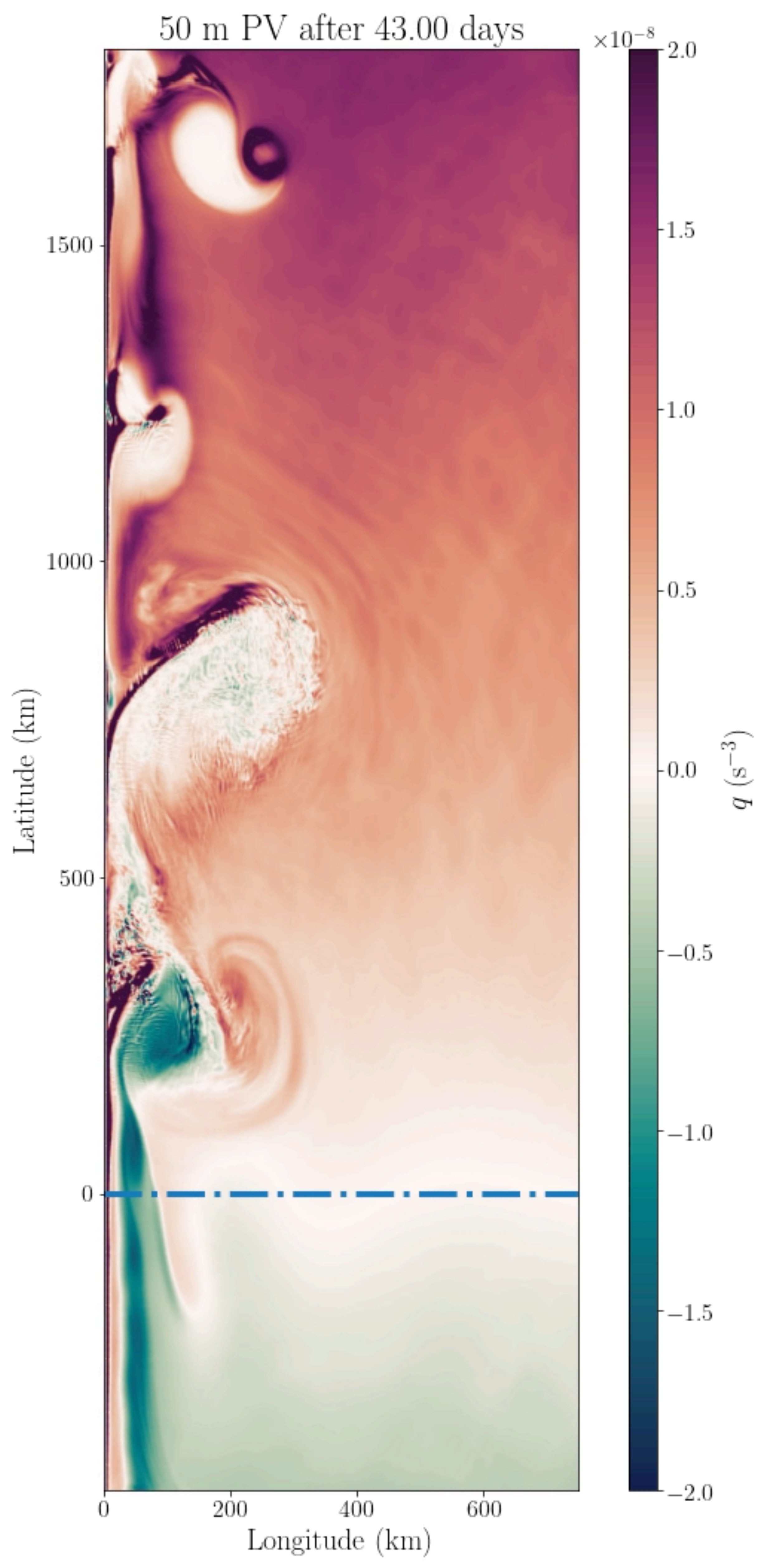


An idealised model

Two types of instability

- PV at 50 m
- What's going on?

