Turbulence et circulation méridionale océanique

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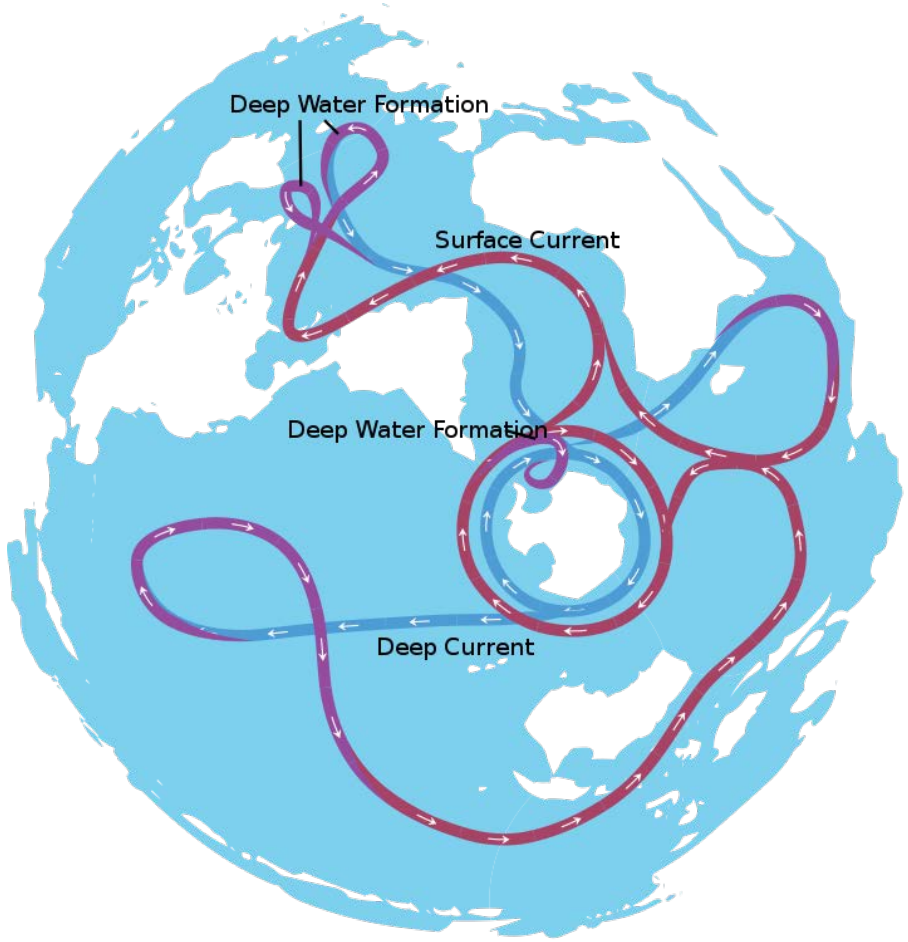
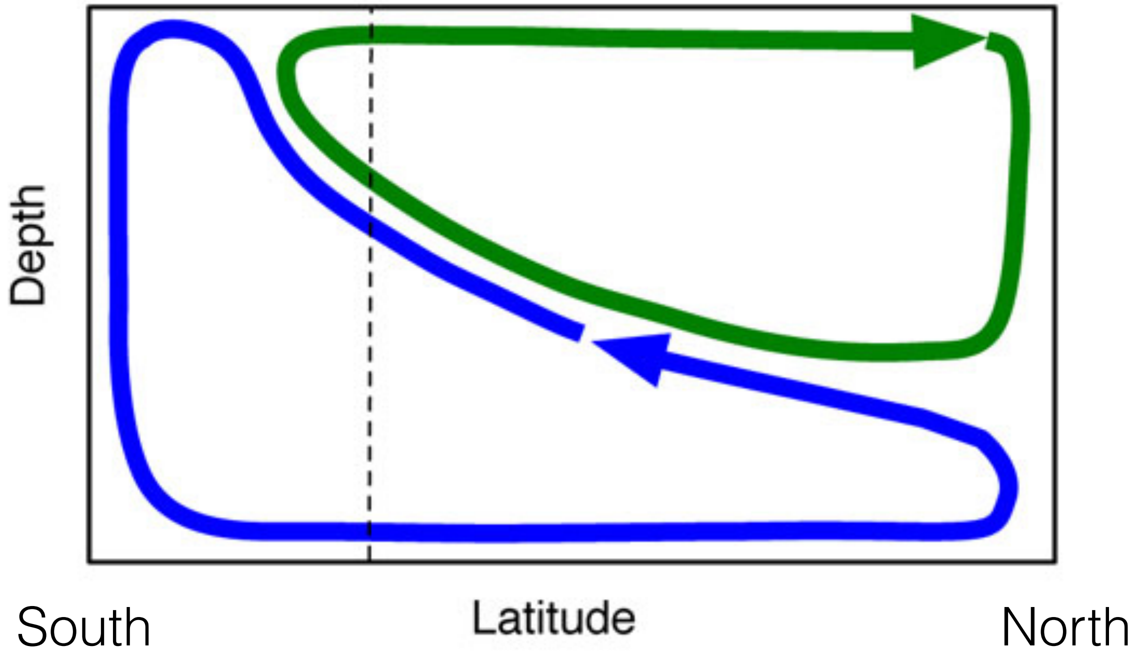
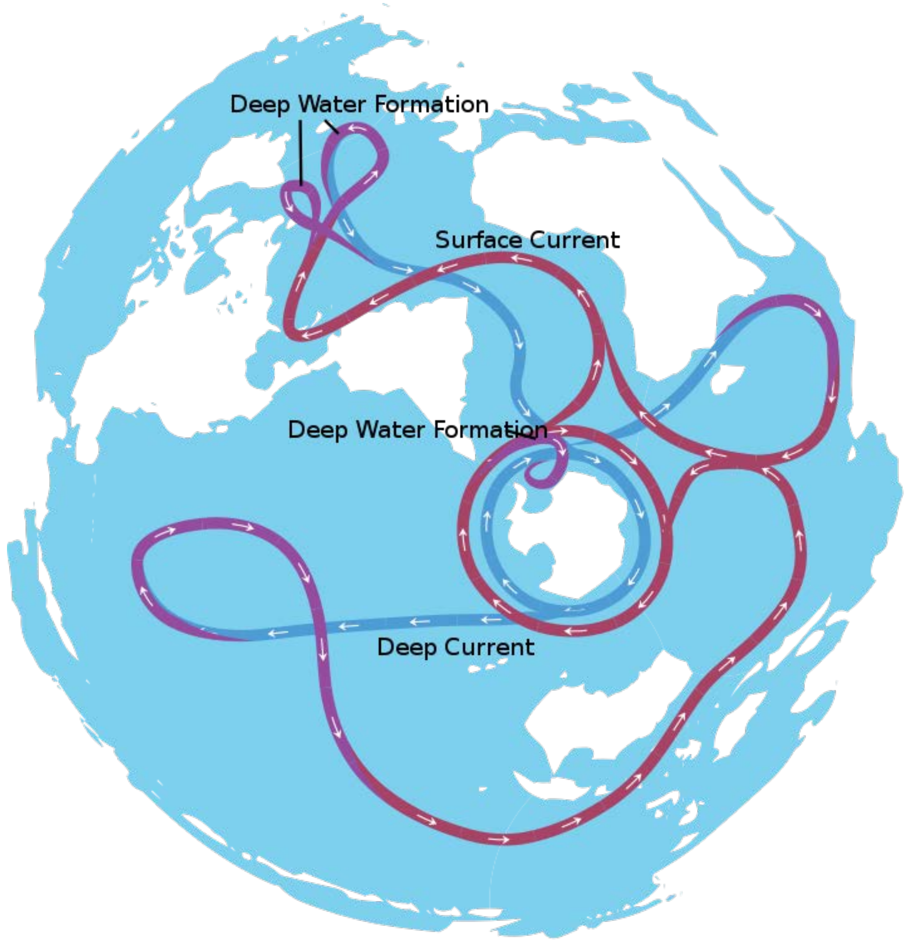
Meridional overturning circulation

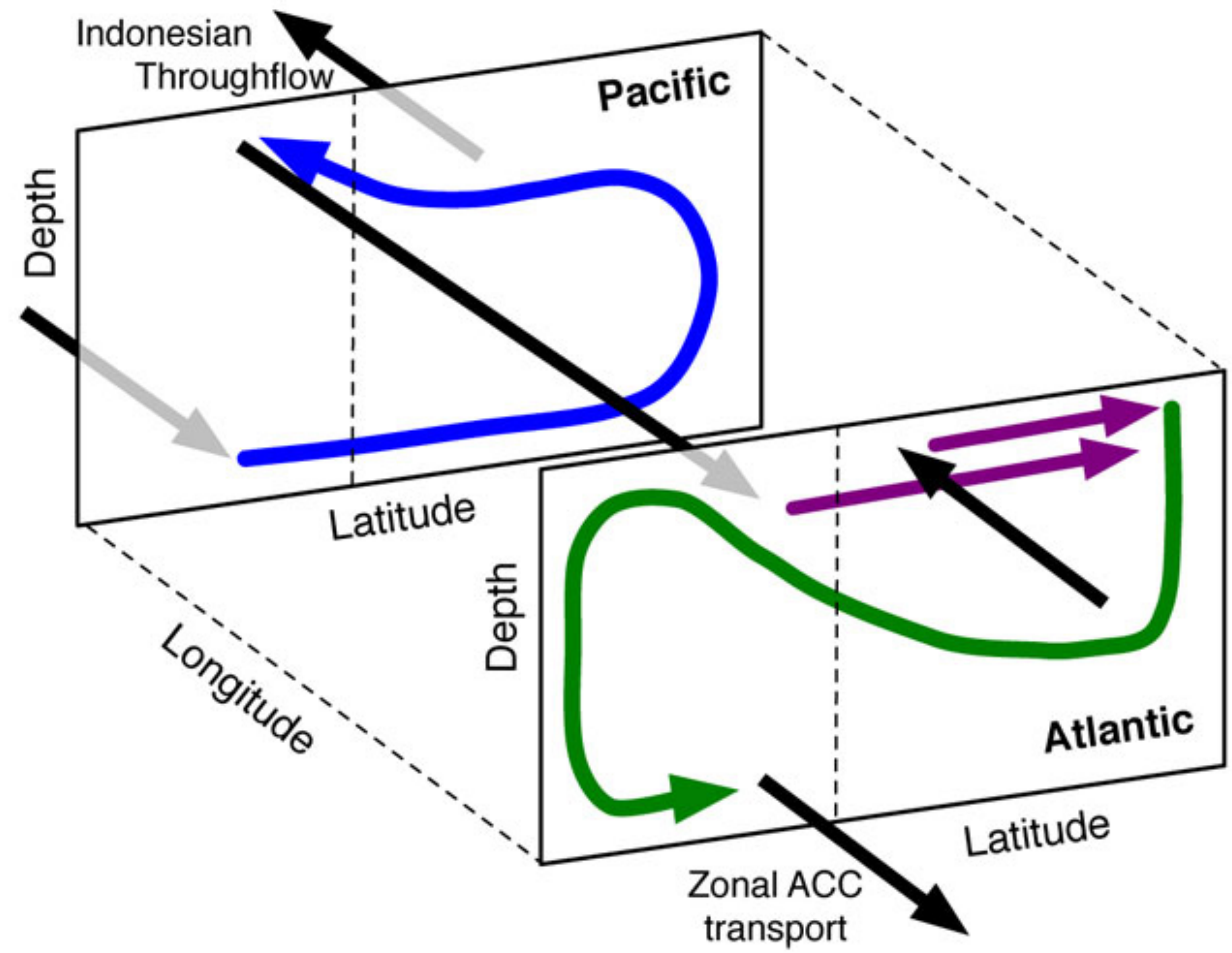


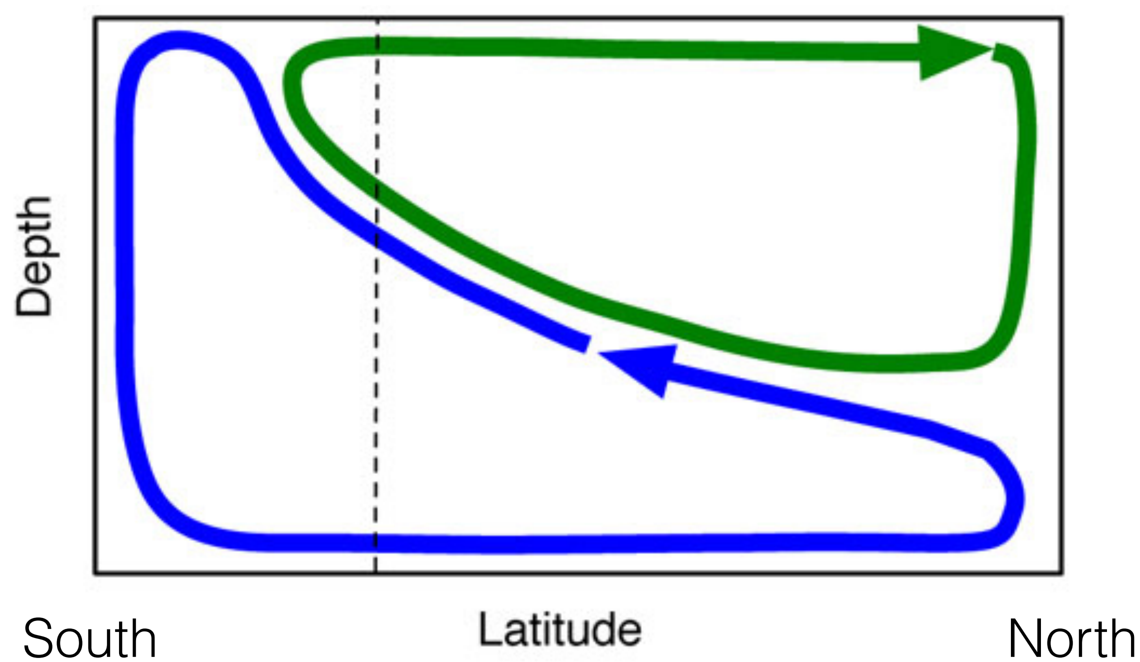


Ocean heat uptake? Sink of atmospheric CO2?
Response to global warming?

Meridional overturning circulation







Ocean heat uptake? Sink of atmospheric CO_2?
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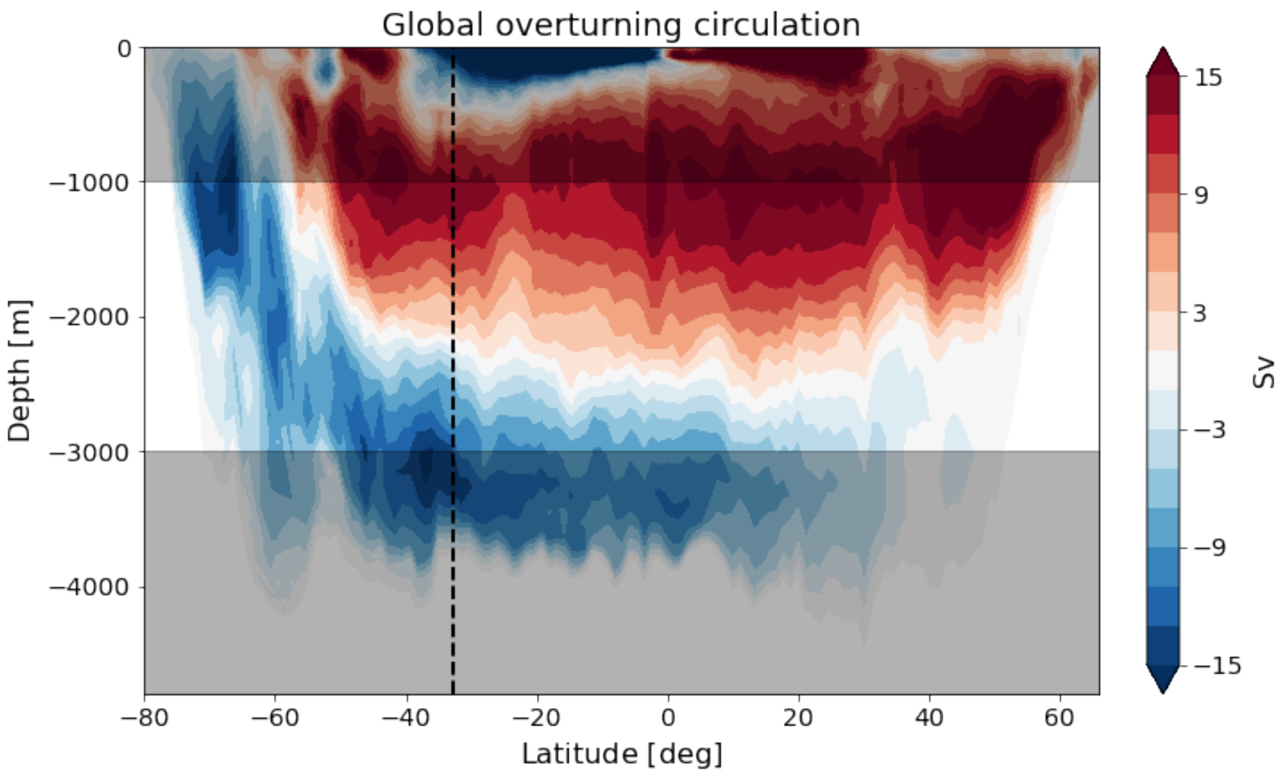
Deeper: Meridional overturning circulation



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ECCOv4 data, processing by M. Rogers, MIT.

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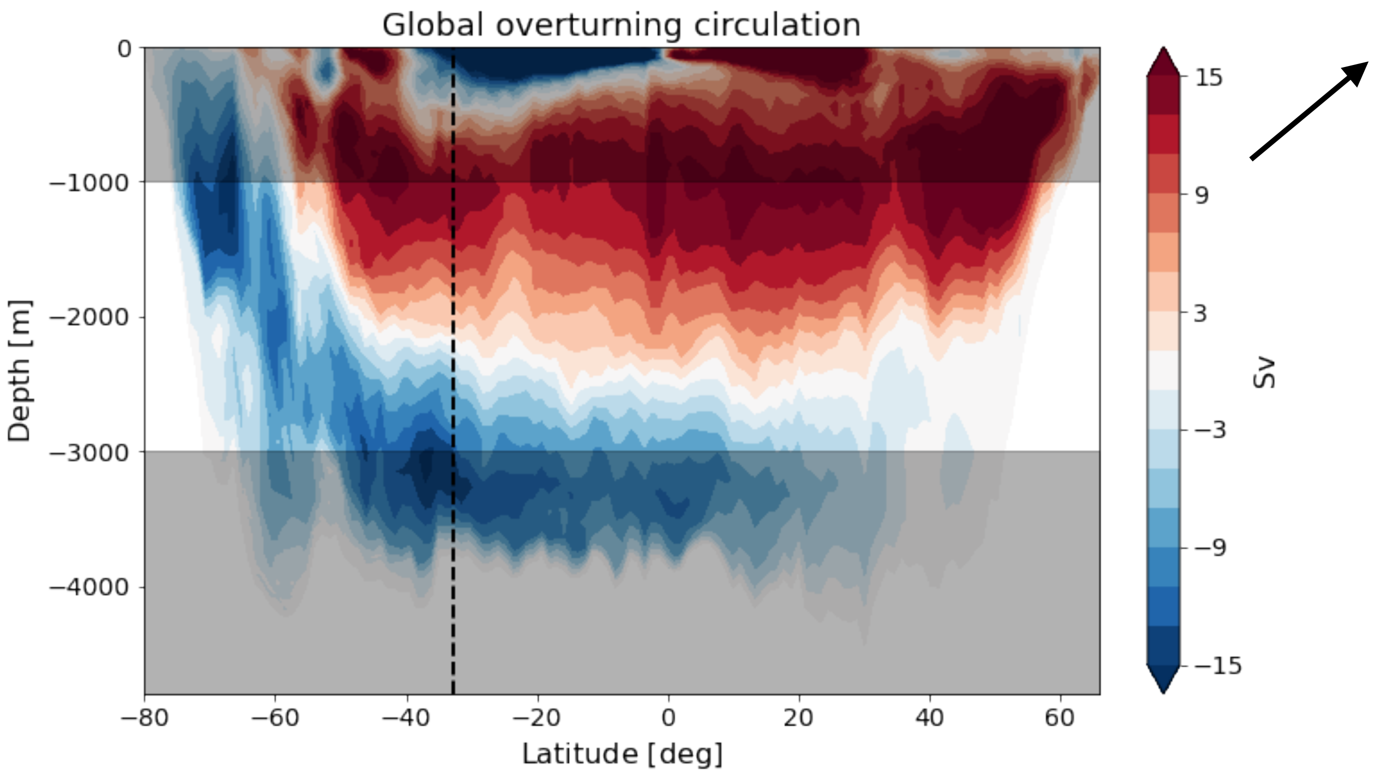

