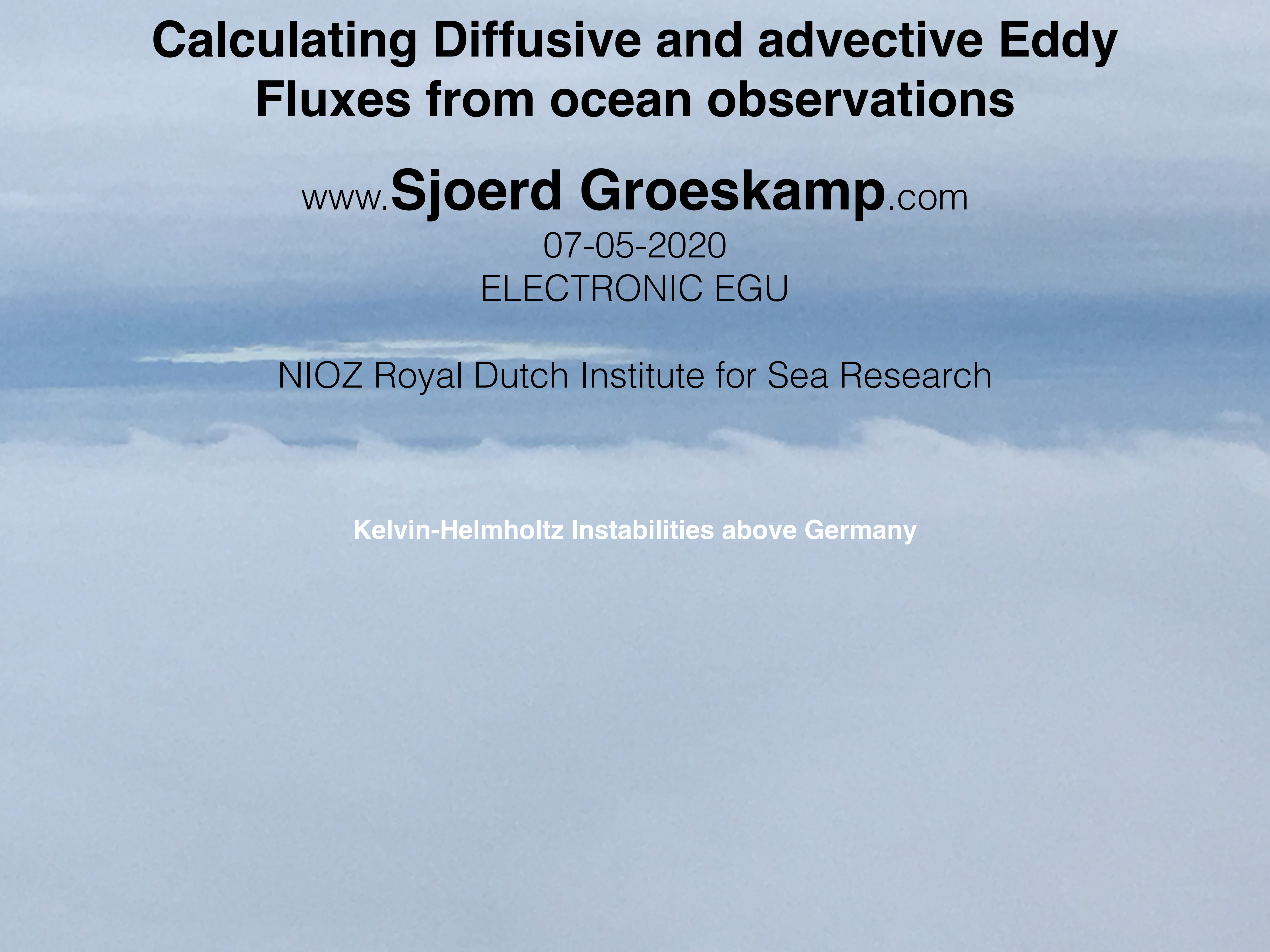
Calculating Diffusive and advective Eddy Fluxes from ocean observations

www.**Sjoerd Groeskamp**.com

07-05-2020

ELECTRONIC EGU

NIOZ Royal Dutch Institute for Sea Research



Kelvin-Helmholtz Instabilities above Germany

Mixing in ~~the ocean~~ a Coffee Cup

Mixing = molecular scales. **Stirring** enhances mixing.