    1. Eddy field develops as fluid crosses the equator — e.g. Edwards & Pedlosky, 1998; Goes et al. 2009.



An idealised model

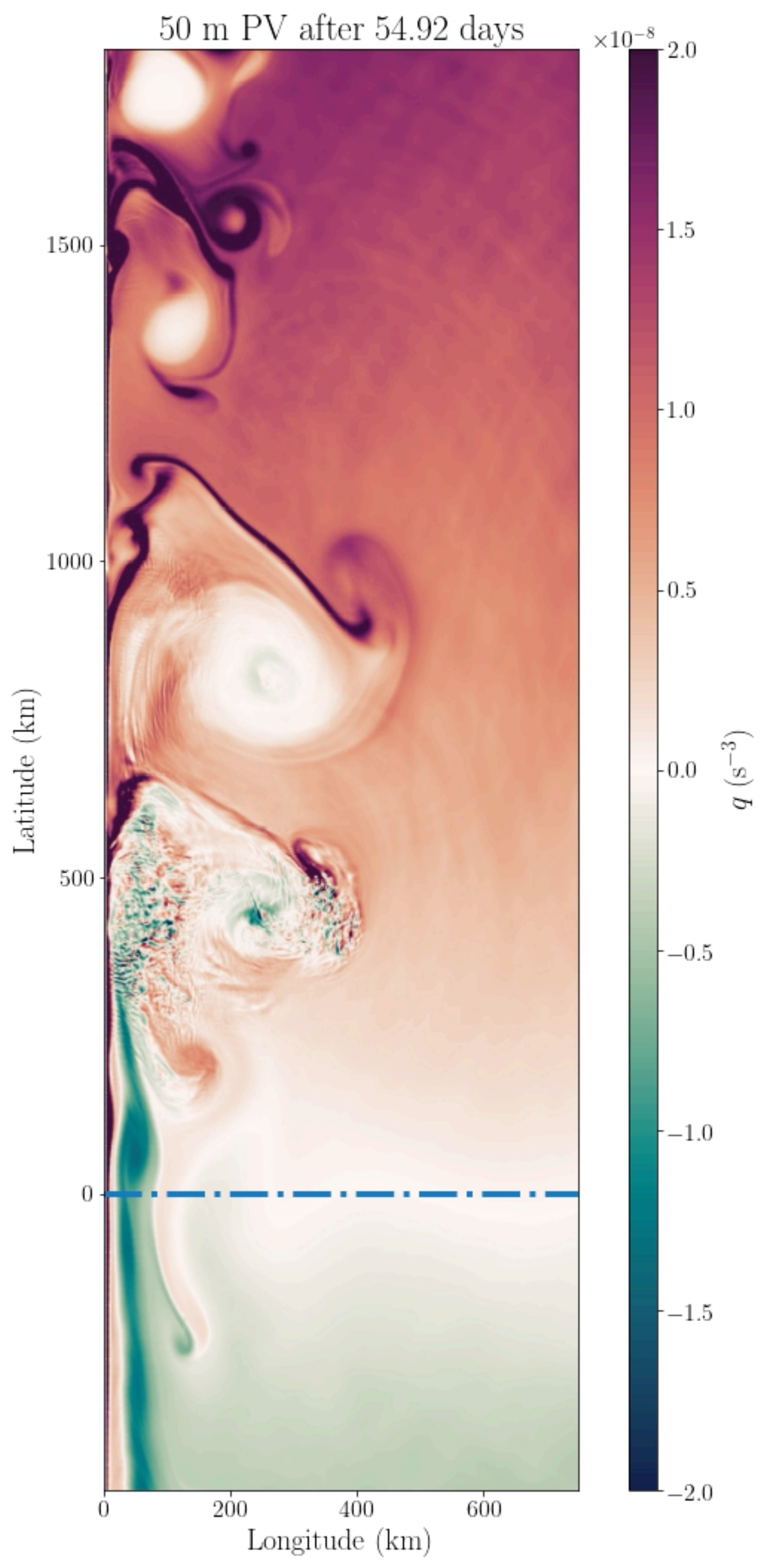
Two types of instability

- PV at 50 m

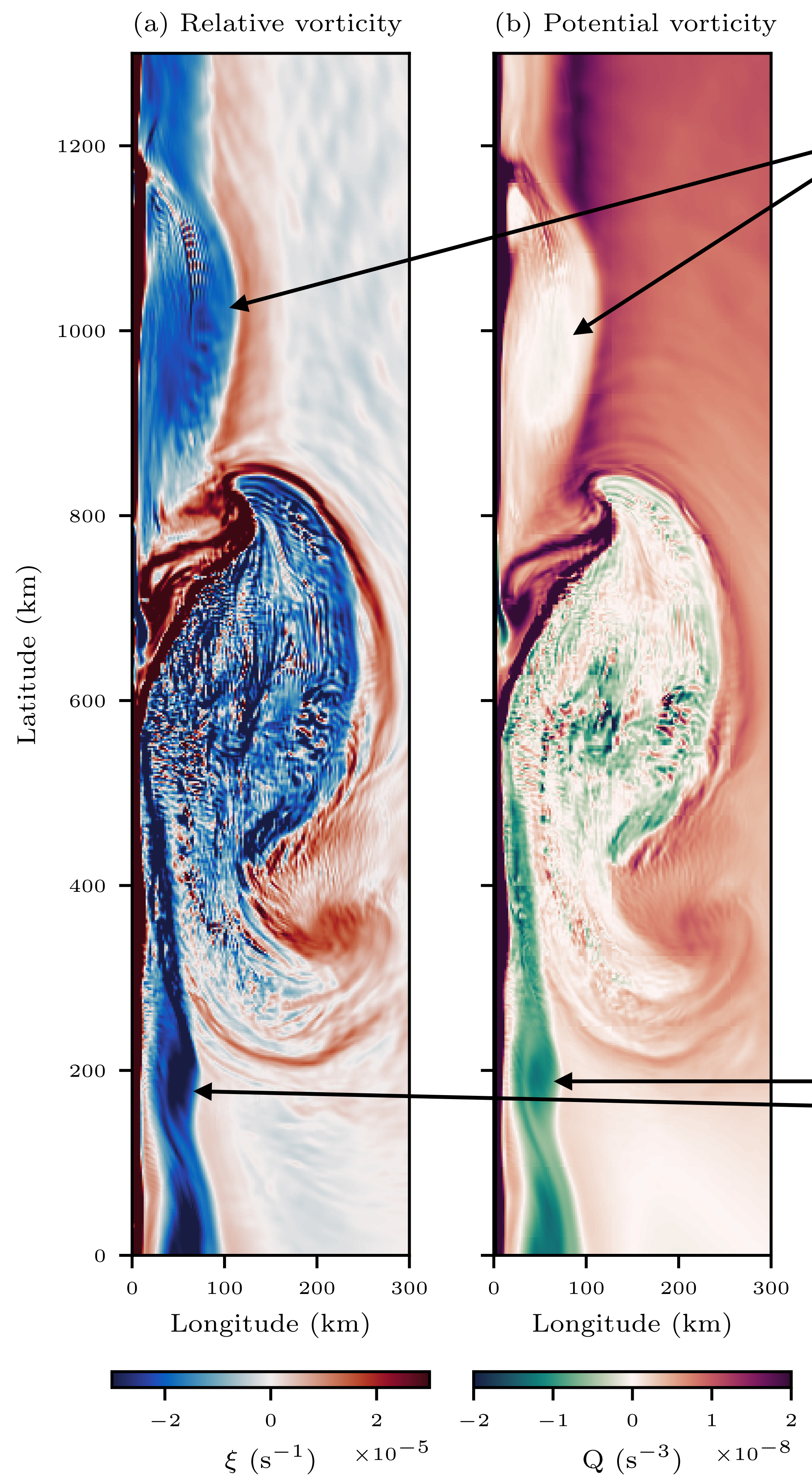
- What's going on?