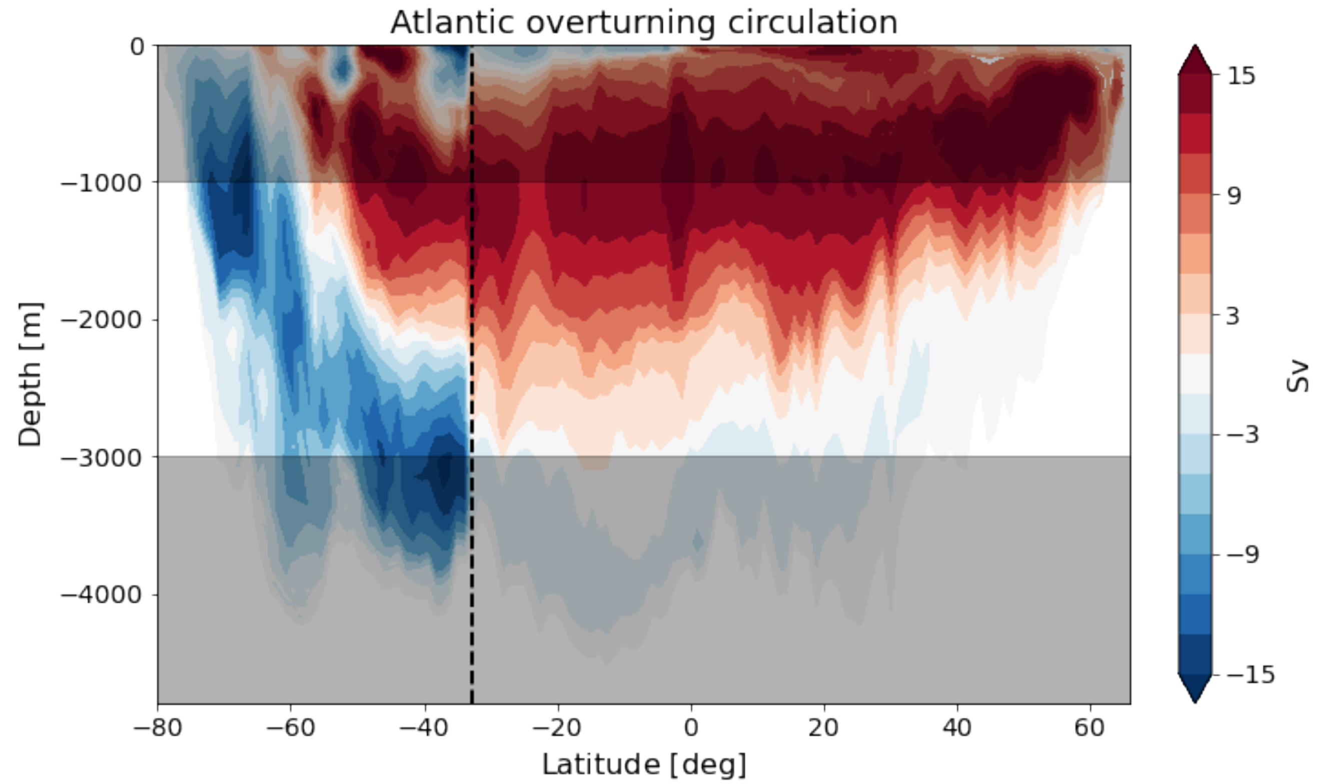

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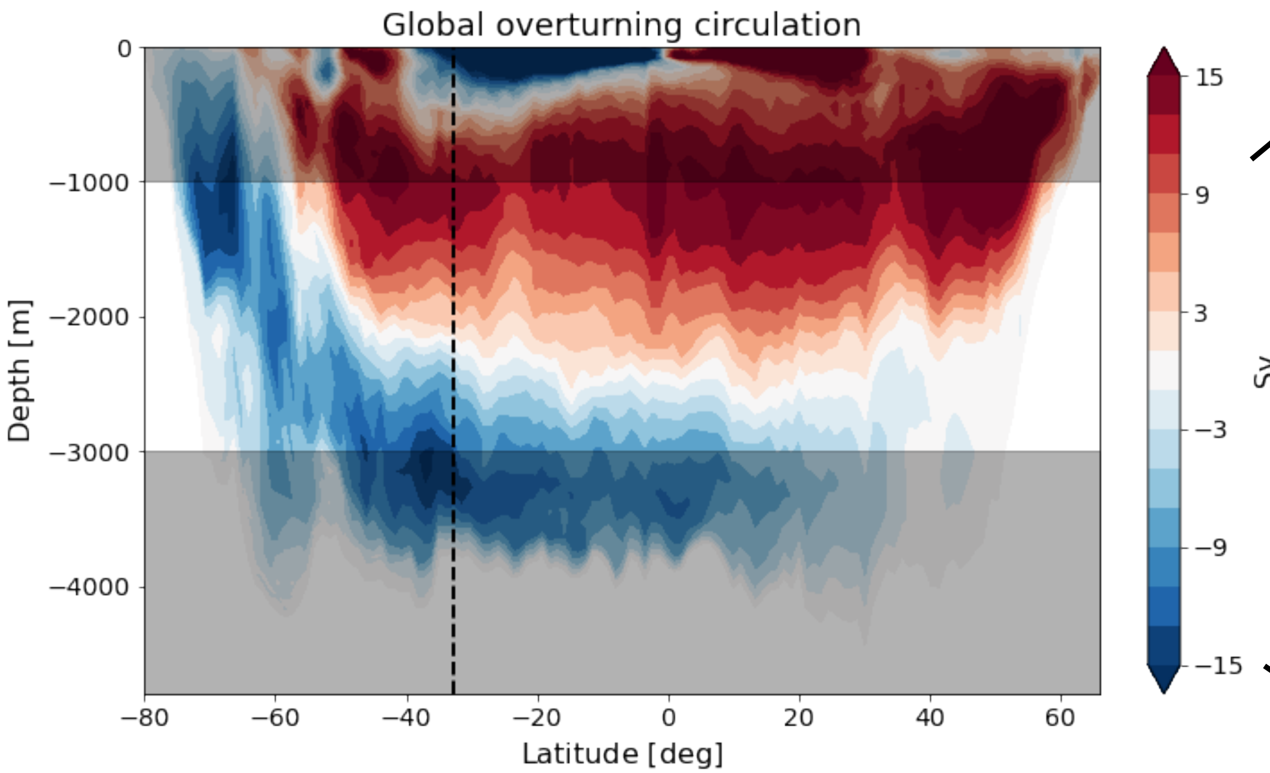

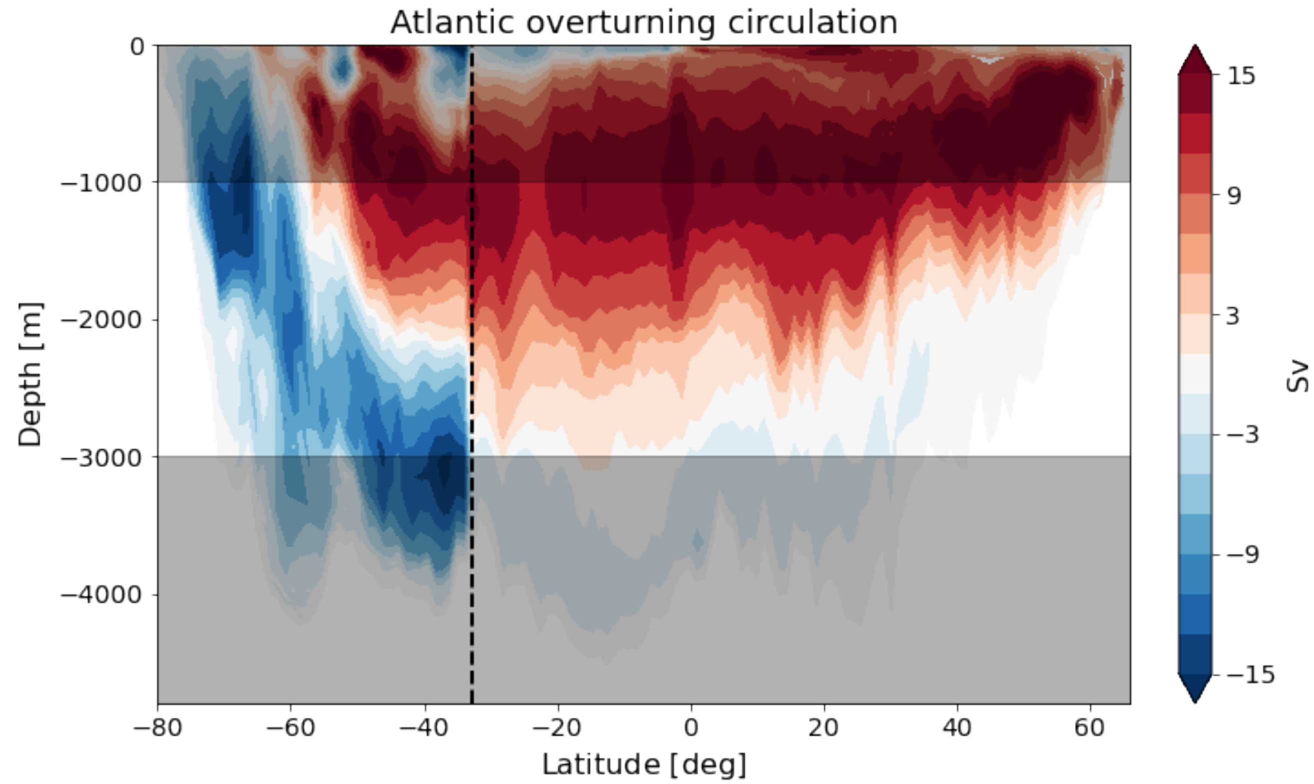

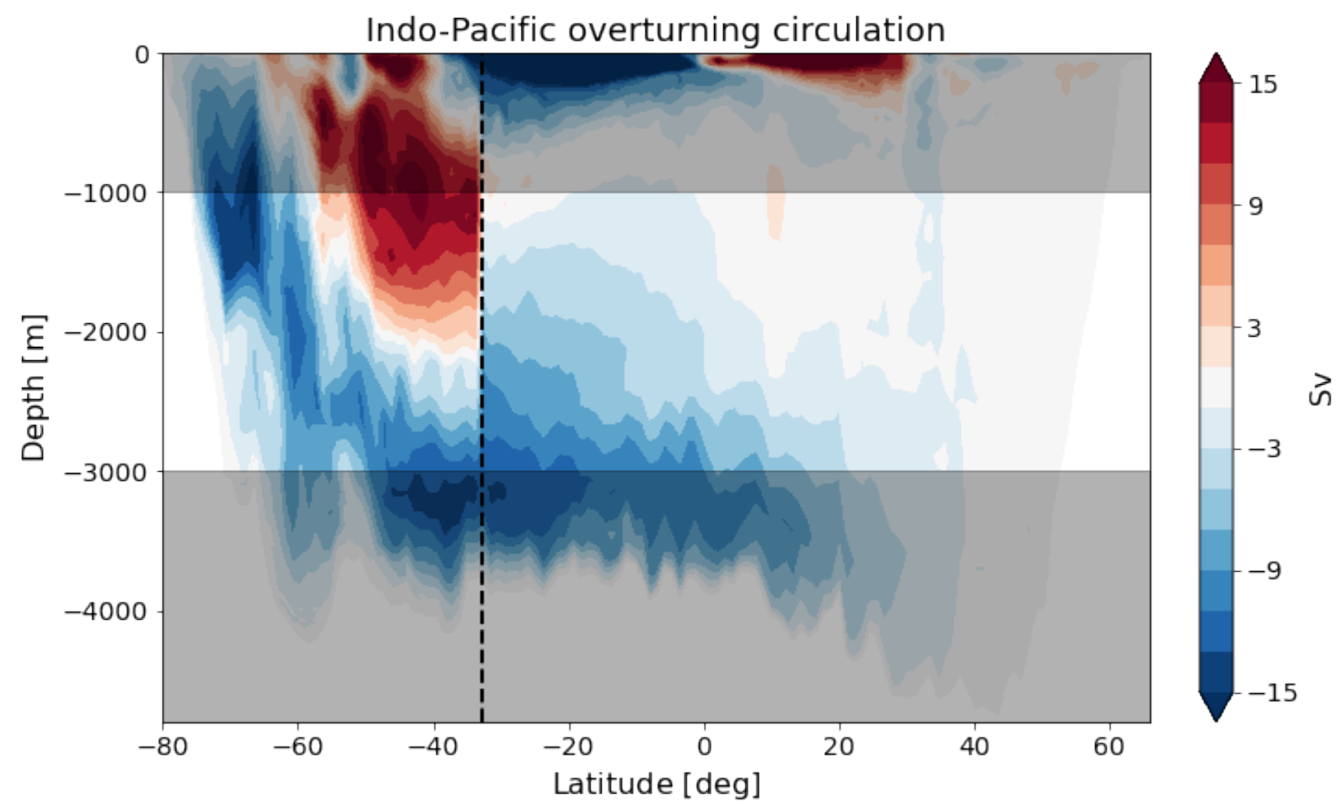

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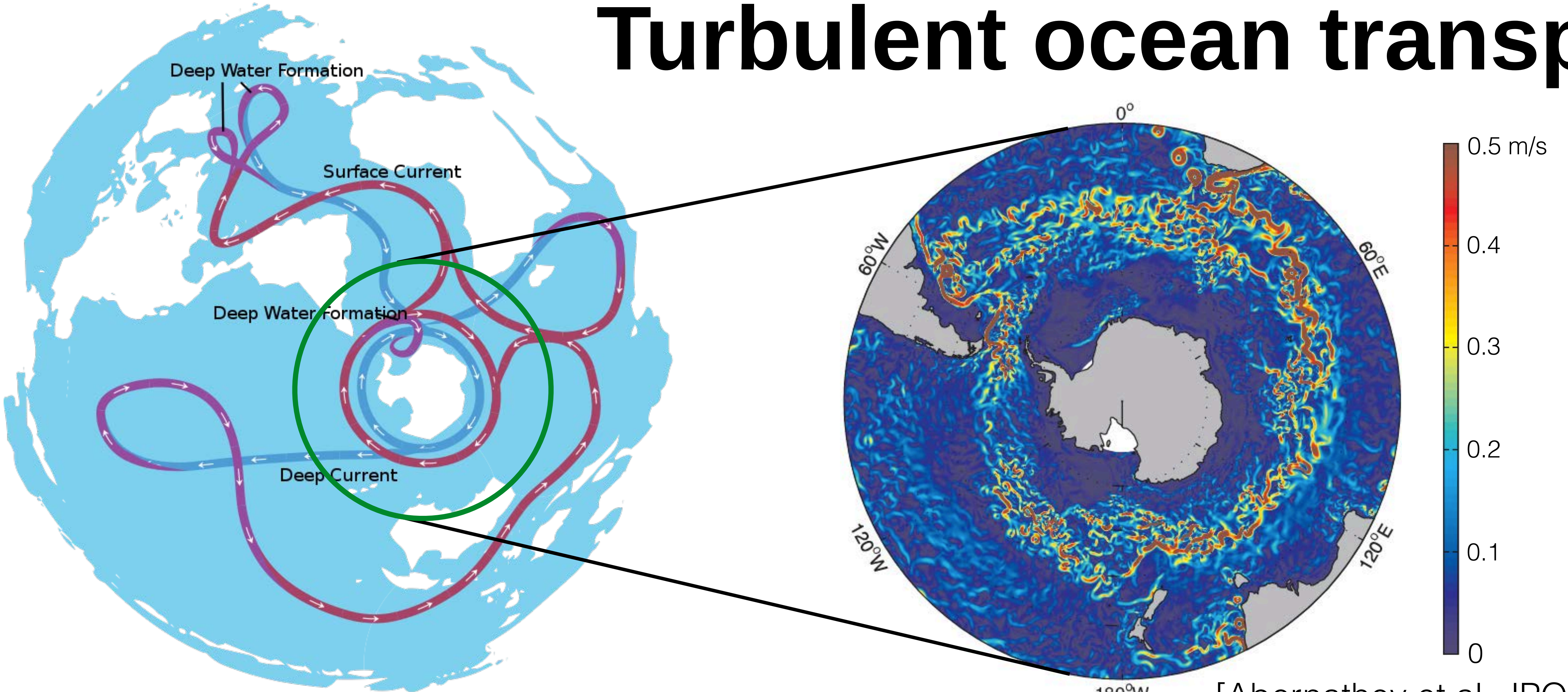
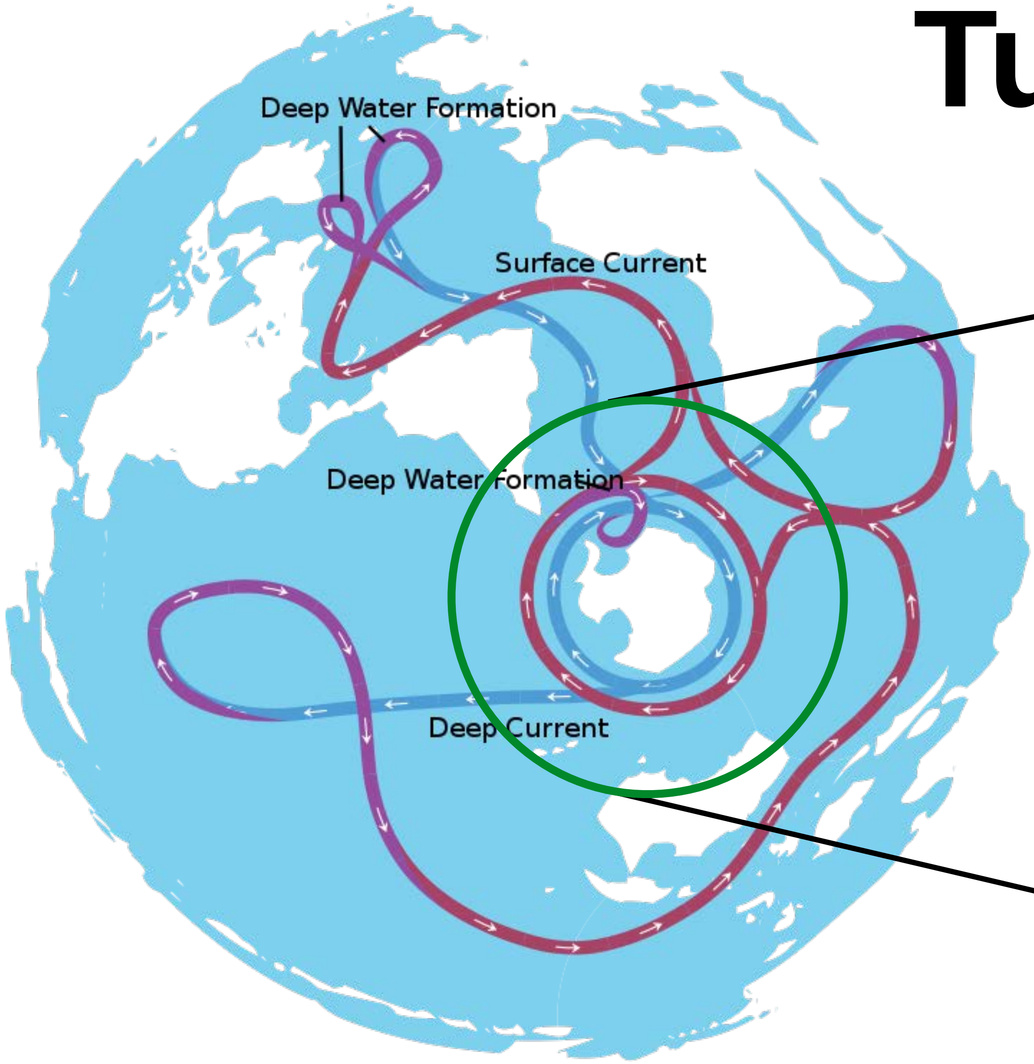
Turbulent ocean transport