Stirring Coffee Cup (Order 0.1- 1 $m^2 s^{-1}$)

Flux:

$$D \nabla Milk$$

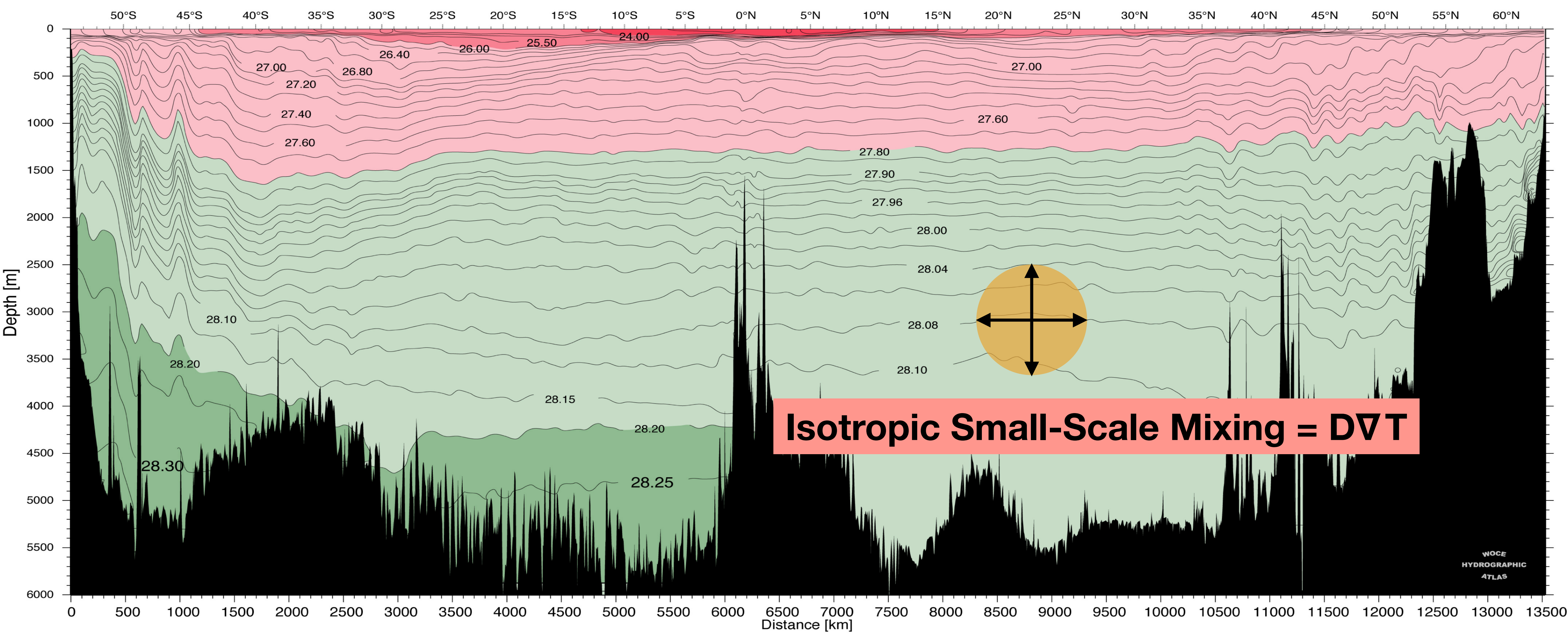
Diffusivity **Gradient of Property**

Representing mixing in numerical ocean models

Isotropic (~vertical) small-scale Mixing

$$\mathbf{D}\ \nabla \mathbf{T} \quad (\approx D\, dT/dz)$$

Small-Scale Mixing (D = Order 10^{-4} m^2 s^{-1}):
E.g. Breaking Internal Waves, Wind, etc.