  1. Eddy field develops as fluid crosses the equator — e.g. Edwards & Pedlosky, 1998; Goes et al. 2009.

  2. SI is excited from 300 km North of the equator.



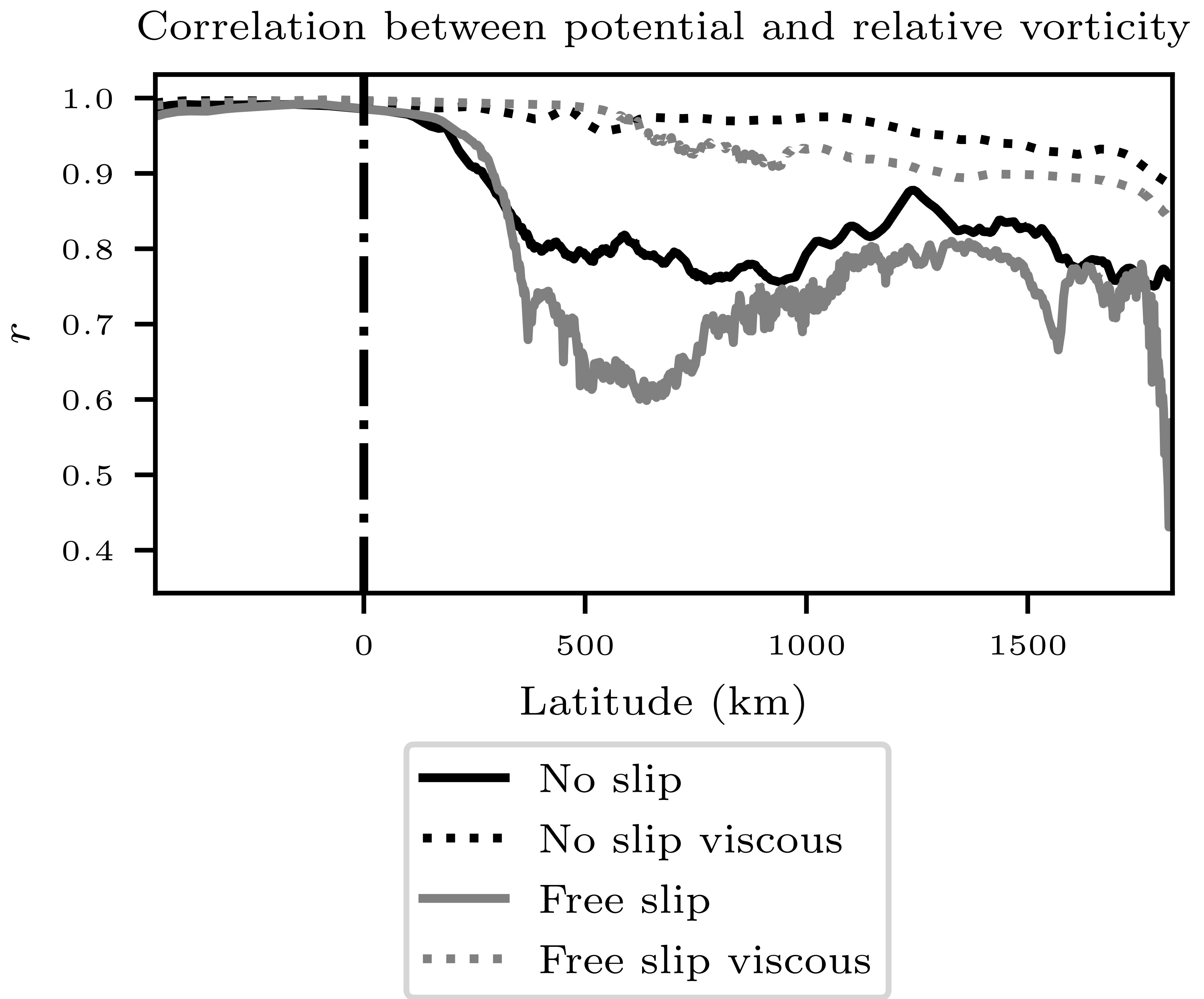
PV and relative vorticity



Sign of RV and PV uncorrelated ⟹ planetary vorticity dominates

Symmetric instability alters the PV balance

Sign of RV and PV match ⟹ relative vorticity dominates



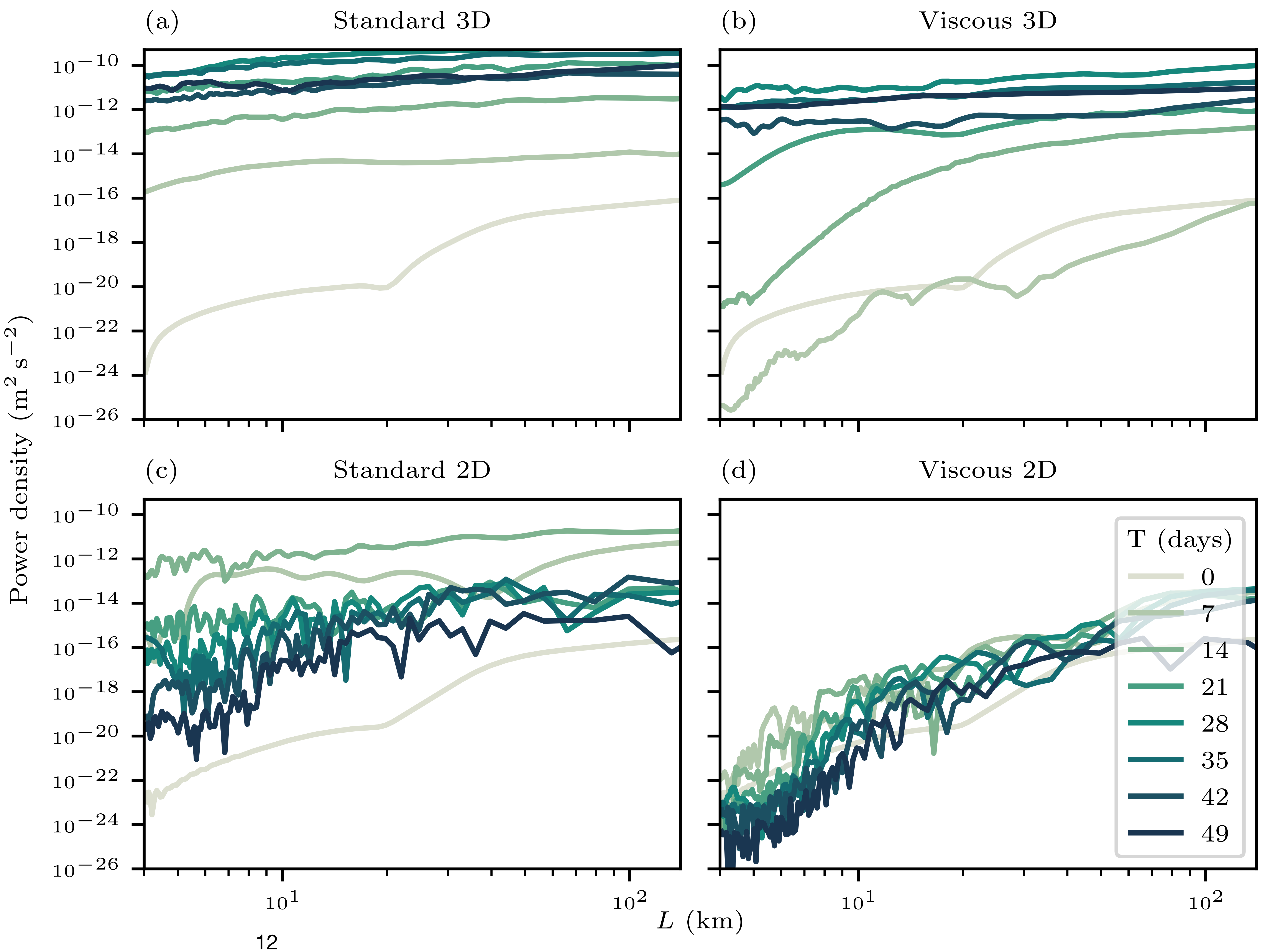
Conclusions

- From theoretical considerations we might expect to observe symmetric instability in cross-equatorial flows.
- Symmetric instability has been observed in an idealised model of cross-equatorial western boundary currents.
- We can see the effects of the instability on:
  - potential vorticity of eddy cores
  - correlations between potential and relative vorticity
- Next steps:
  - Deep western boundary currents
  - LLC4320 model
  - Existing glider datasets?
- For more details see Goldsworth et al. (2021), *Journal of Physical Oceanography* (early online release)

Supplementary slides

Instability & power spectra

- Spatially Fourier transform $w^2/2$ at 50 m
- Plot at week long intervals
- SI causes flattening and lifting of the spectra
- See also Yankovsky & Legg (2019)