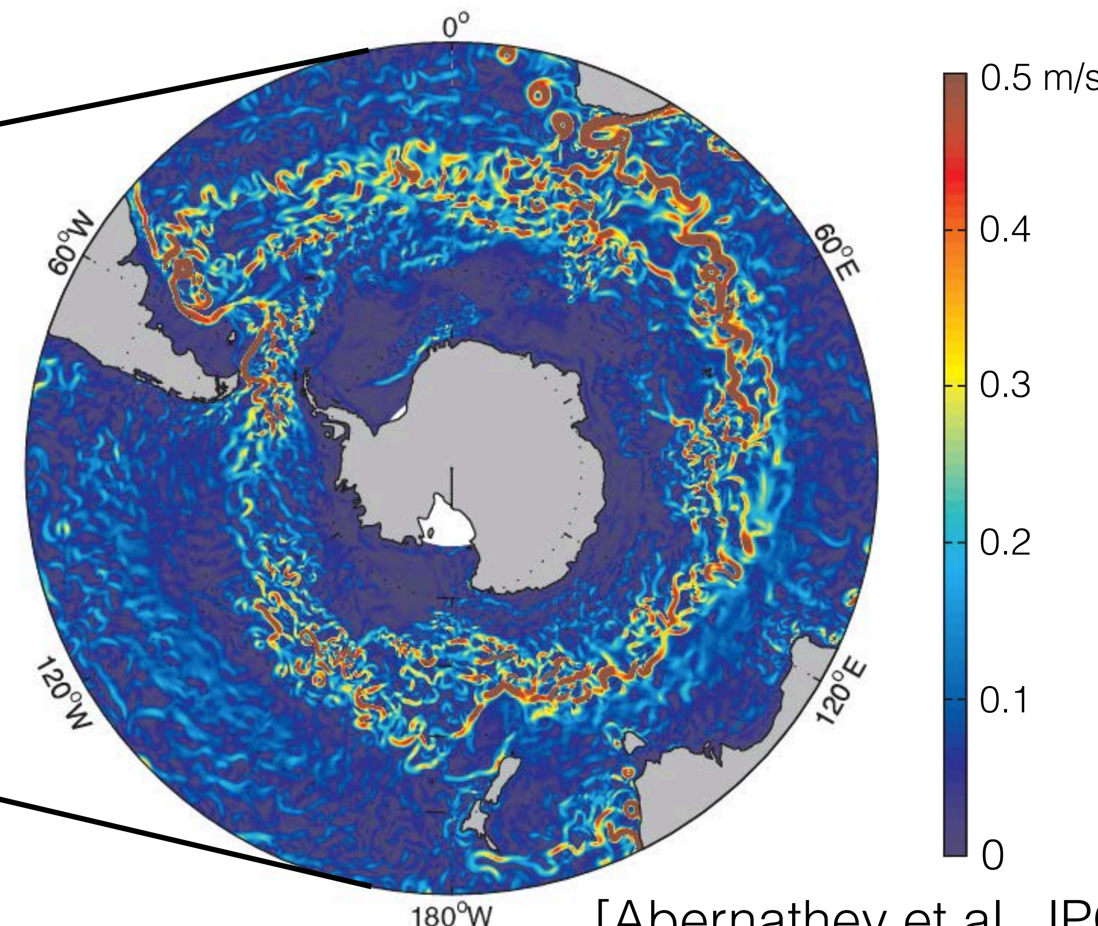


[Abernathey et al. JPO, 2010]

Strong baroclinic turbulence in the Southern Ocean

Turbulent ocean transport





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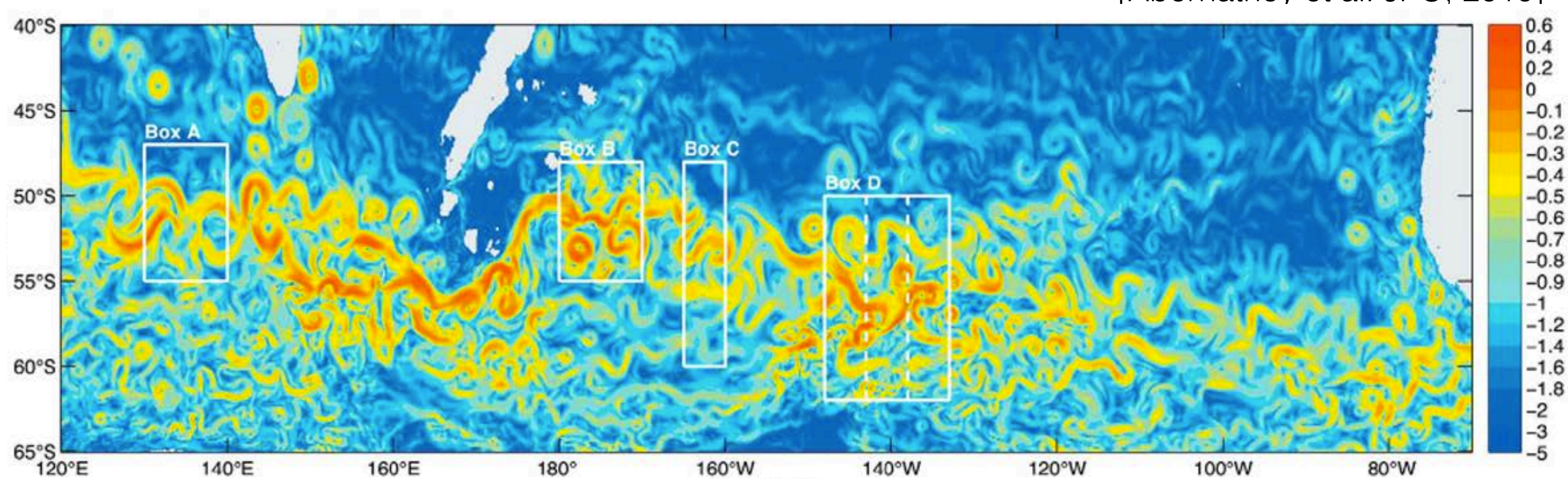
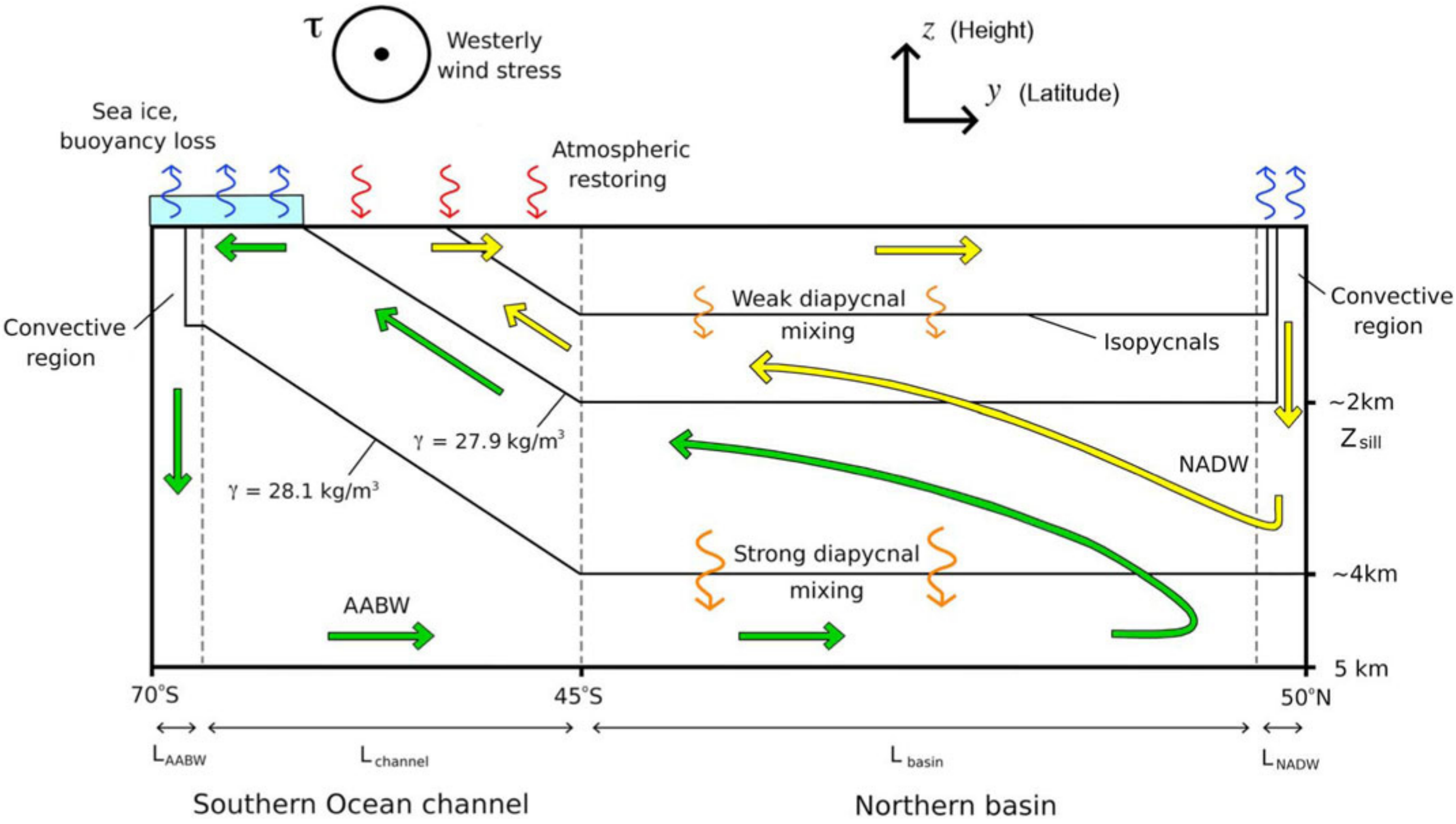


Strong baroclinic turbulence in the Southern Ocean

Ubiquitous turbulence



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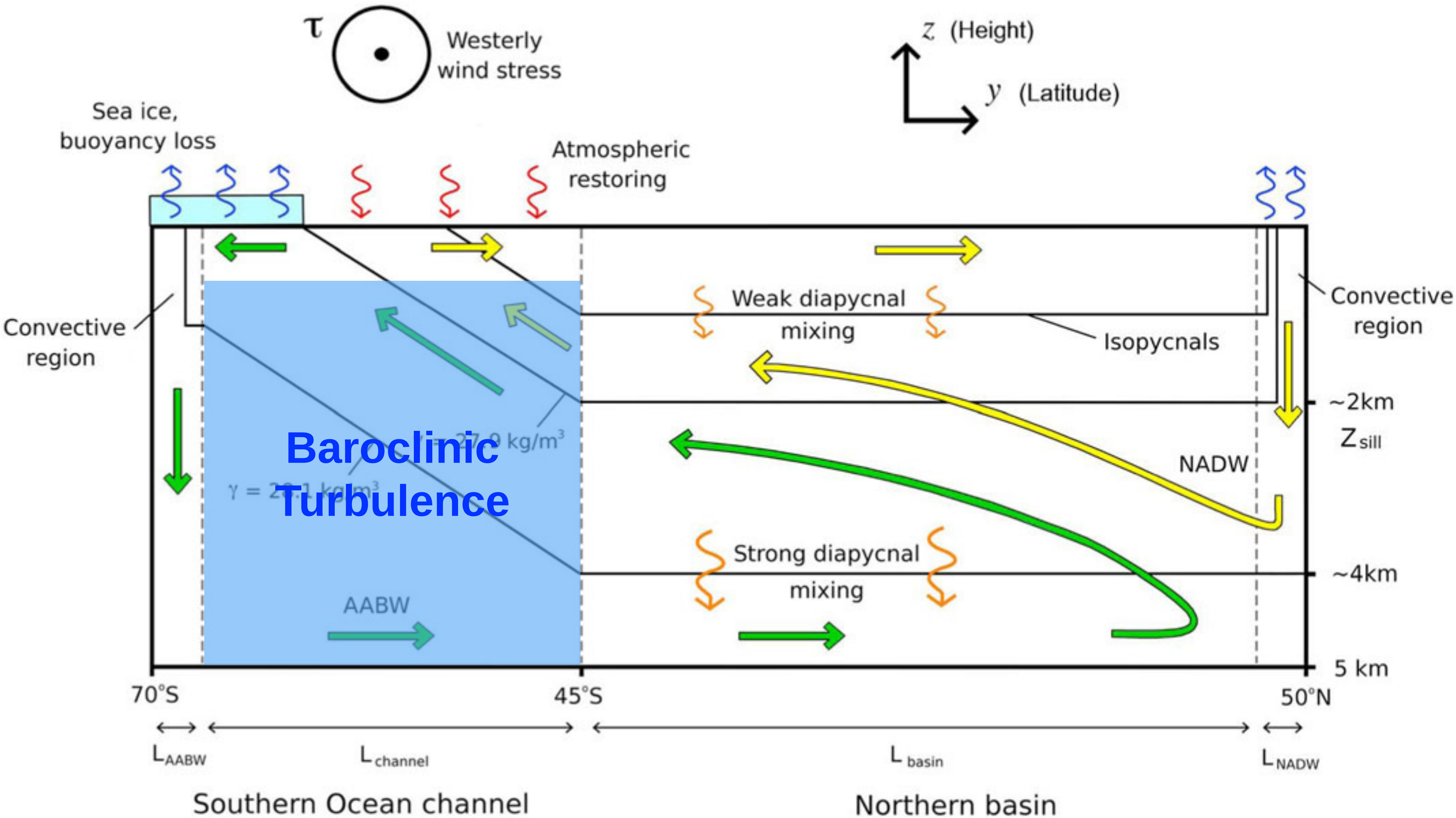

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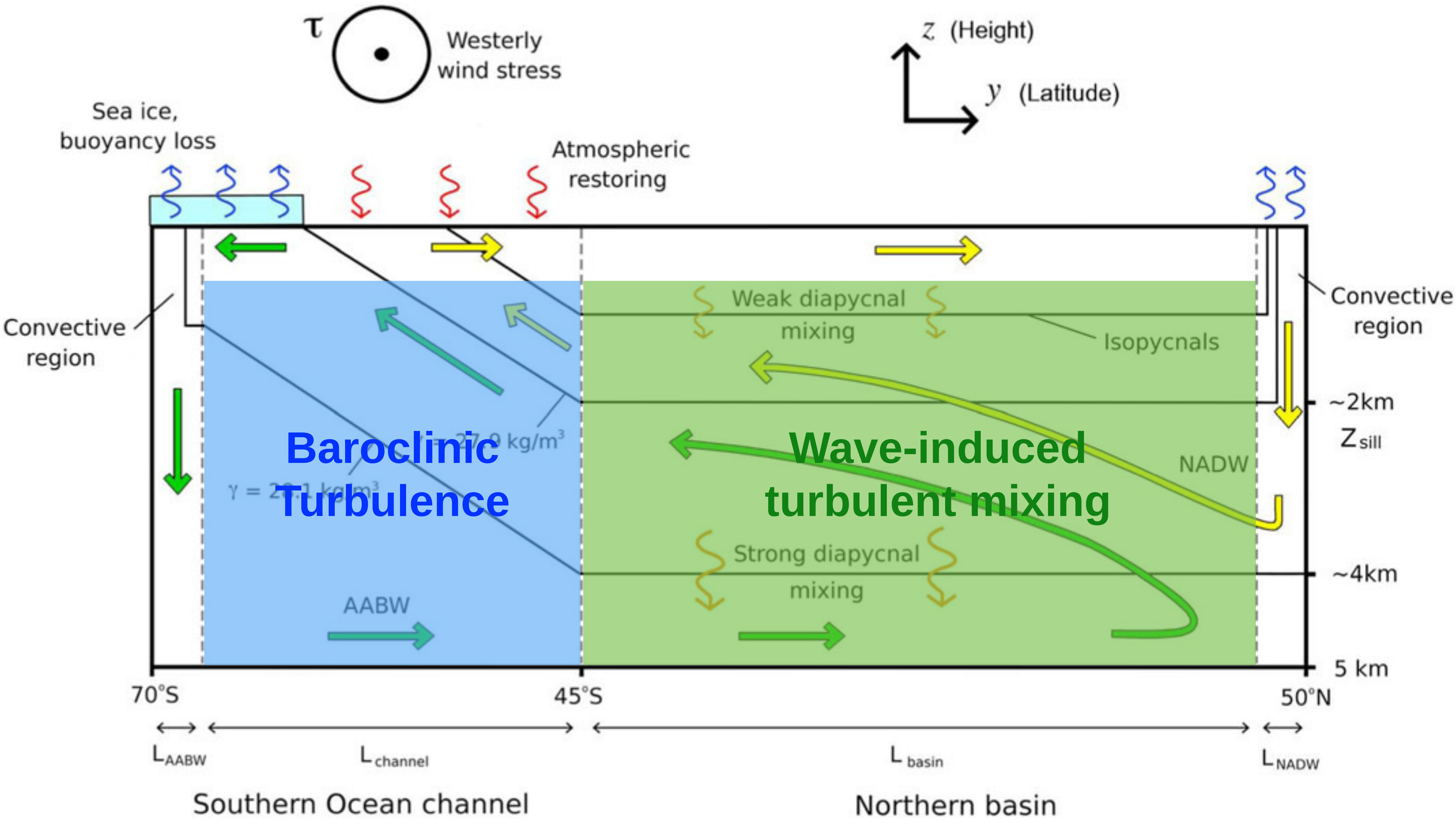

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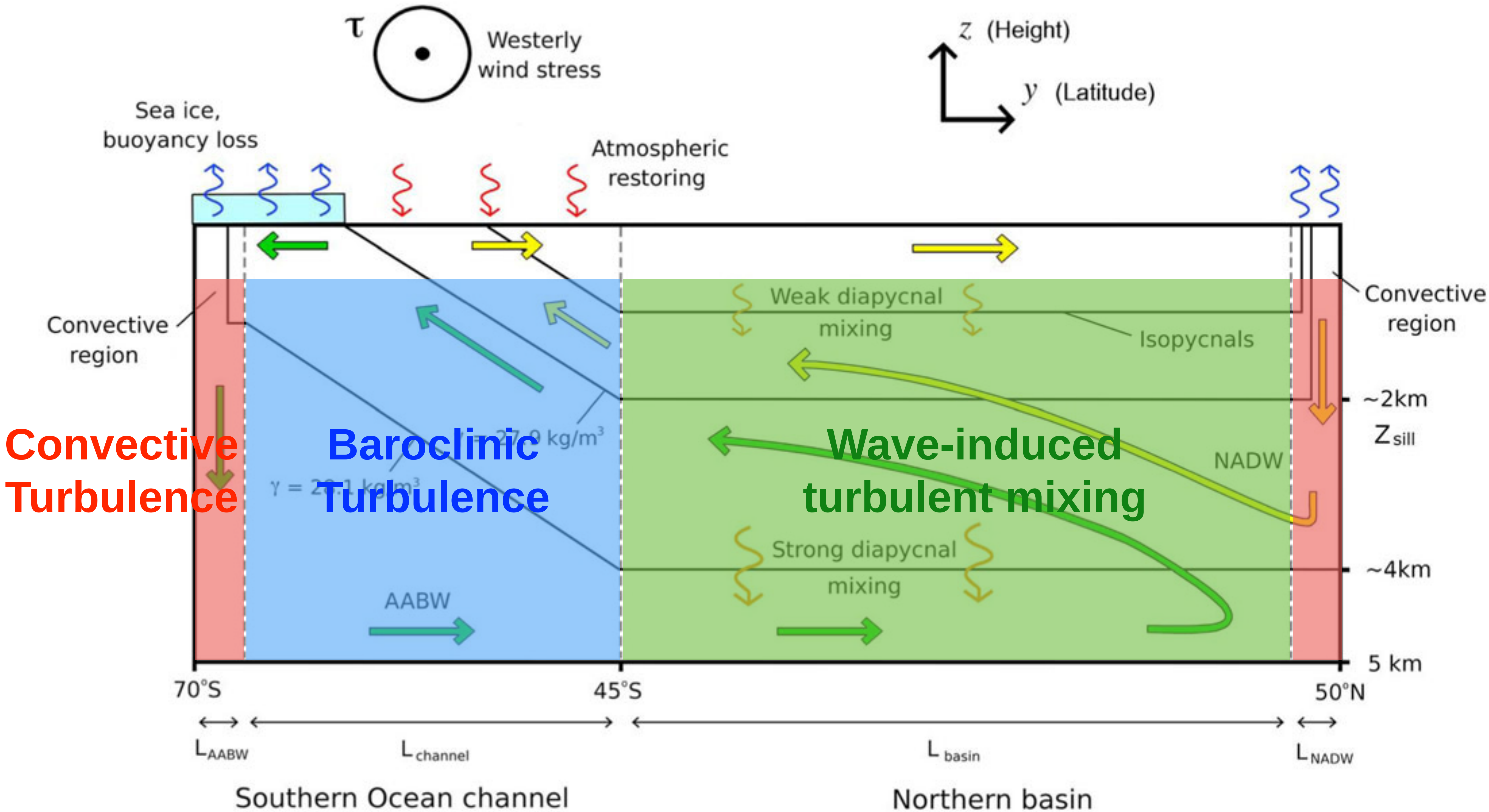

Turbulent transport and mixing

Turbulence is unresolved in climate models (ocean part)

- Parameterized through ad hoc coefficients, tuned to produce the expected behavior.
- Not always fully physically motivated.

→ Order-one phenomenon, that we need to understand physically to make accurate predictions.

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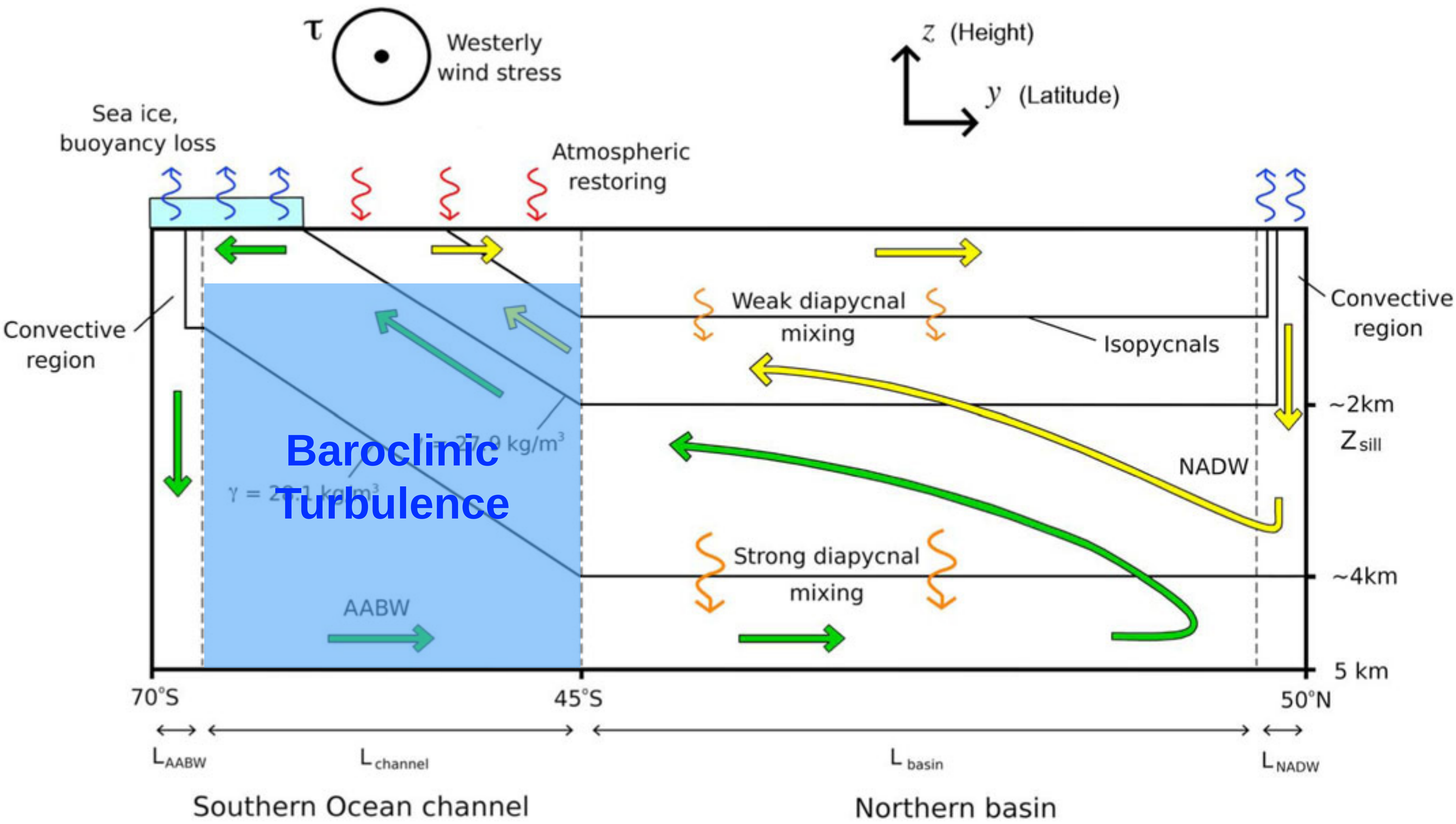
Magnitude of the buoyancy flux

- Overall buoyancy transport?
- Dependence on stratification, vertical shear, bottom drag, beta, topography?

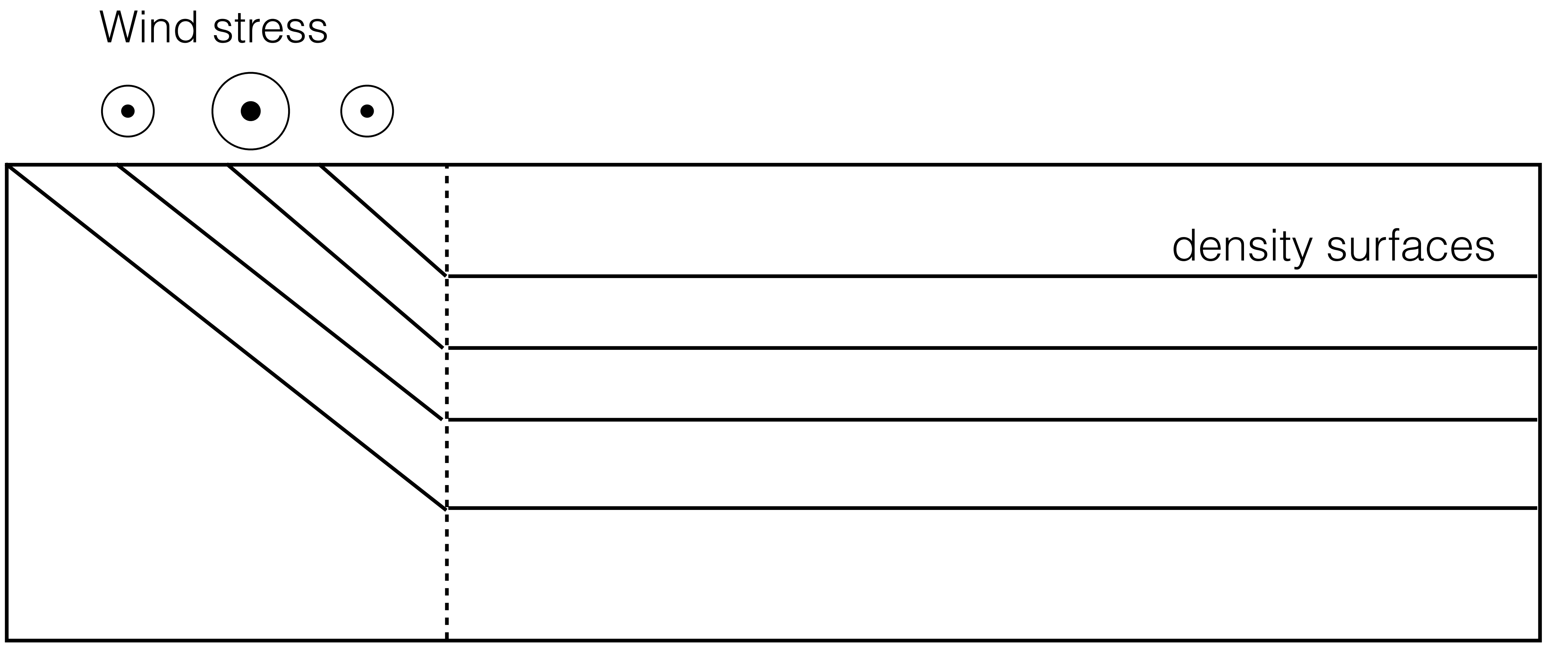
Three-dimensional structure of buoyancy transport

- Direction of the buoyancy flux vector?
- Vertical structure of the turbulent diffusivity?

I. Baroclinic turbulence



Origin of the stratification



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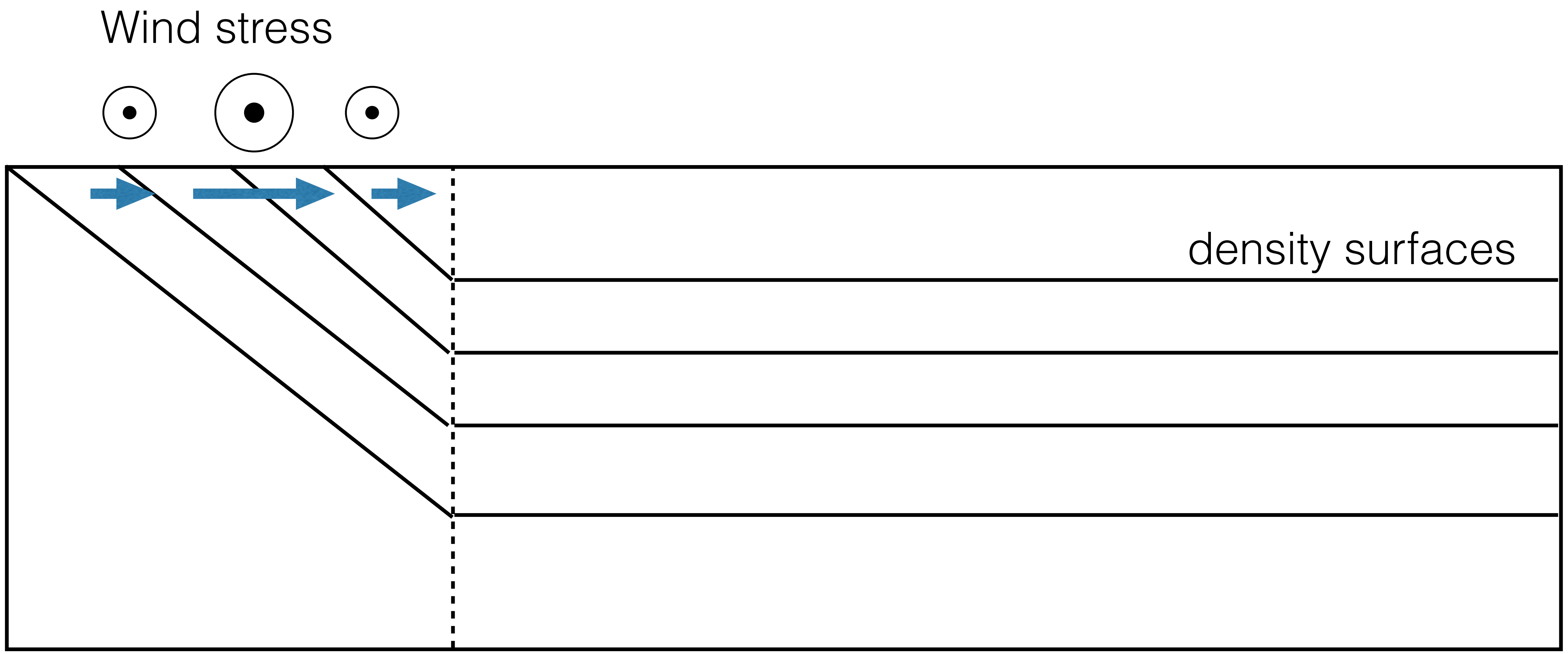

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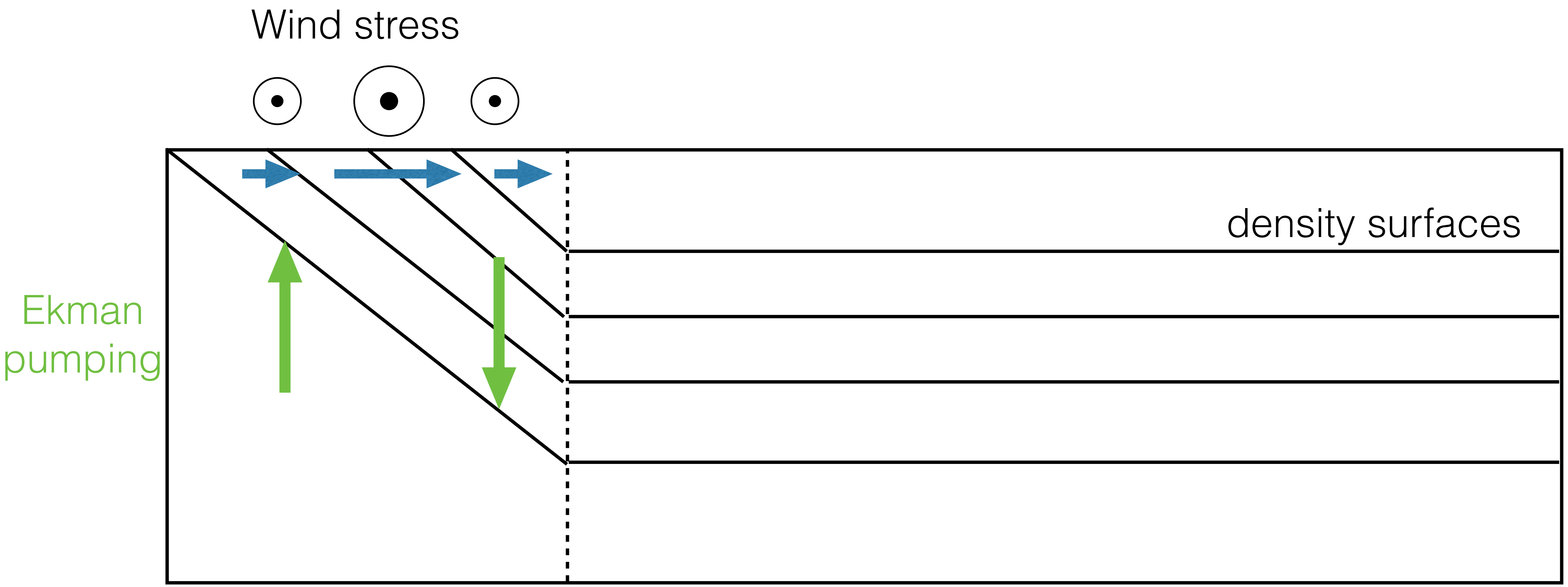

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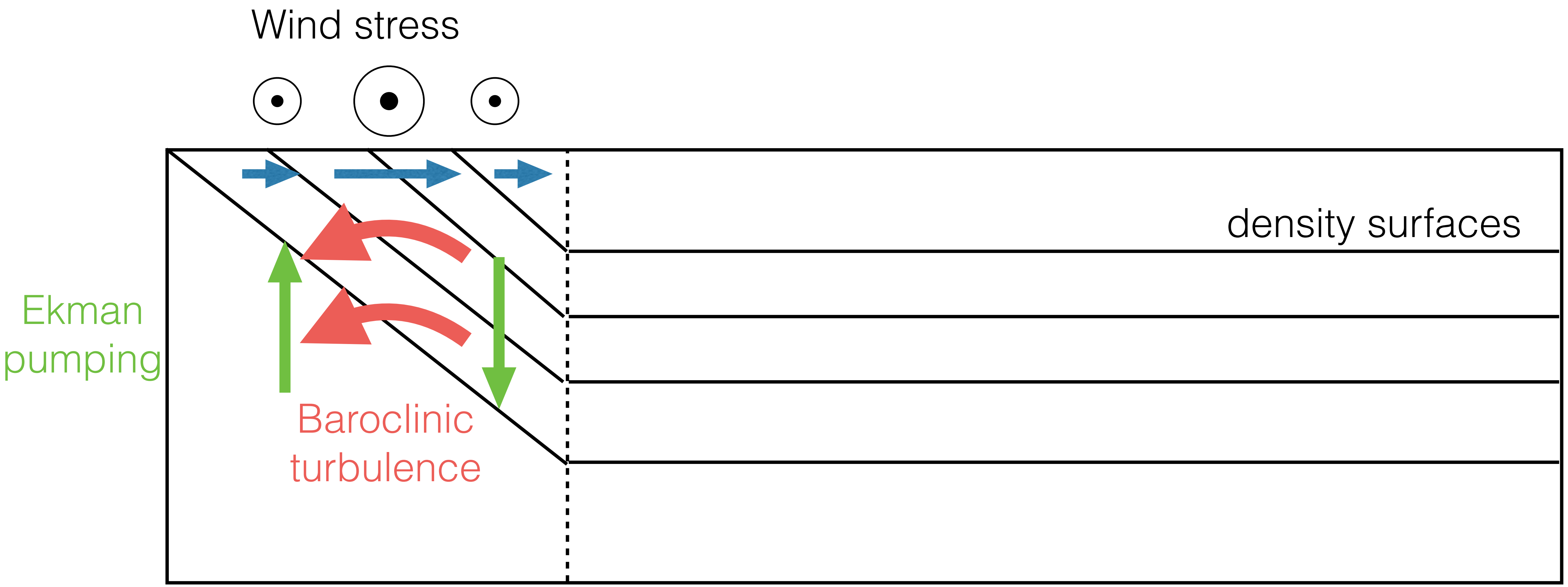

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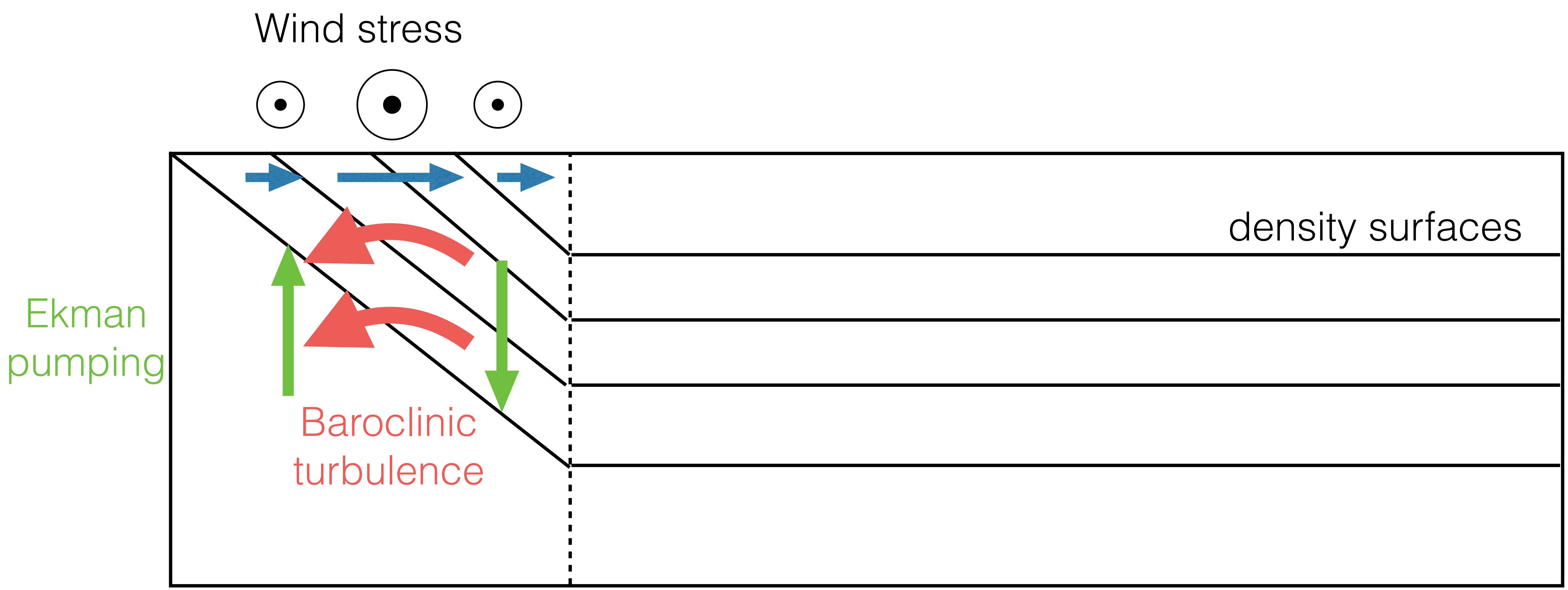
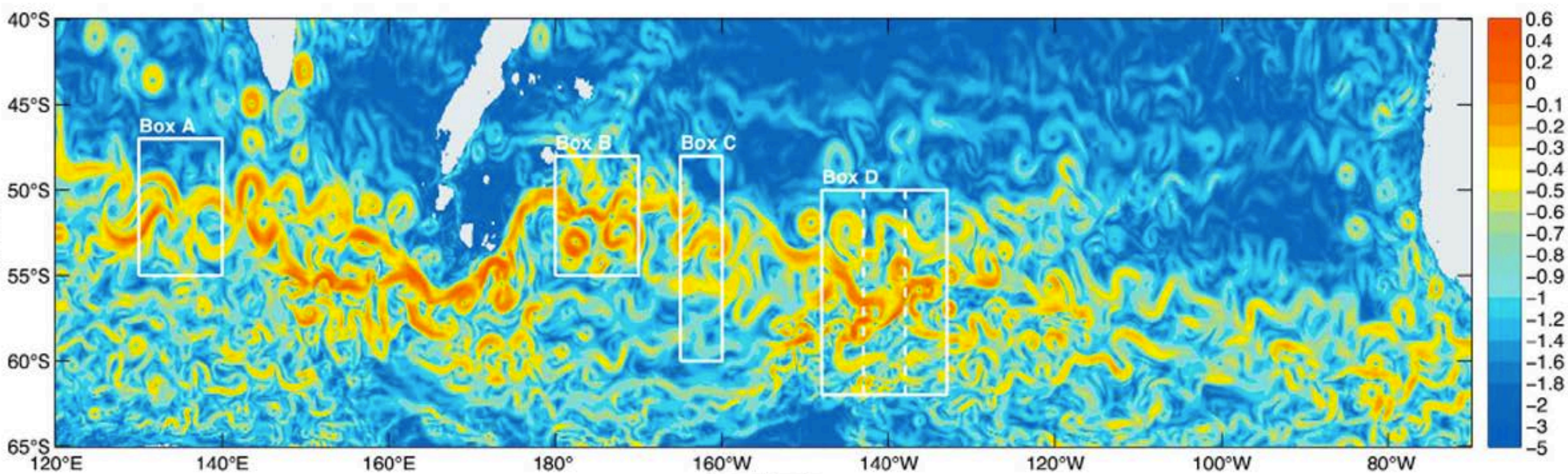


Competition between Ekman pumping and baroclinic turbulence sets the slope of the density surfaces, and thus the stratification of ocean basins.

➡ Need for a physically based parameterization of baroclinic turbulence.