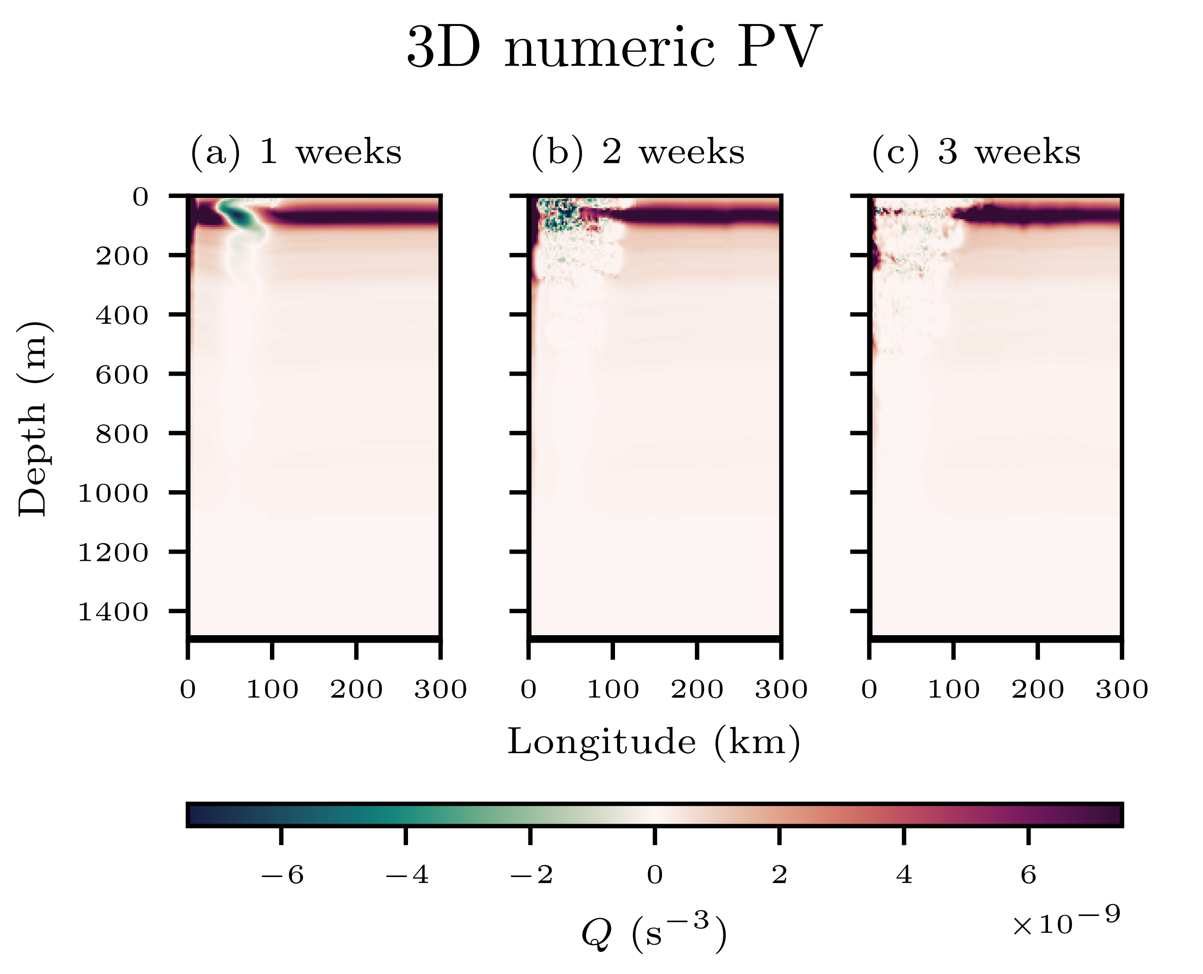


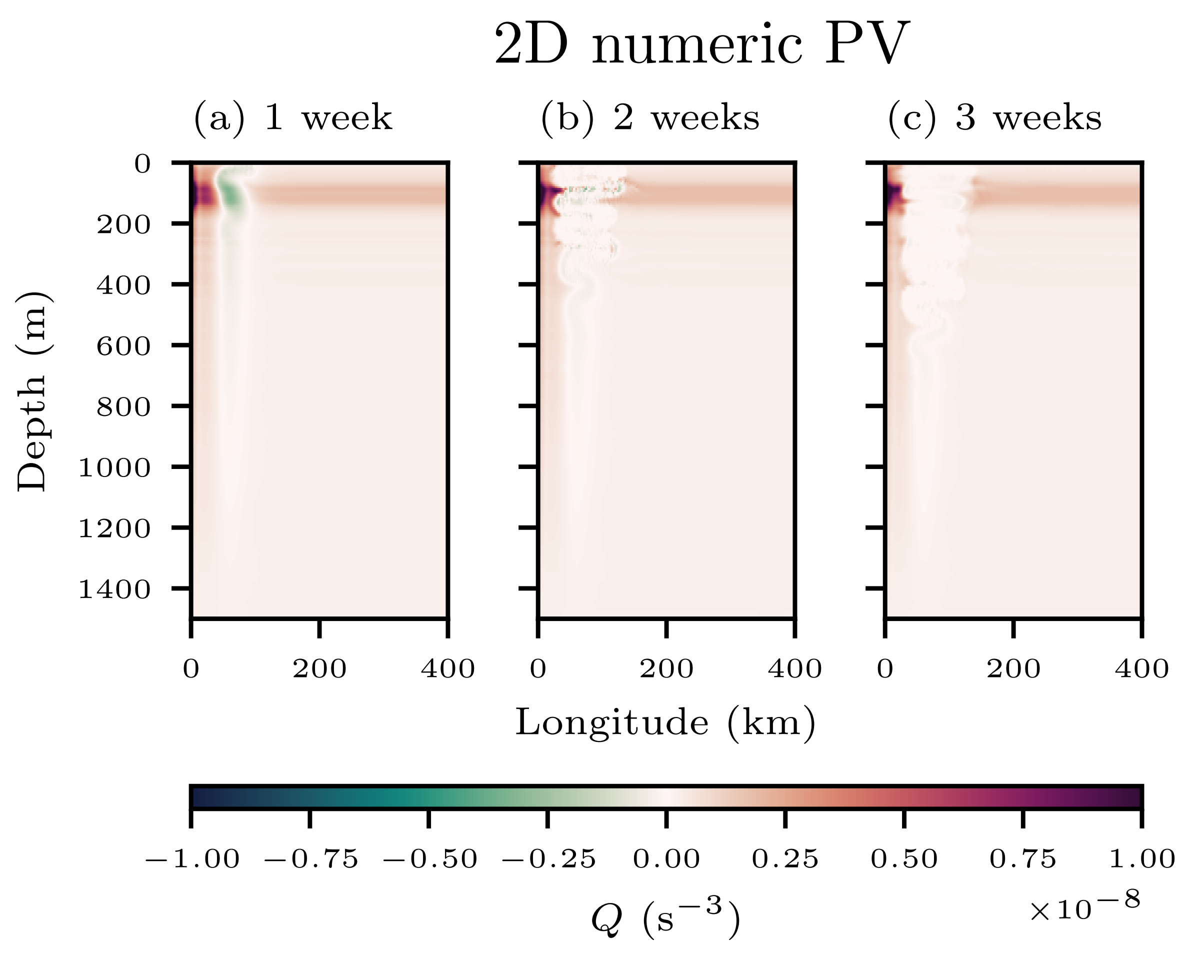
Evidential summary

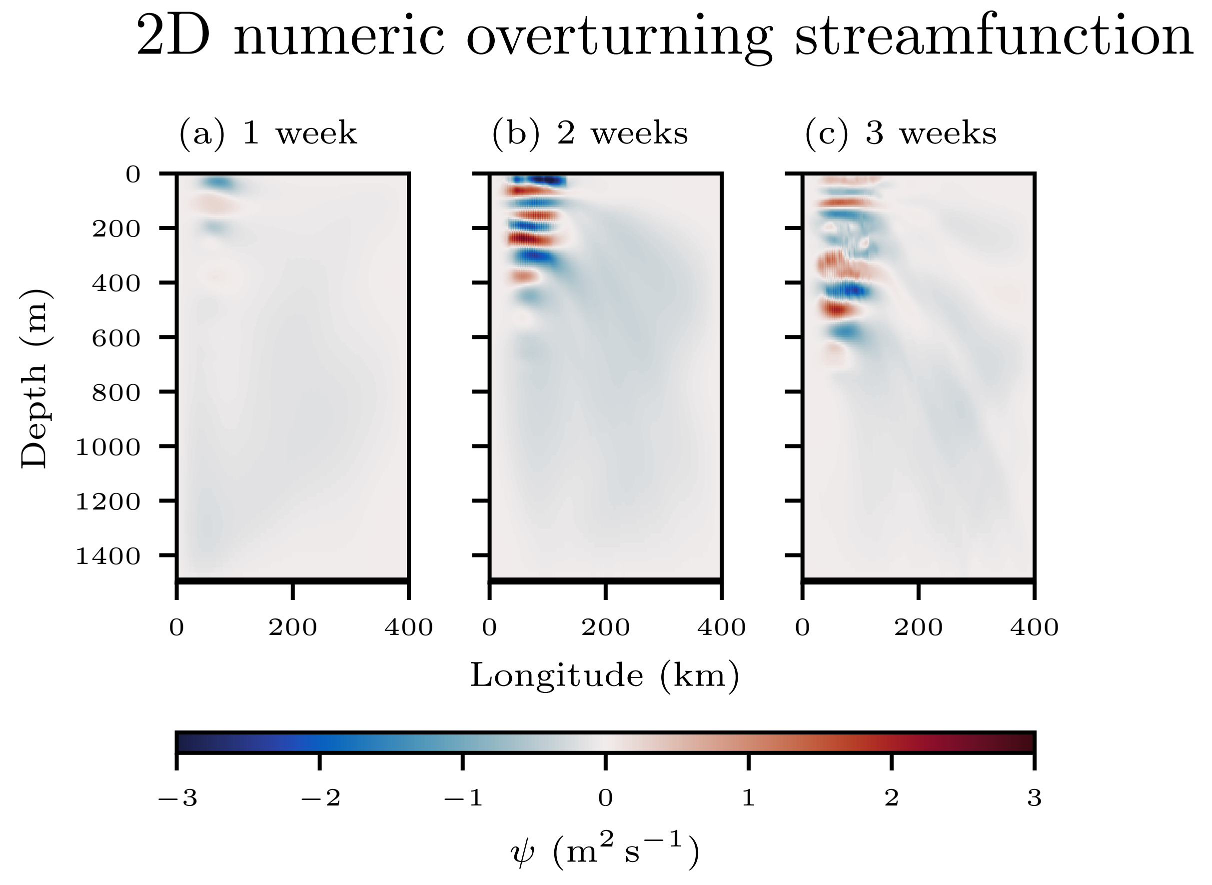
1. Regions of negative PV are unstable
2. Vertical scale
3. Horizontal scale
4. Time scale
5. Viscosity dependence
6. Structure of overturning
7. General agreement between linear stability analysis, simplified two dimensional models and 3 dimensional models
8. Power spectra of the vertical KE
9. Correlations between PV and relative vorticity