Diffusive parameterization of baroclinic turbulence

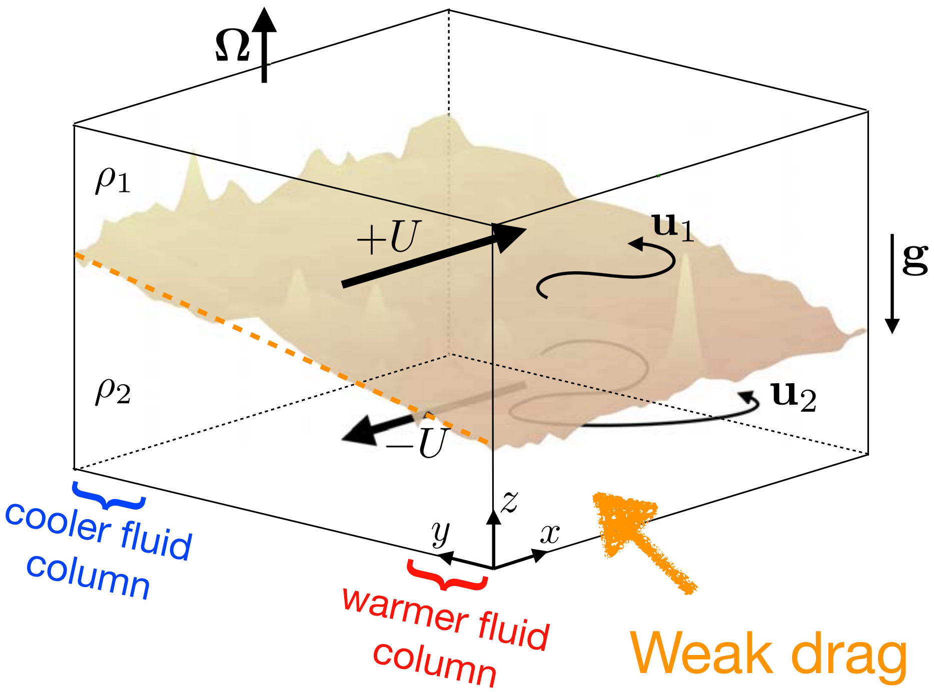


Scale separation → 'Turbulent' diffusion

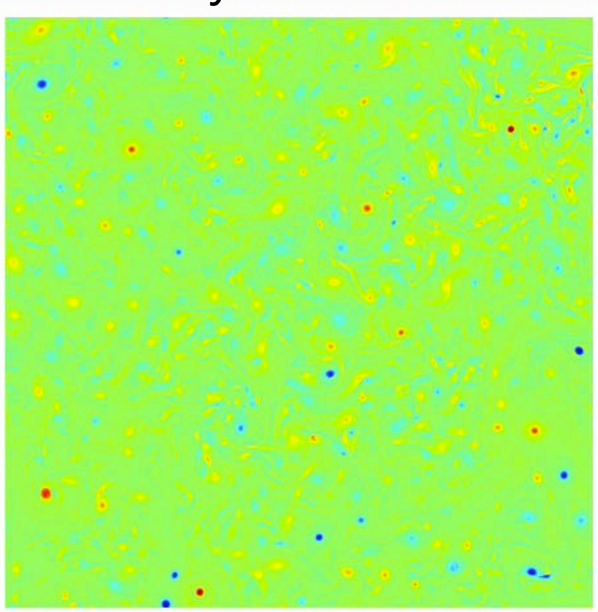
Magnitude and depth-dependence of the diffusivity?

Hierarchy of models

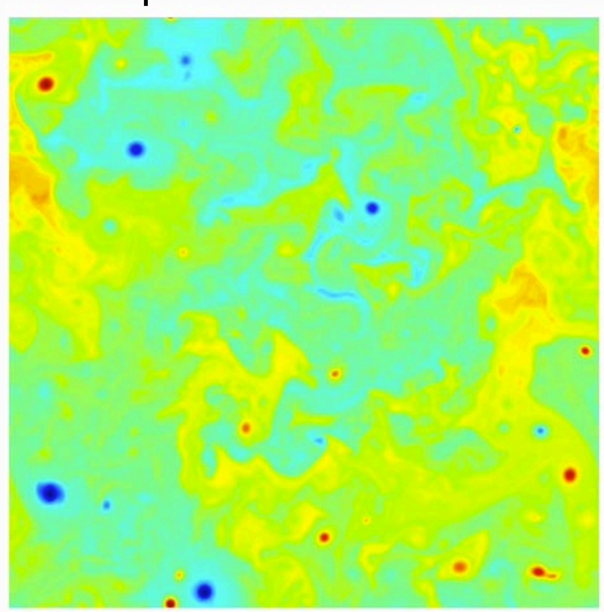
Two-layer model [Phillips 1954]:



Vorticity:



Temperature:



[Gallet & Ferrari, PNAS 2020]

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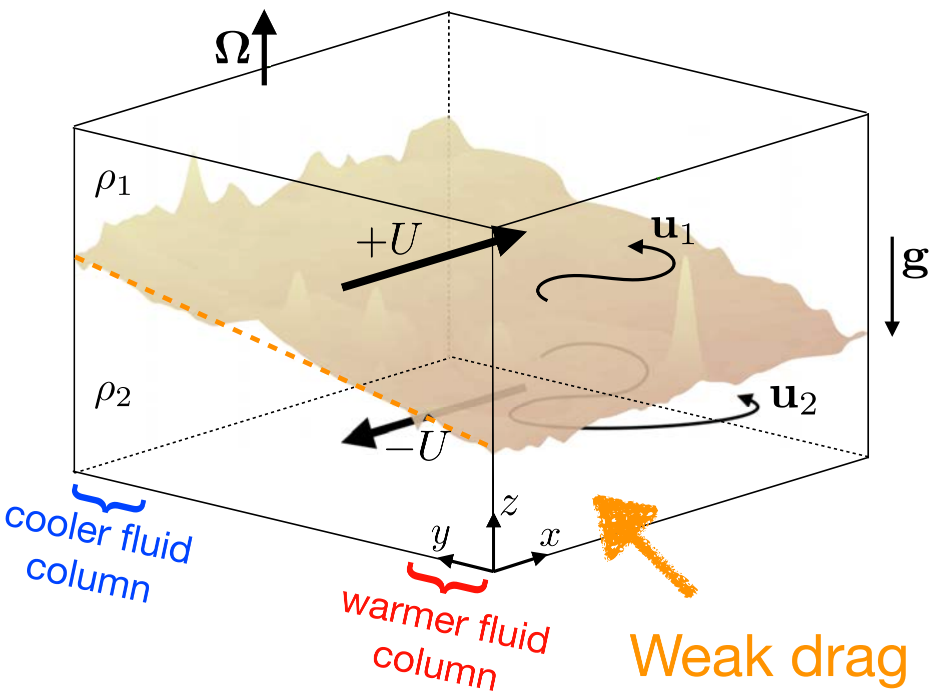

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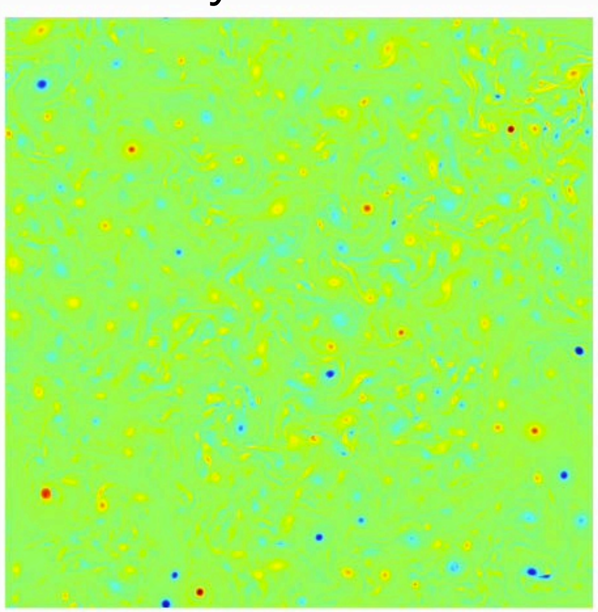

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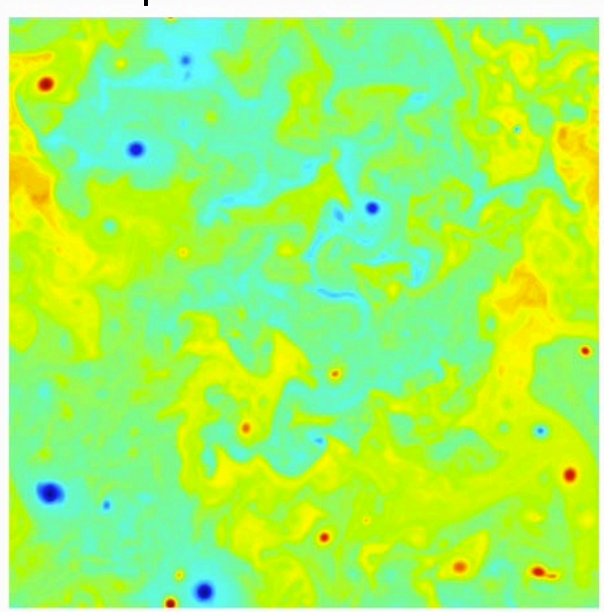

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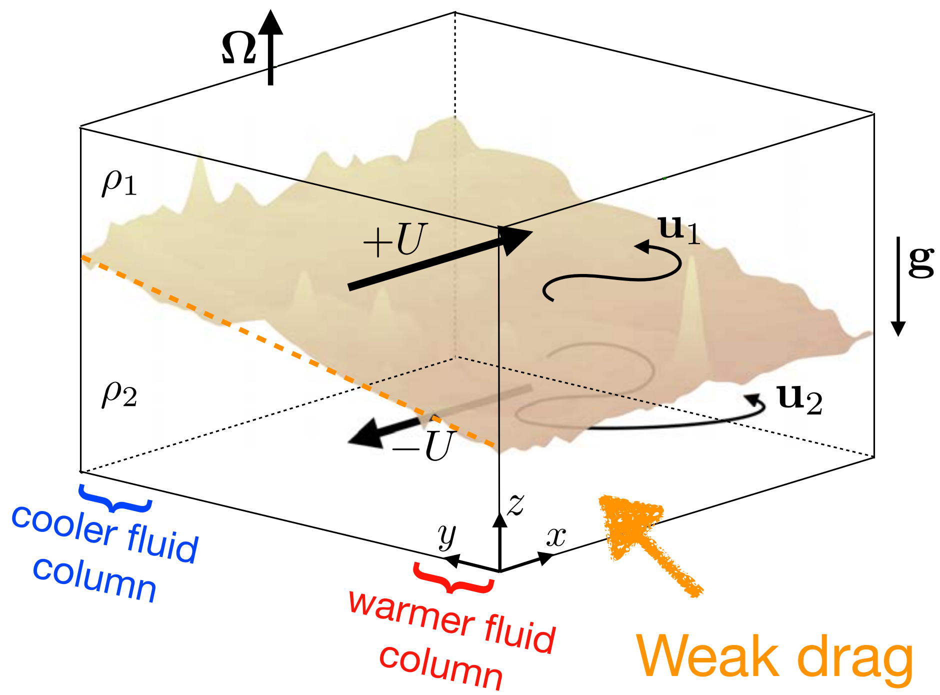

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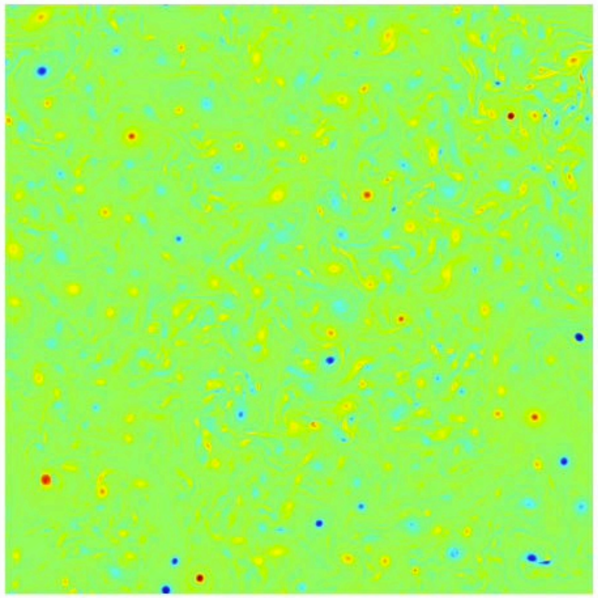

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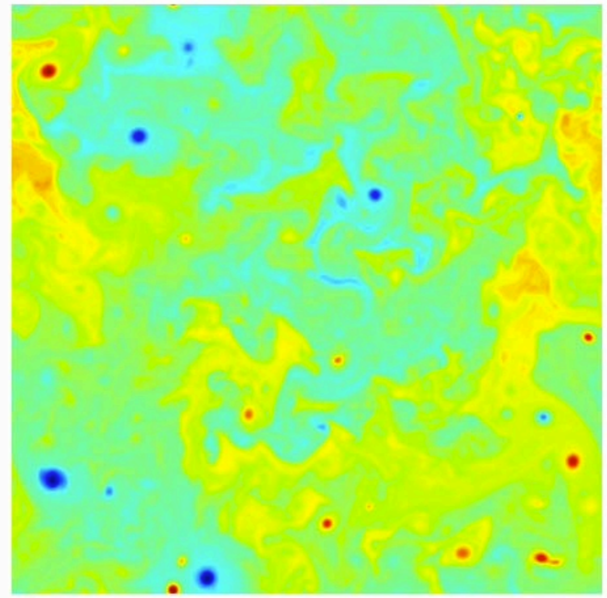

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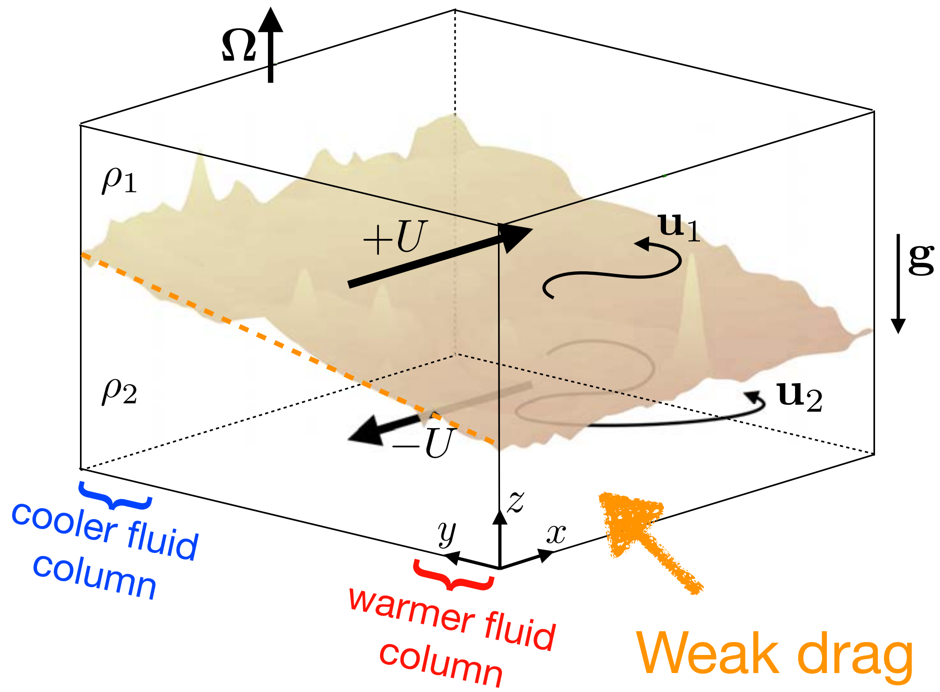
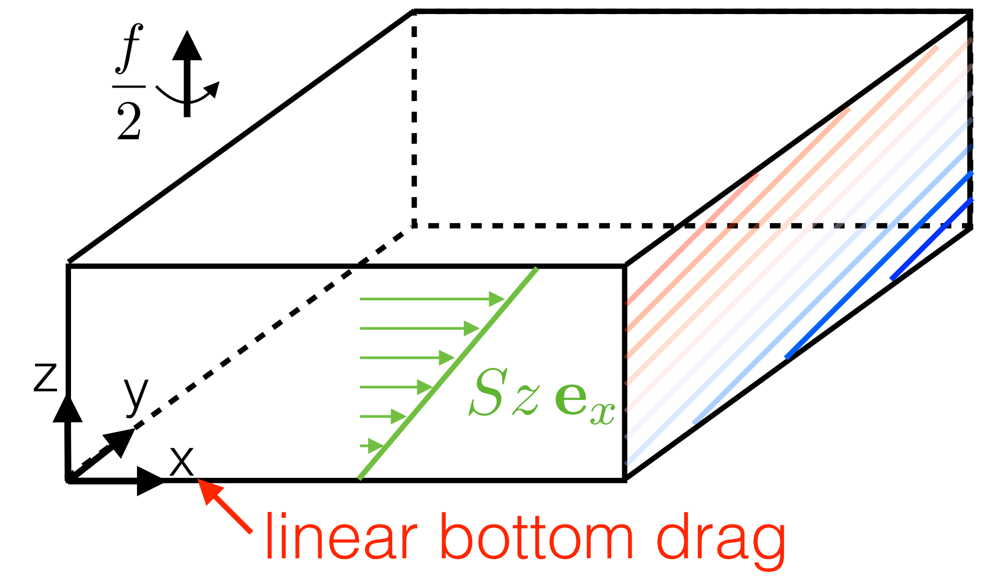


Fully 3D model:



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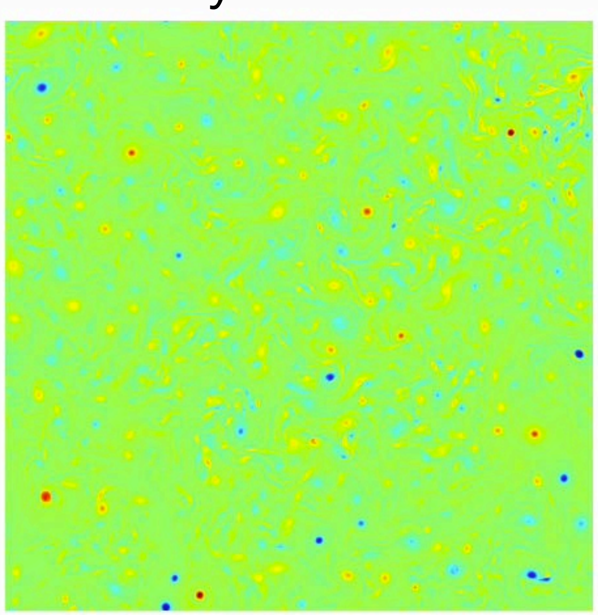

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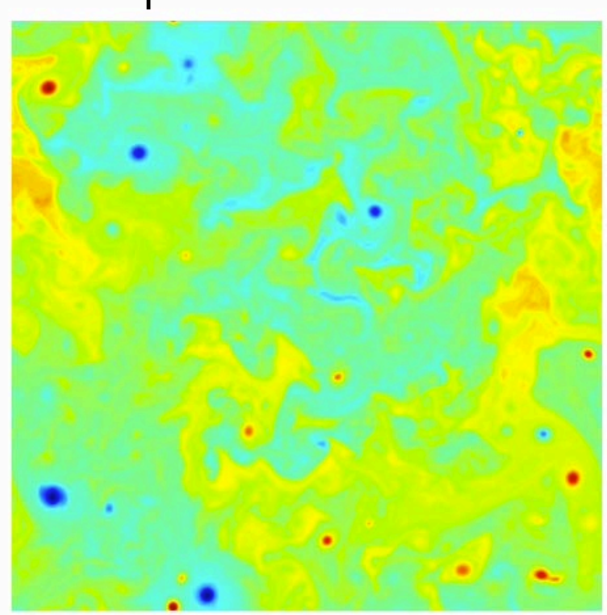

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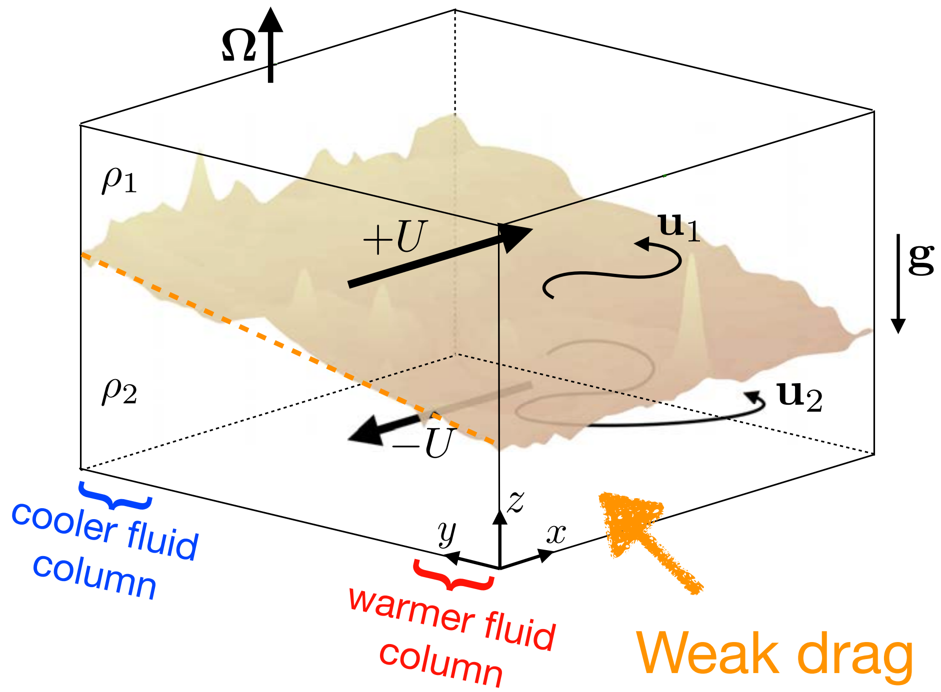

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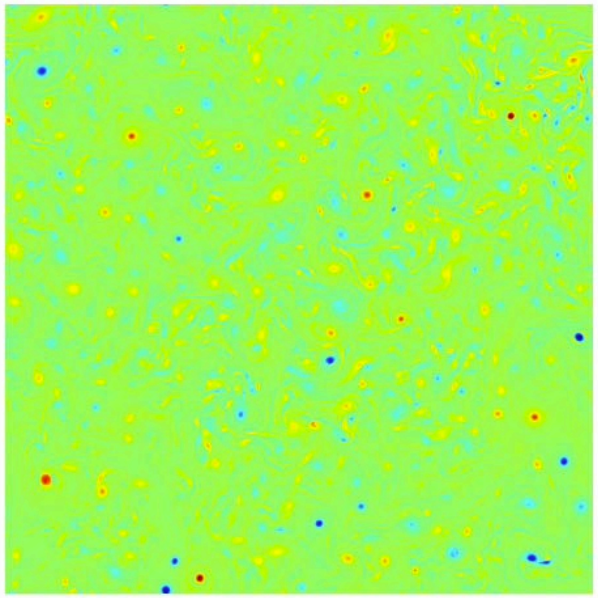

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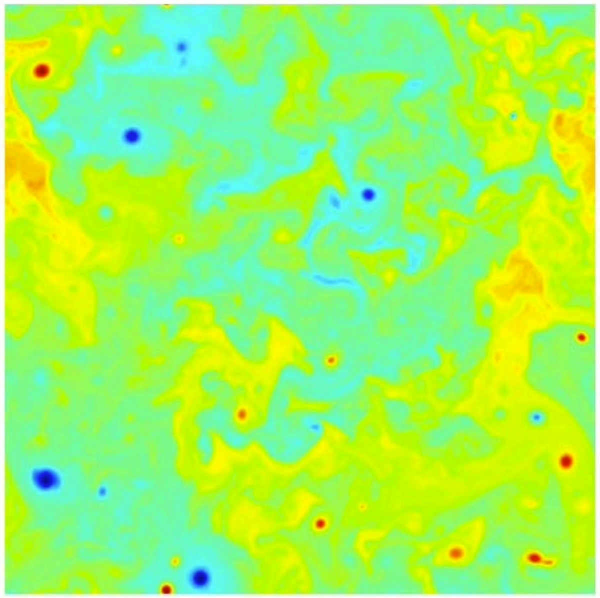

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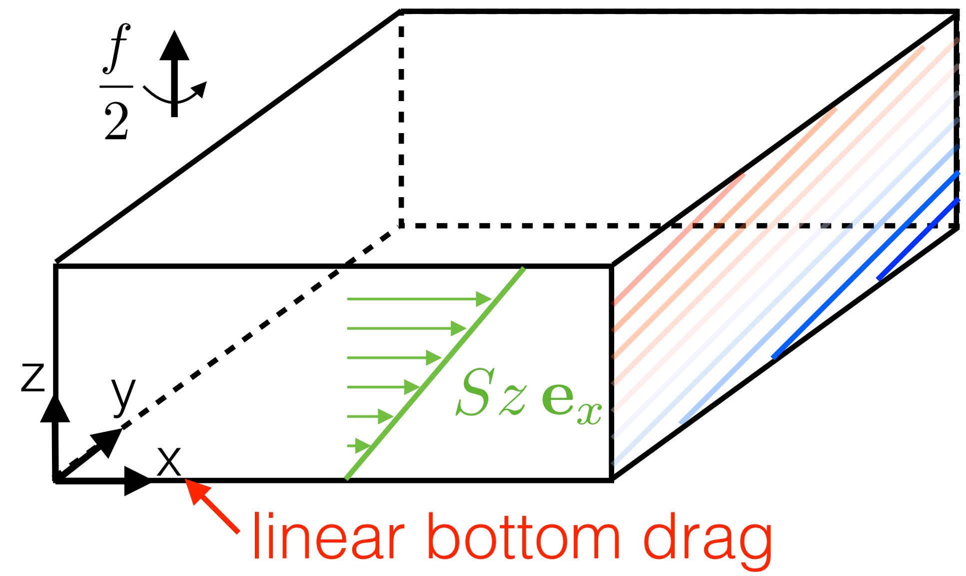

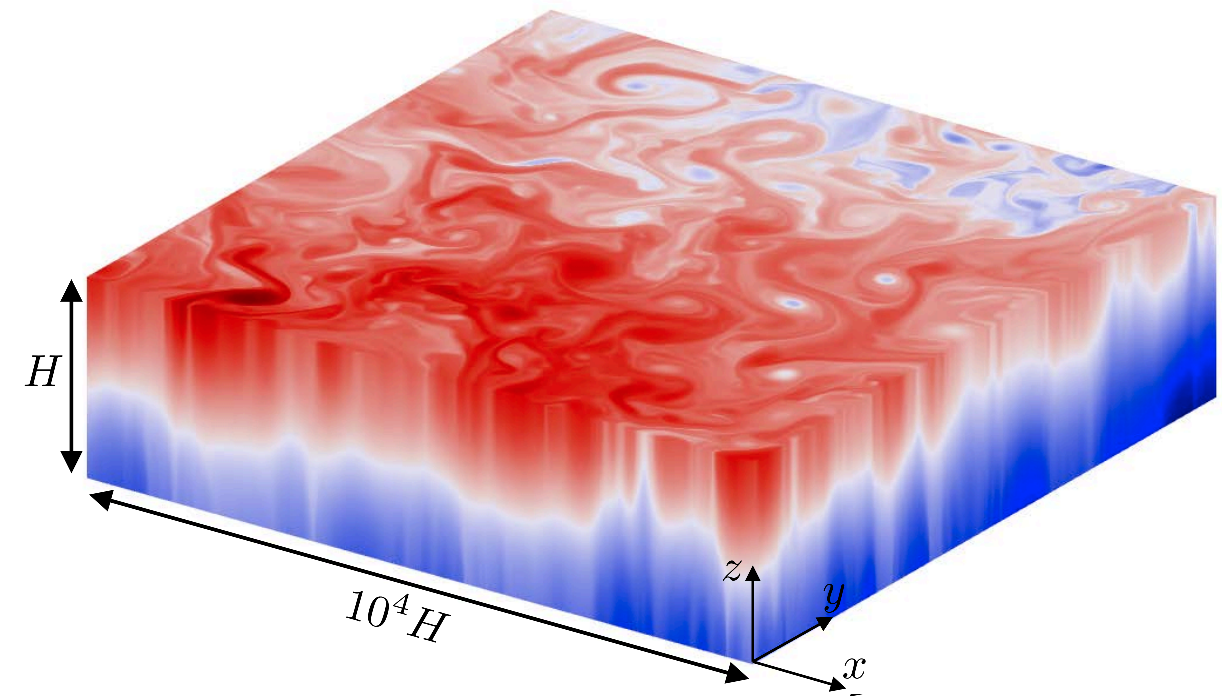

[Gallet et al., JFM 2022]

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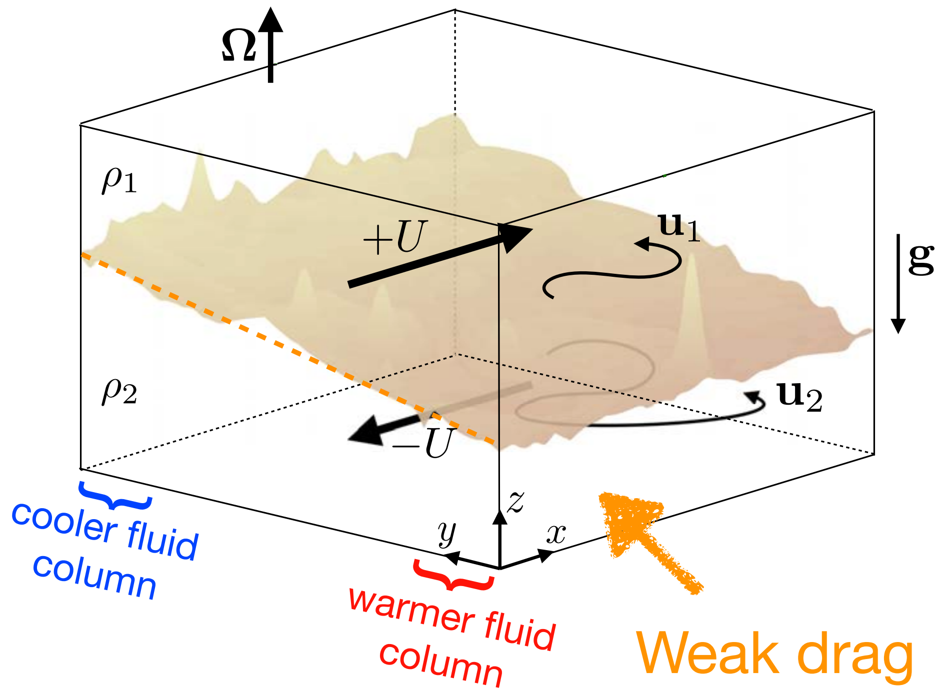

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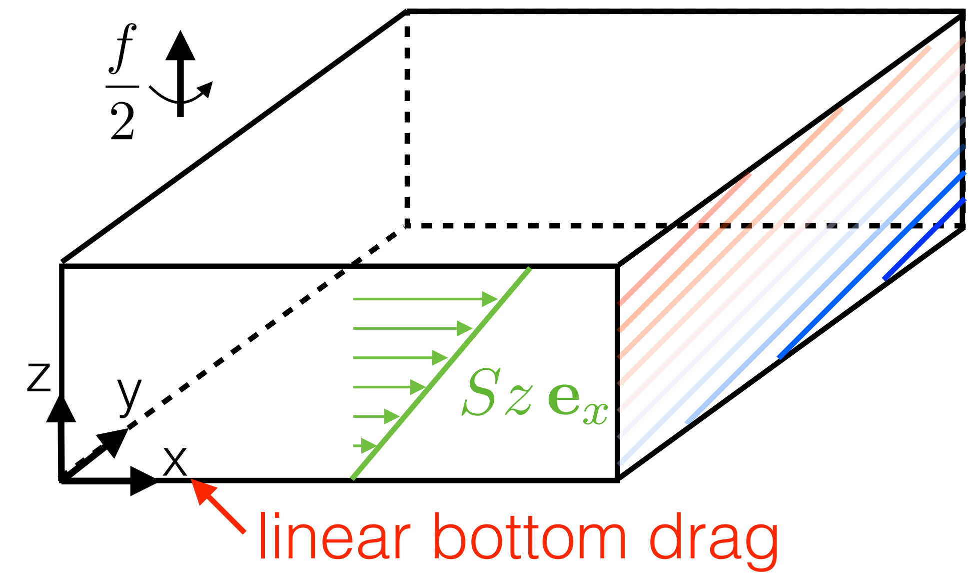

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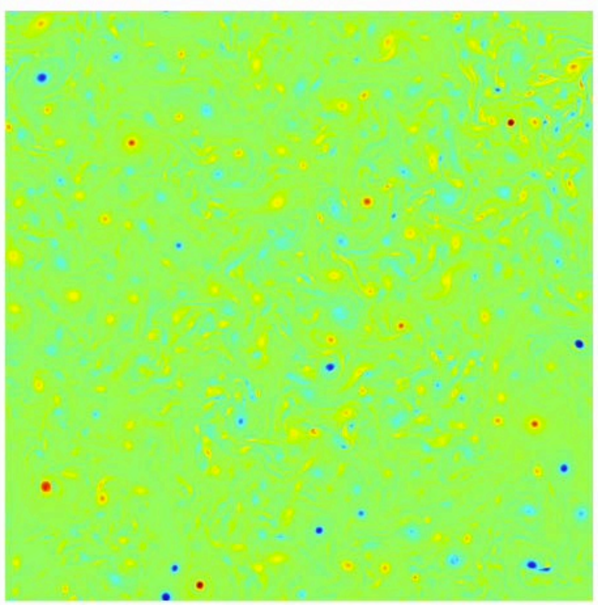

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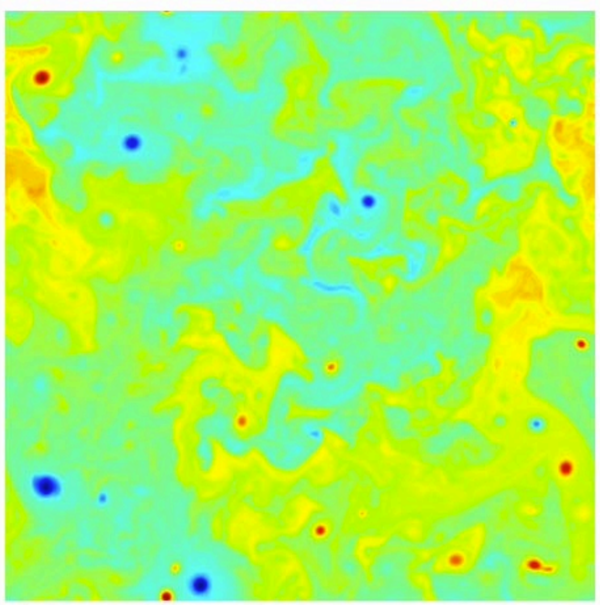

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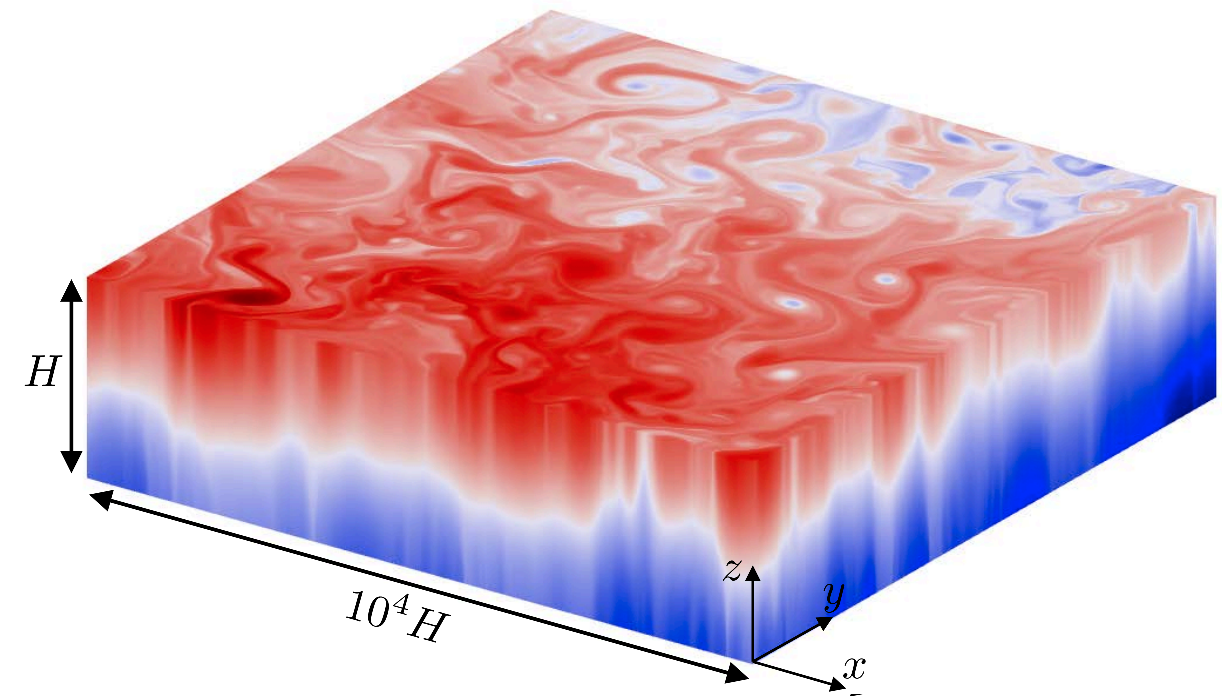
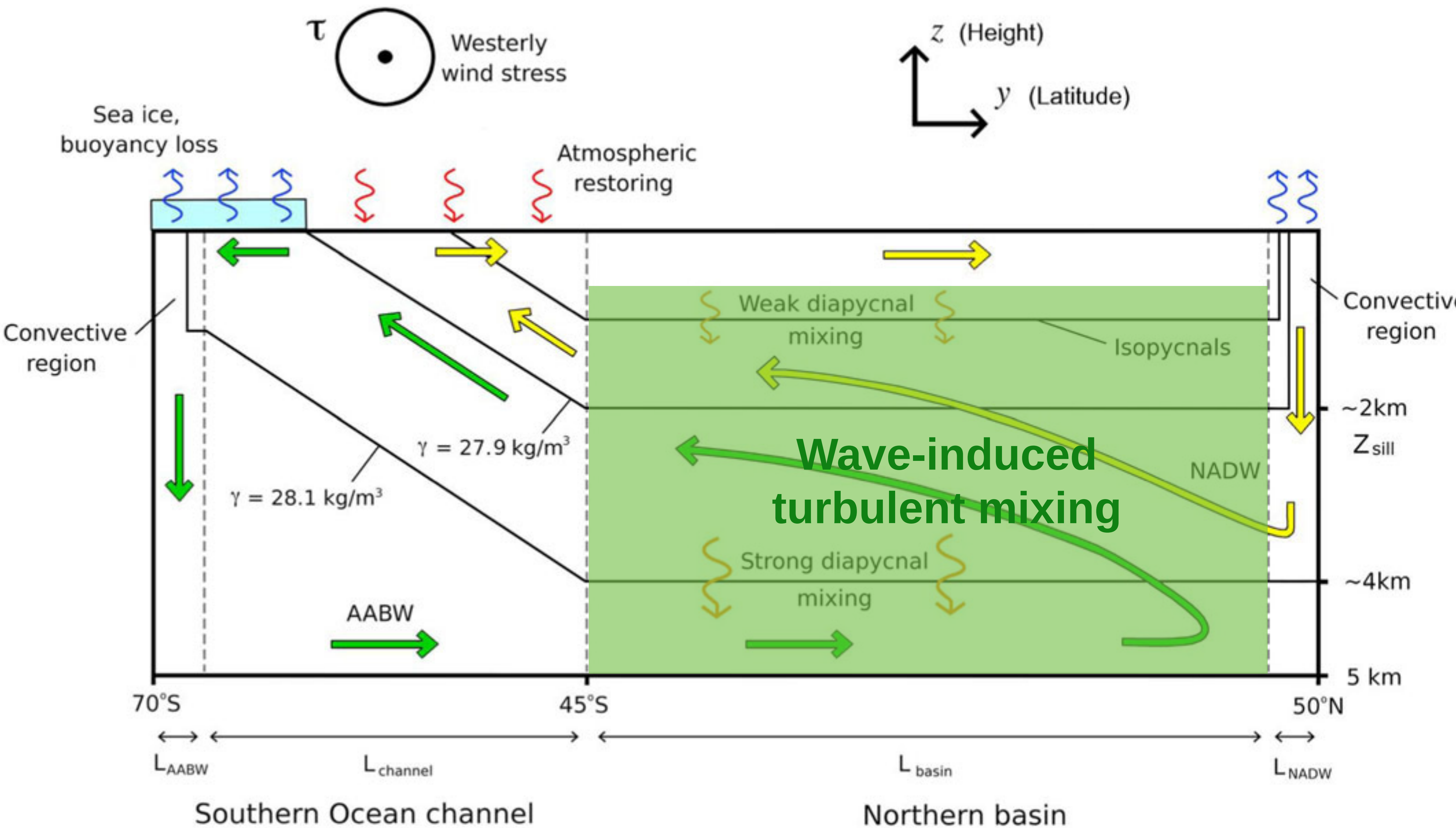


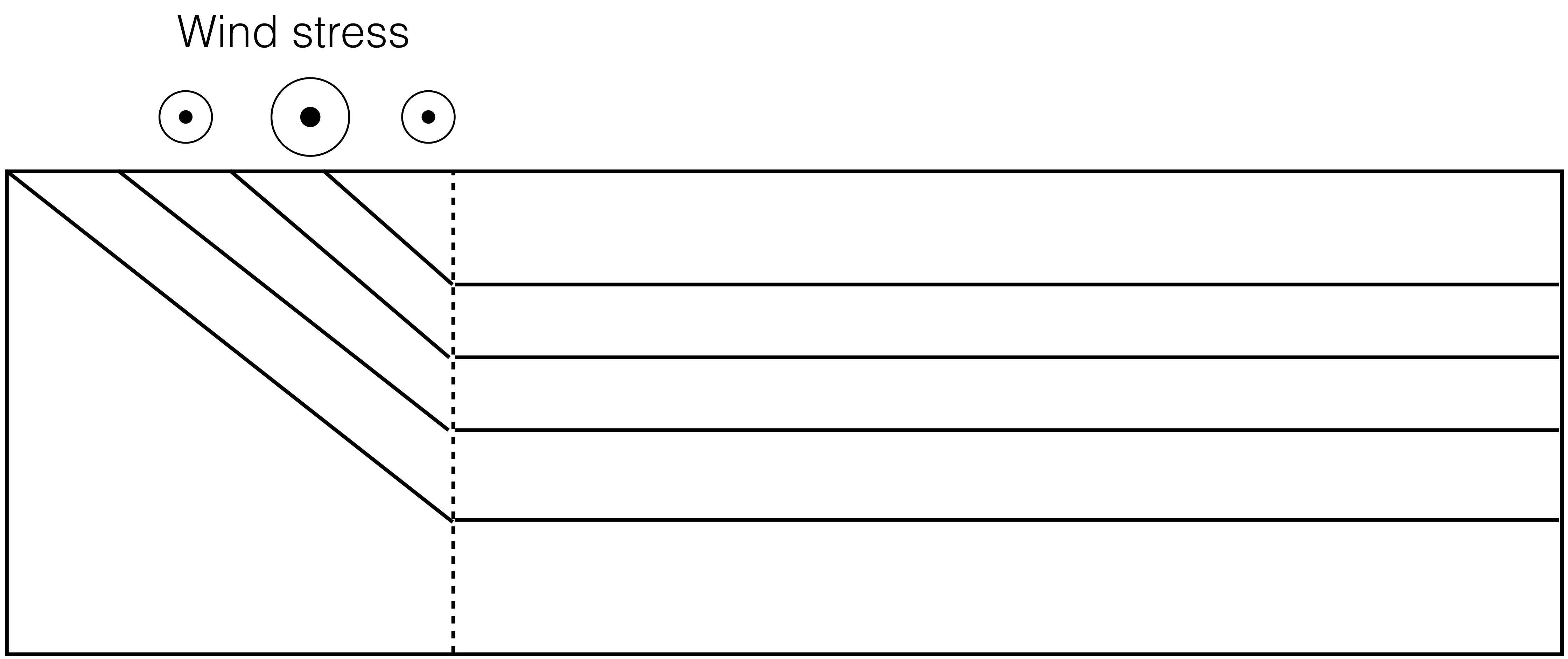
[Gallet et al., JFM 2022]

Can we gradually include all the relevant physical ingredients?