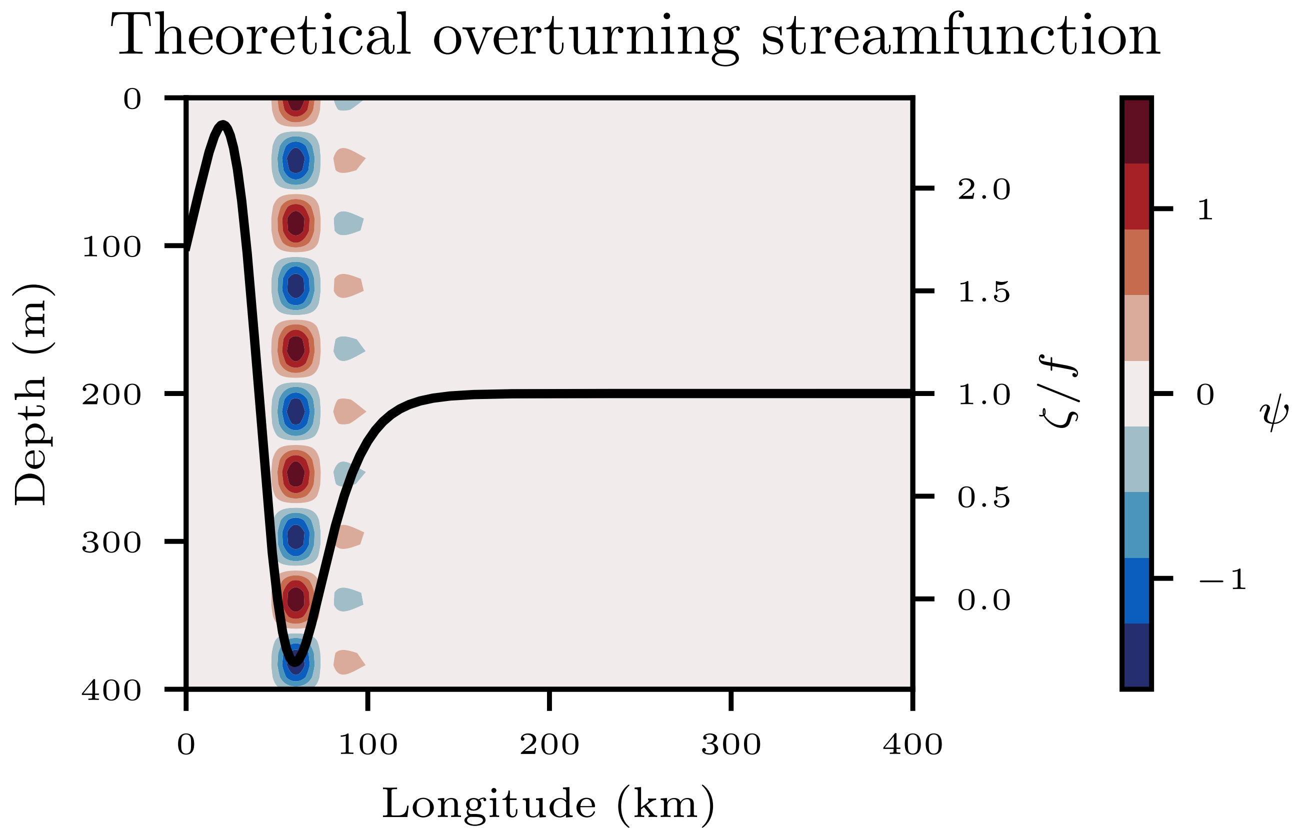
Why symmetric instability?

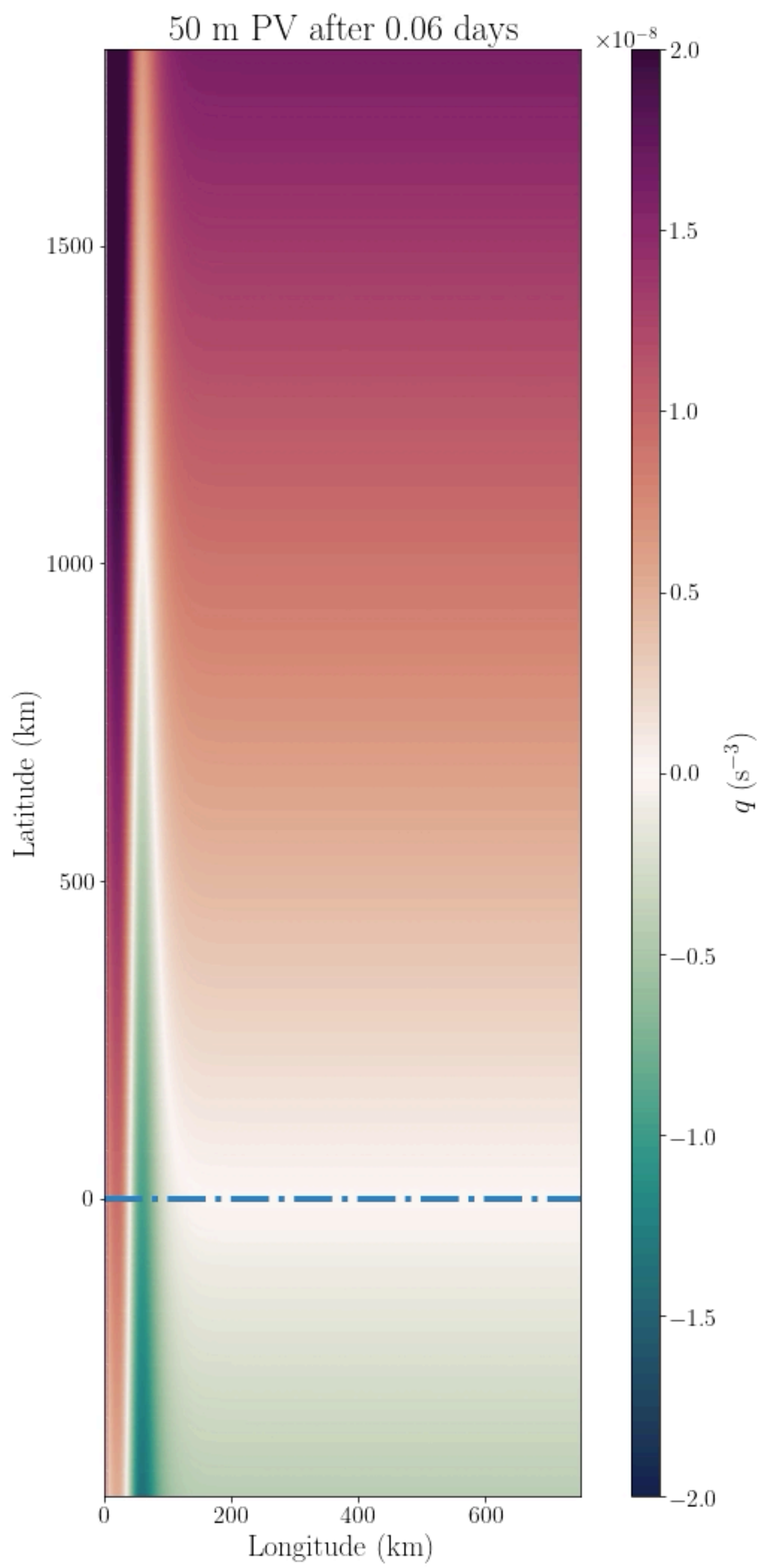
Predictions from a hierarchy of models







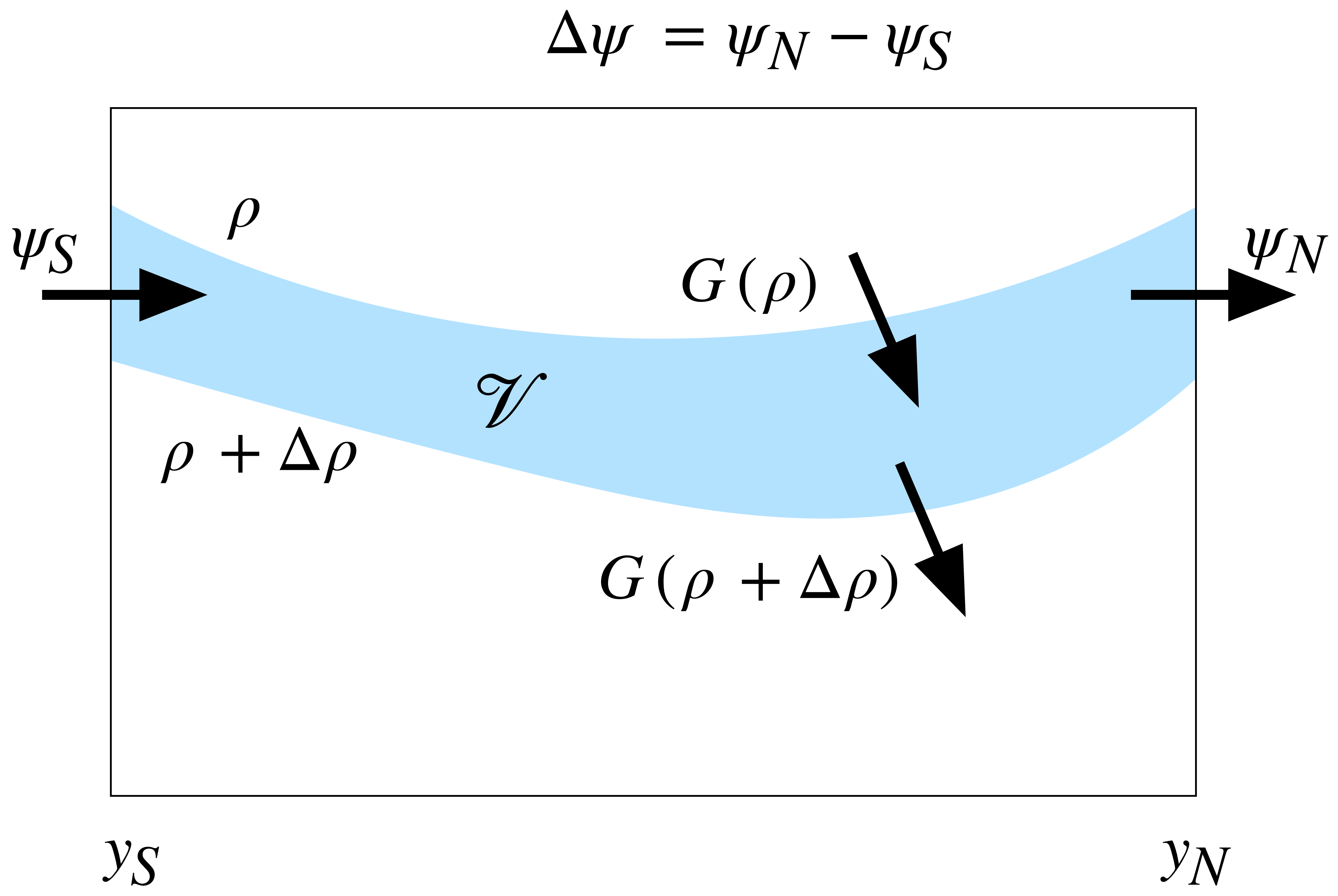




Water mass formation

The Wallin framework

$$F = \frac{\partial \mathscr{V}}{\partial t} + \Delta\psi = G(\rho) - G(\rho + \Delta\rho)$$



Water mass formation

The Wallin framework