II. Wave-induced mixing



Origin of the overturning circulation



Turbulent diffusion in the large ocean basin allows for a circulation that crosses density surfaces.

→ Magnitude and vertical structure of the diffusivity?

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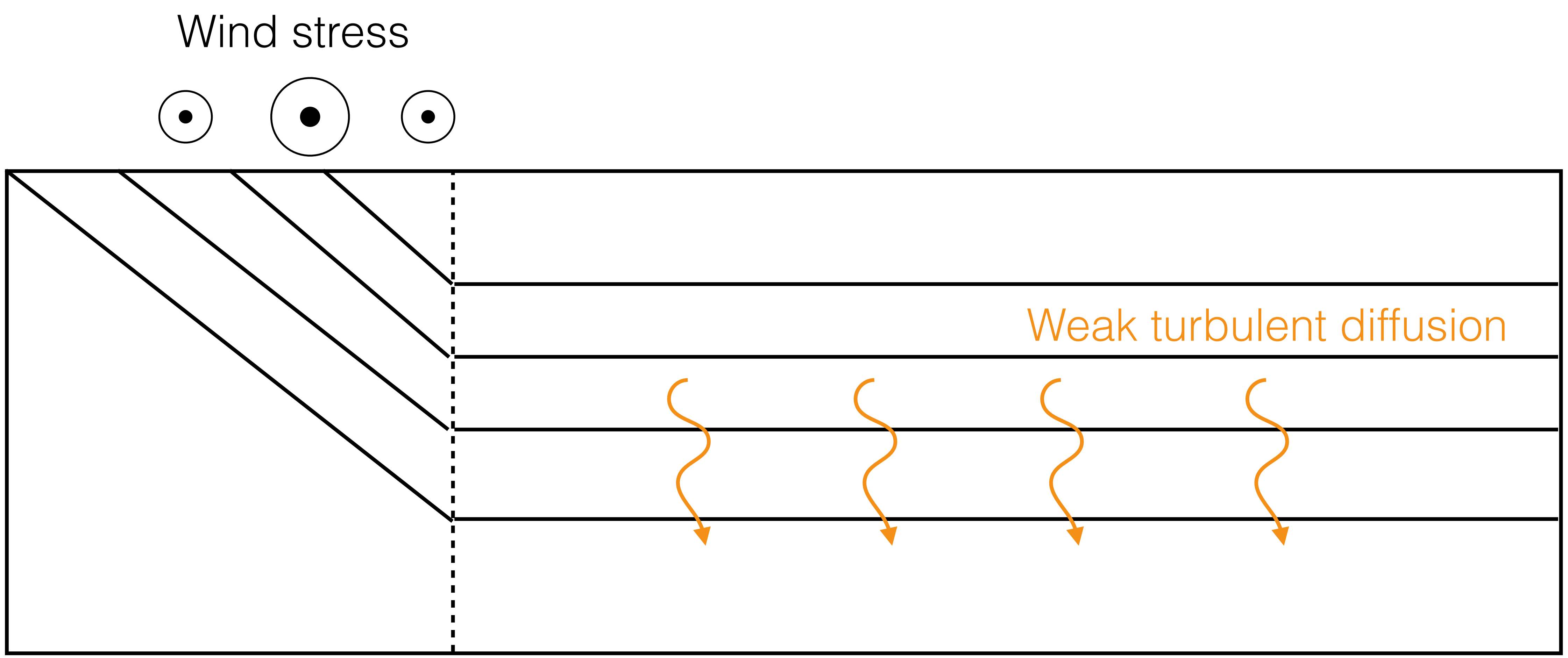

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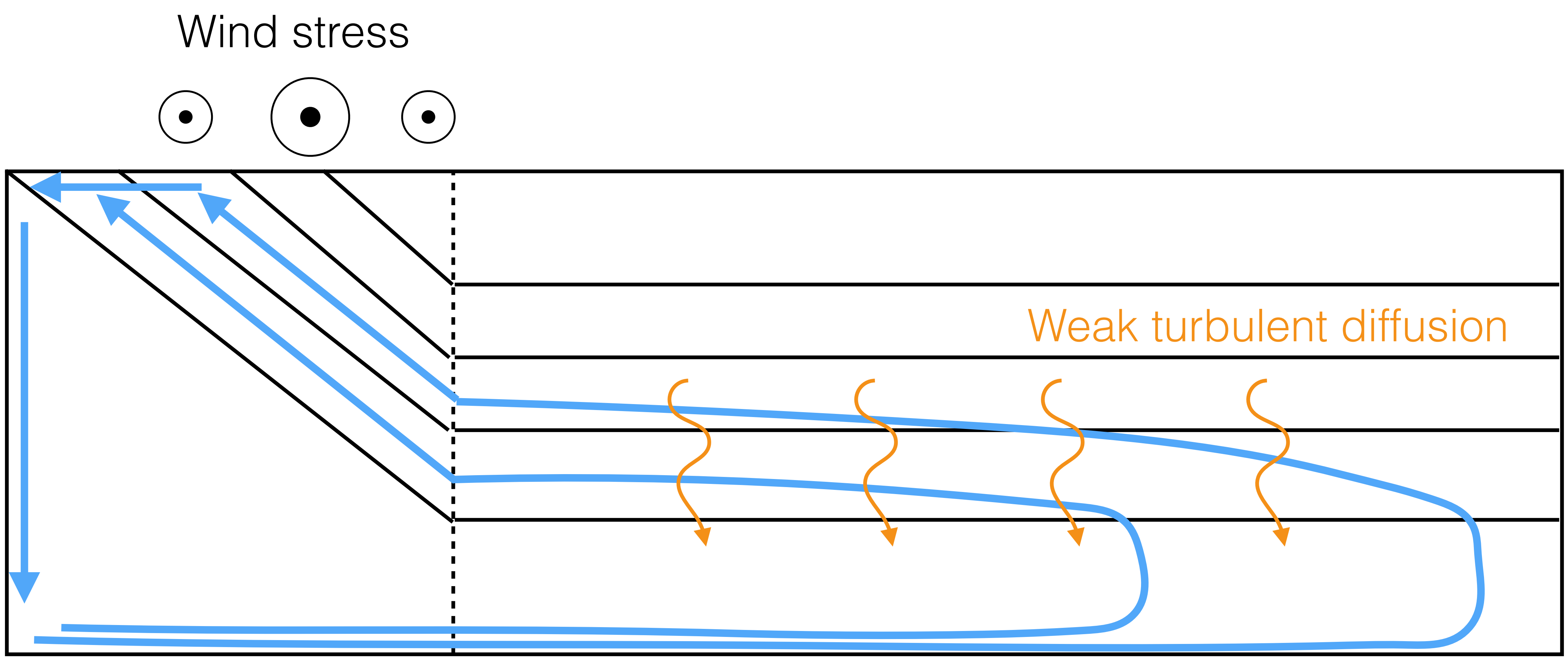

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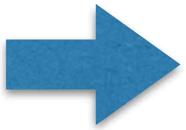


Magnitude and vertical structure of the diffusivity?

Wave-induced turbulent mixing

Generation of internal gravity waves through interaction of flows with bottom topography

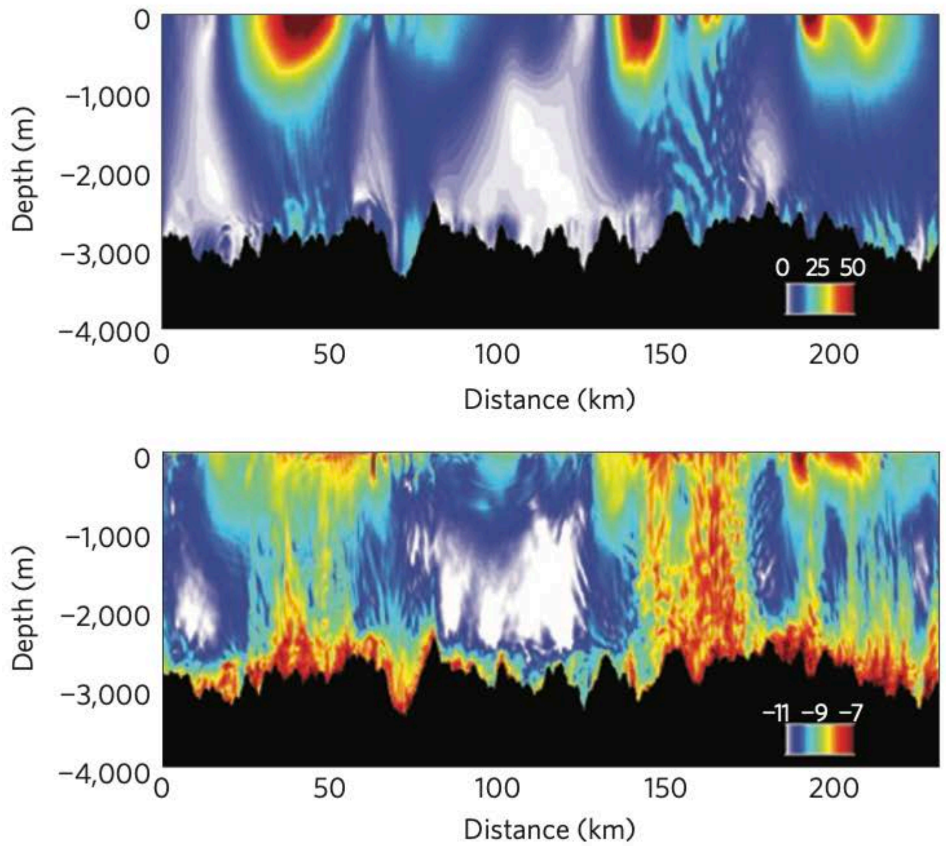
Radiated power ?
Spectrum of emitted waves ?

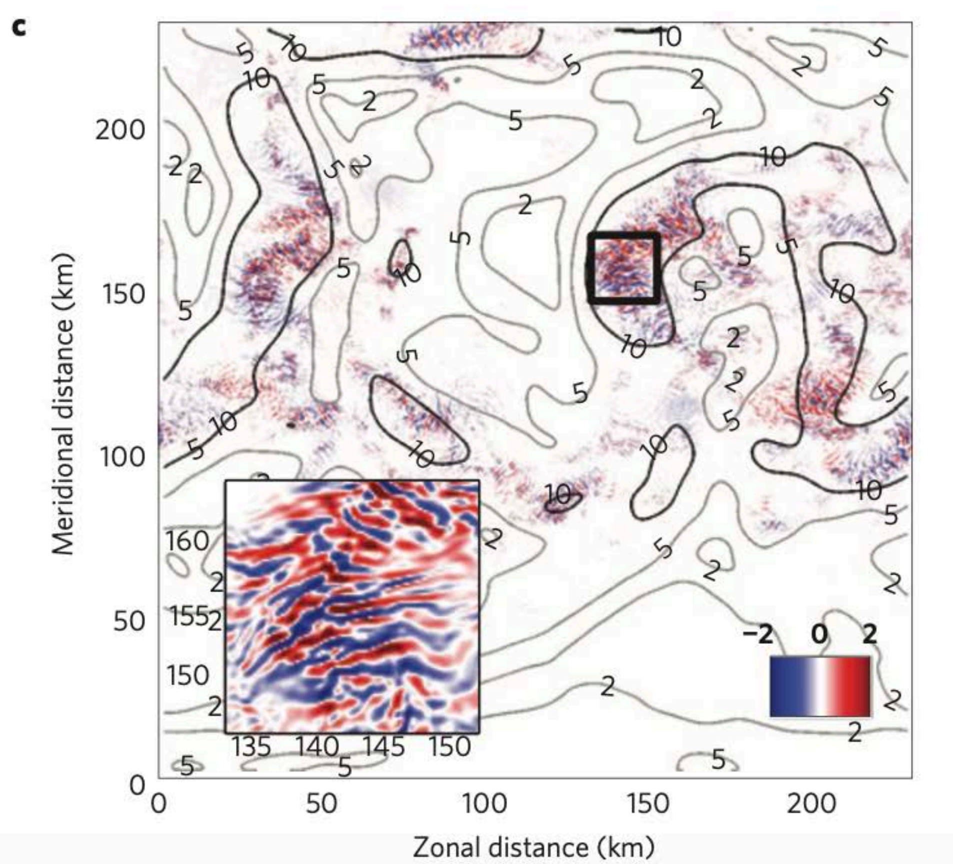
Nonlinear wave interactions away from the topography.

A wave turbulence regime ?
Breaking of steep internal waves ?
Interaction between waves and slow mean flow?

Wave-induced turbulent mixing

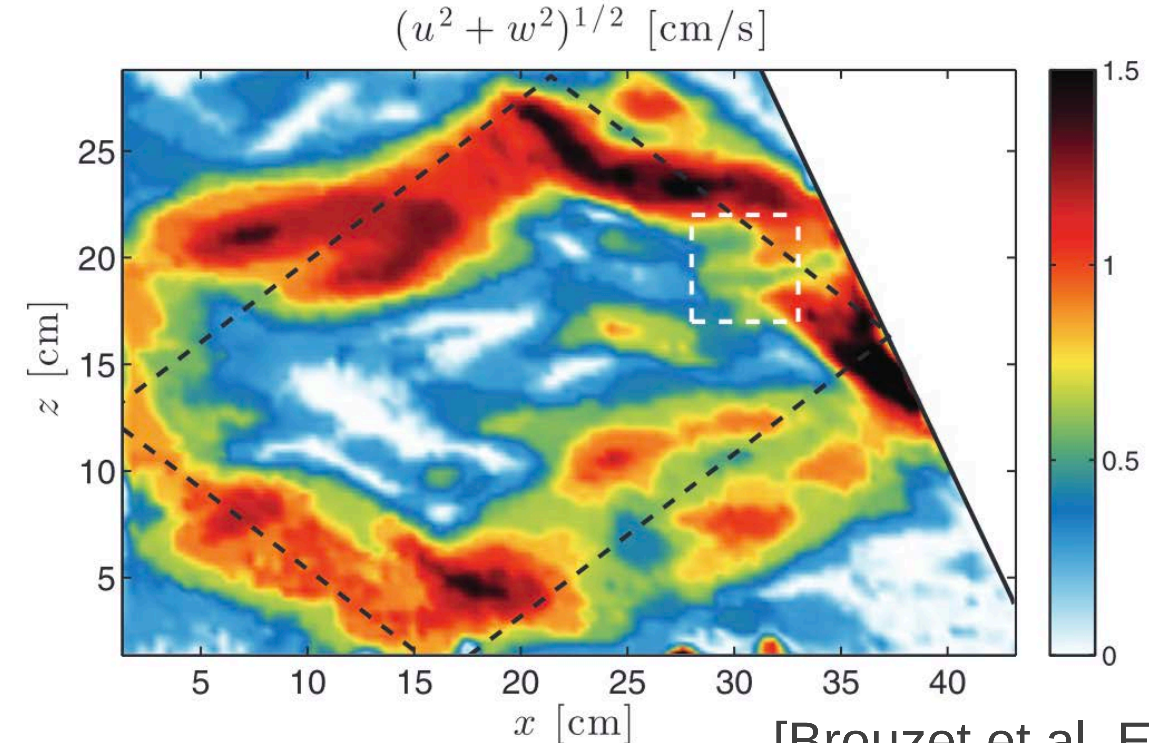
Wave radiation by topography:





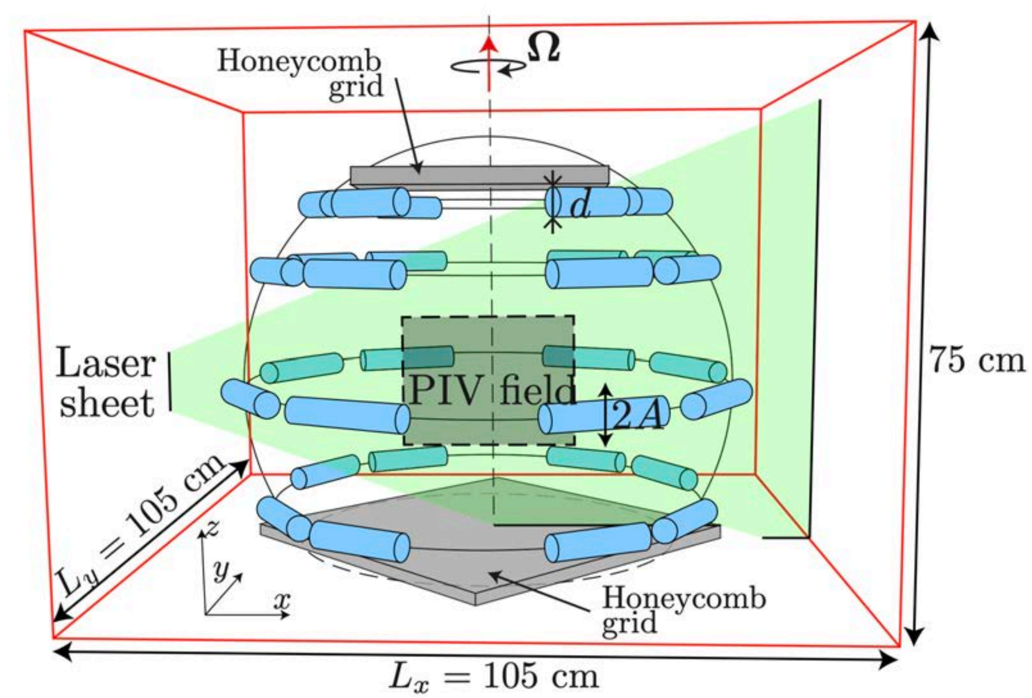
[Nikurashin et al. Nat. Geosciences]

Internal wave attractor:



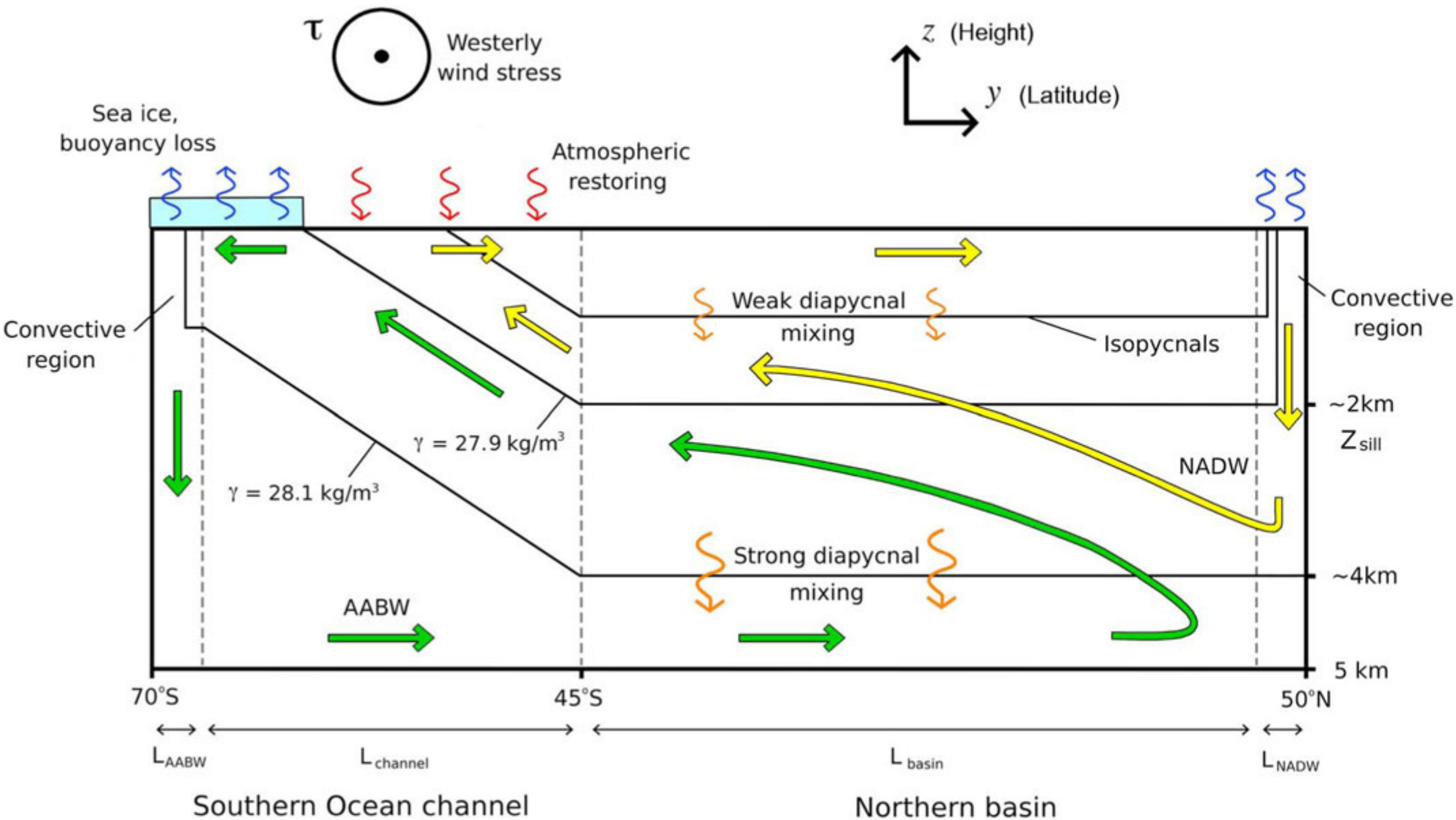
[Brouzet et al. EPL]

Inertial wave turbulence:



[Brunet et al. PRL, Monsalve et al. PRL]

III. Convective turbulence



Role for the strength of the Atlantic Meridional Overturning Circulation?

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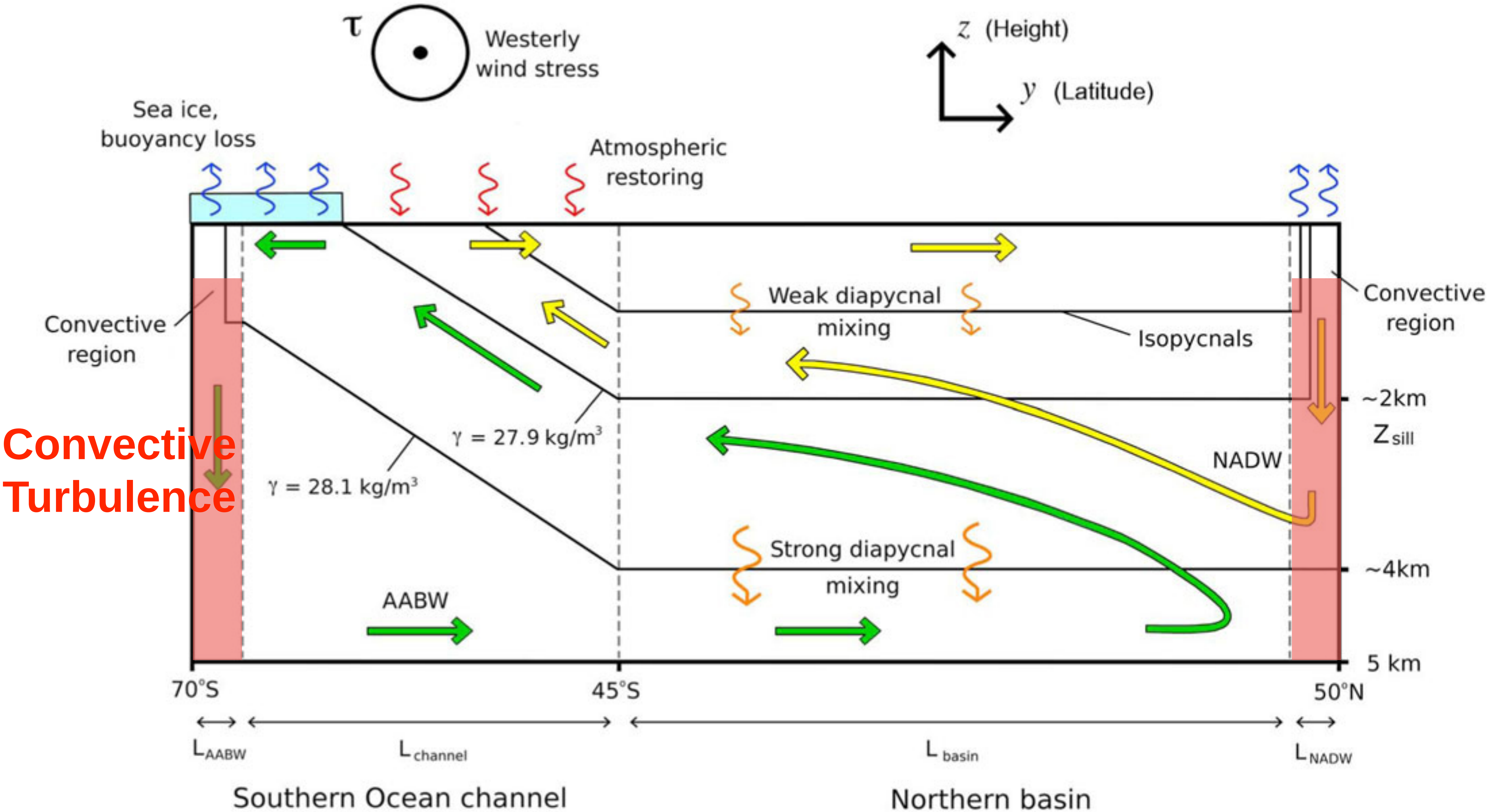


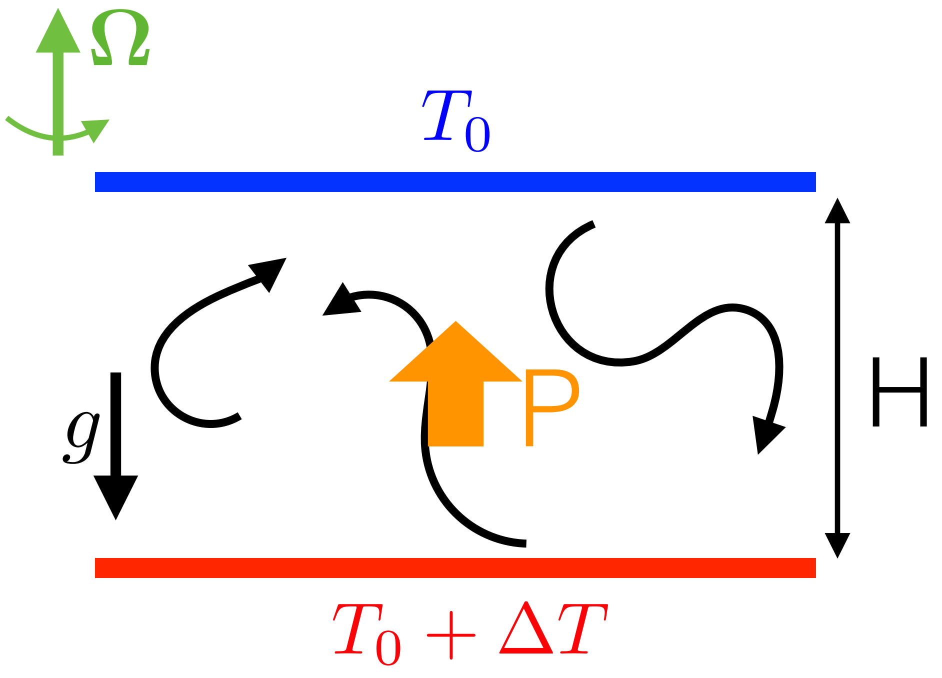
Role for the strength of the Atlantic Meridional Overturning Circulation?

Convection subject to rotation

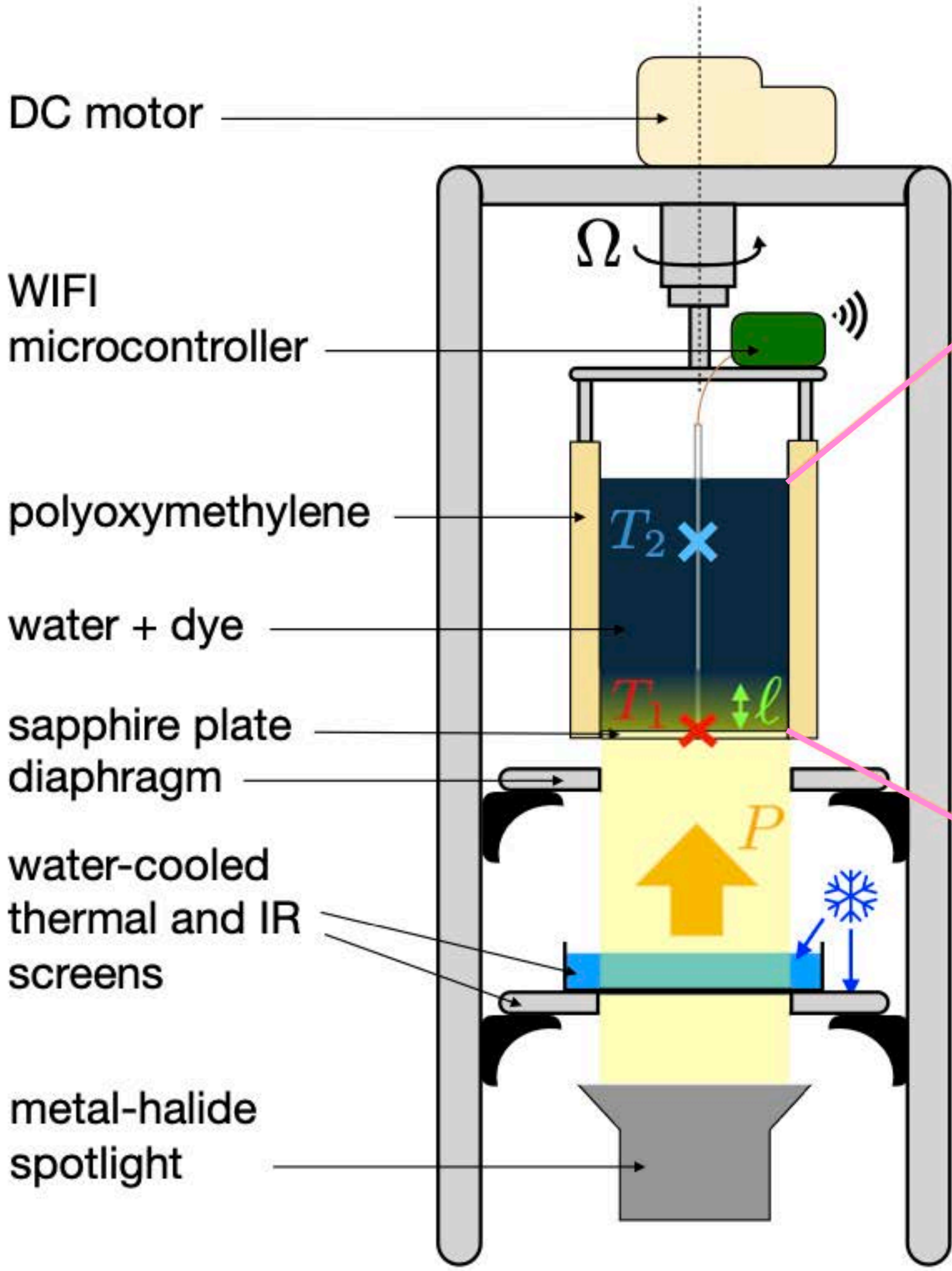
- Scaling arguments for temperature drop, velocity scale, vertical scale, in terms heat flux and rotation rate.

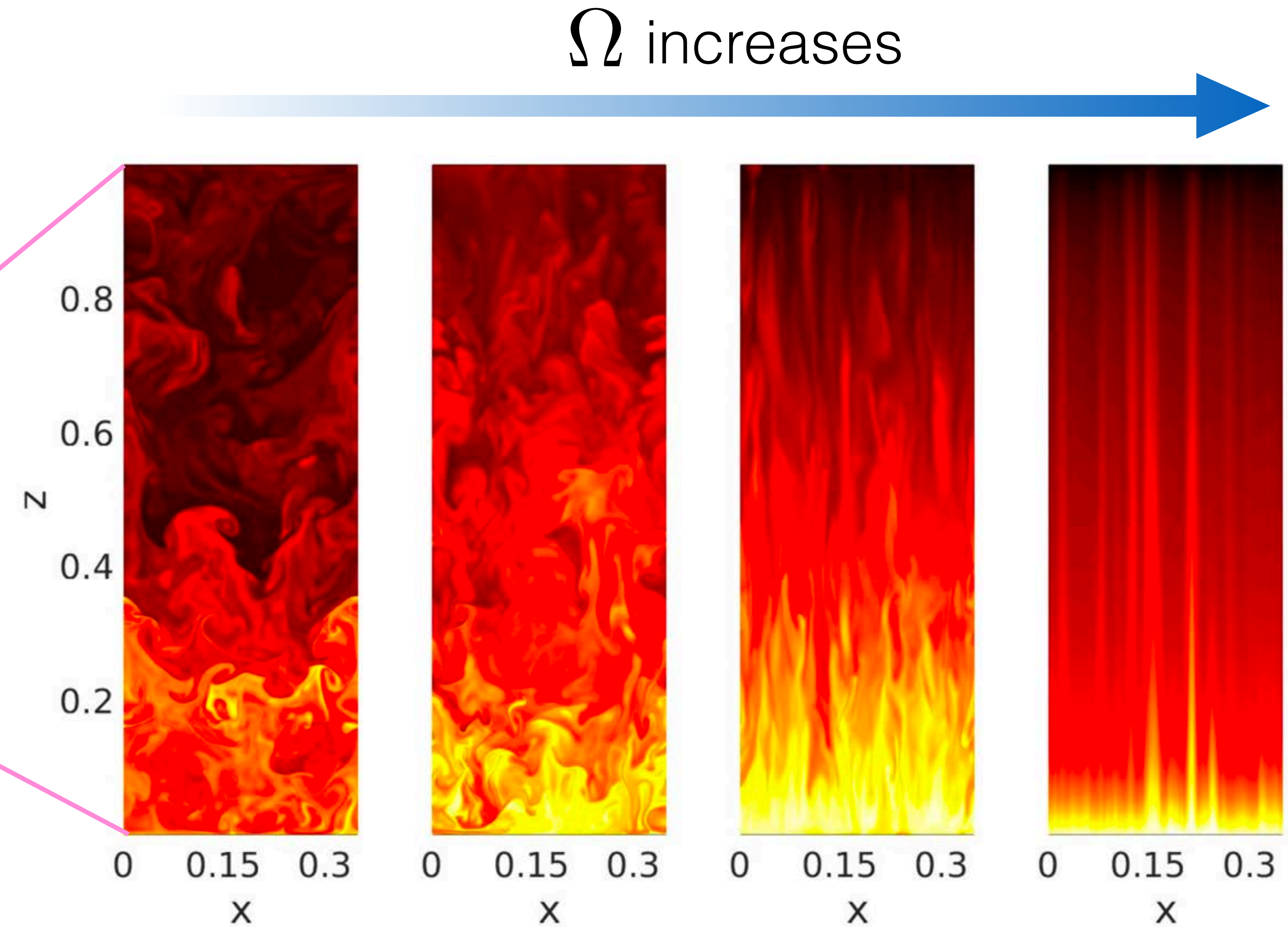
- Viscosity and diffusivities play no role according to oceanographers.

- However, standard numerical and experimental setups show strong dependence on diffusivities (Rayleigh-Bénard).



Introducing a new idealized setup



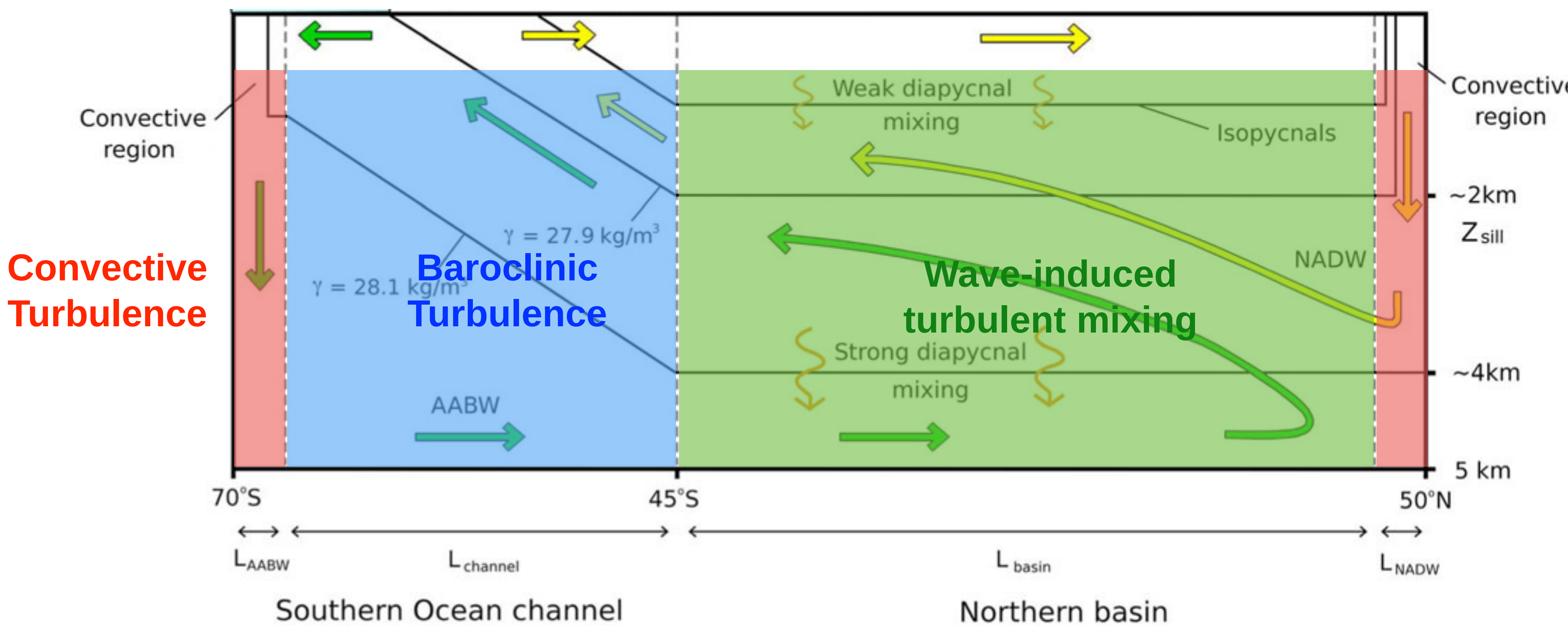


[Lepot et al., PNAS 2018]
[Bouillaut et al., PNAS 2021]

Leads to **diffusivity-free scaling-laws:** first observation of the 'geostrophic turbulence' regime of rotating convection. [Julien & Knobloch]

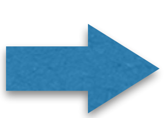
Conclusions

- Turbulence is everywhere in the ocean, under various forms.



- Strong control of turbulence on large-scale ocean structure: flow and stratification.

- Studied by physicists using idealized setups of increasing complexity



Physically-based parameterizations to be implemented in global climate models.

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