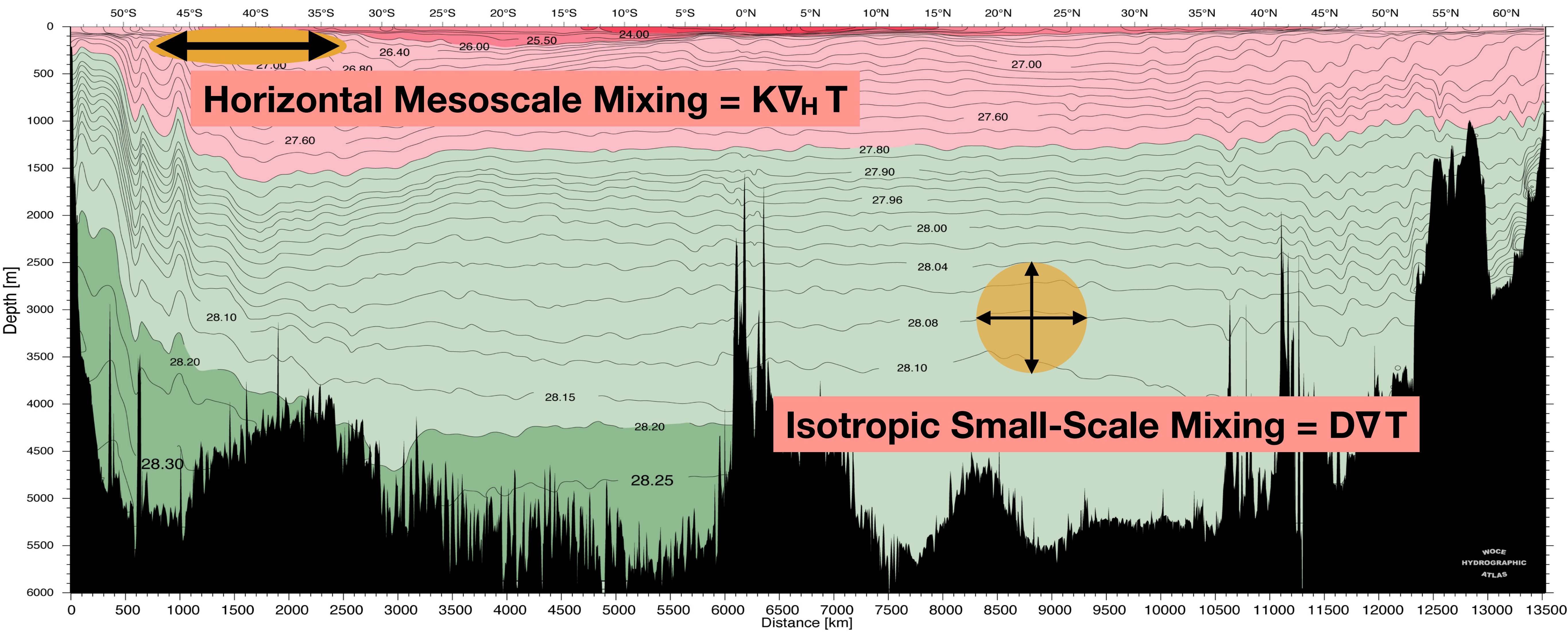


Representing mixing in numerical ocean models

Horizontal Mesoscale Mixing

$$K \nabla_H T$$

Mesoscale Eddy: large scale variations of mean flow (**K** = Order 10^3 m^2 s^{-1}):



Representing mixing in numerical ocean models

Isoneutral Mesoscale Mixing

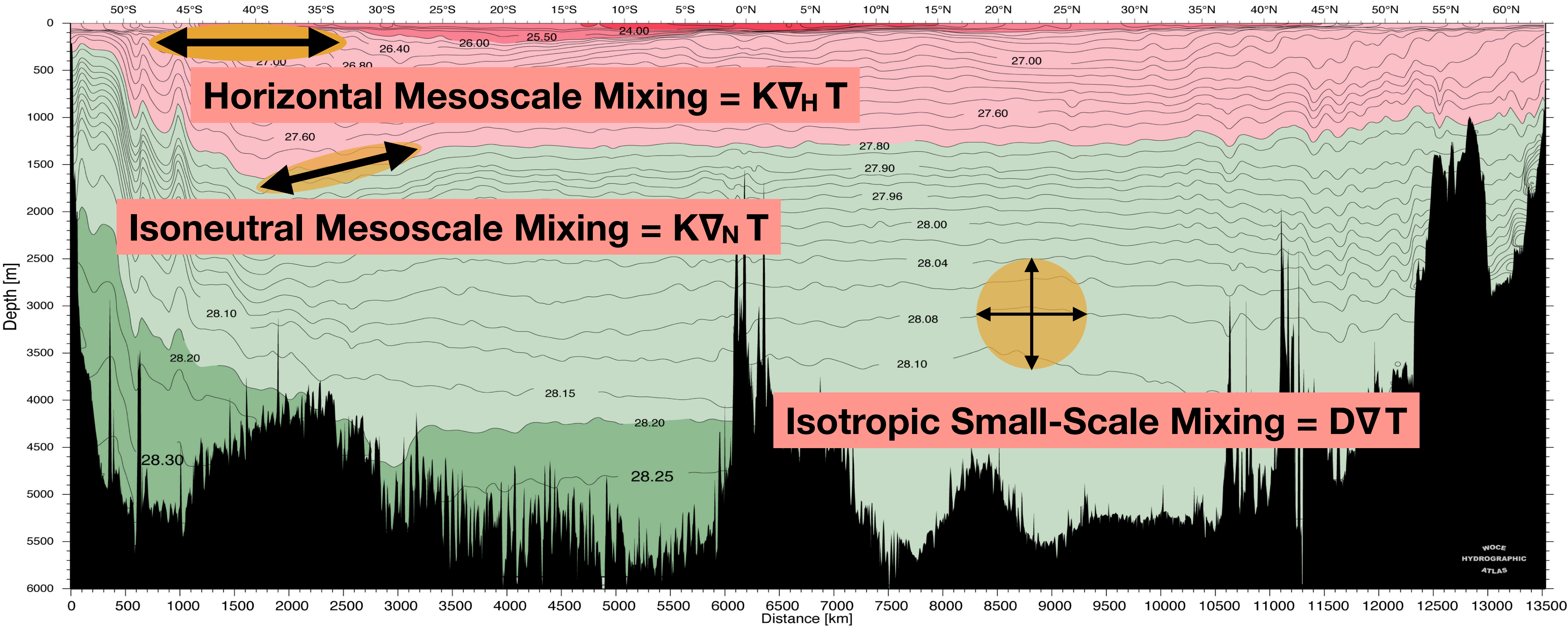
$$K \nabla_N T$$

Isoneutral motion - Except for changes in buoyancy:

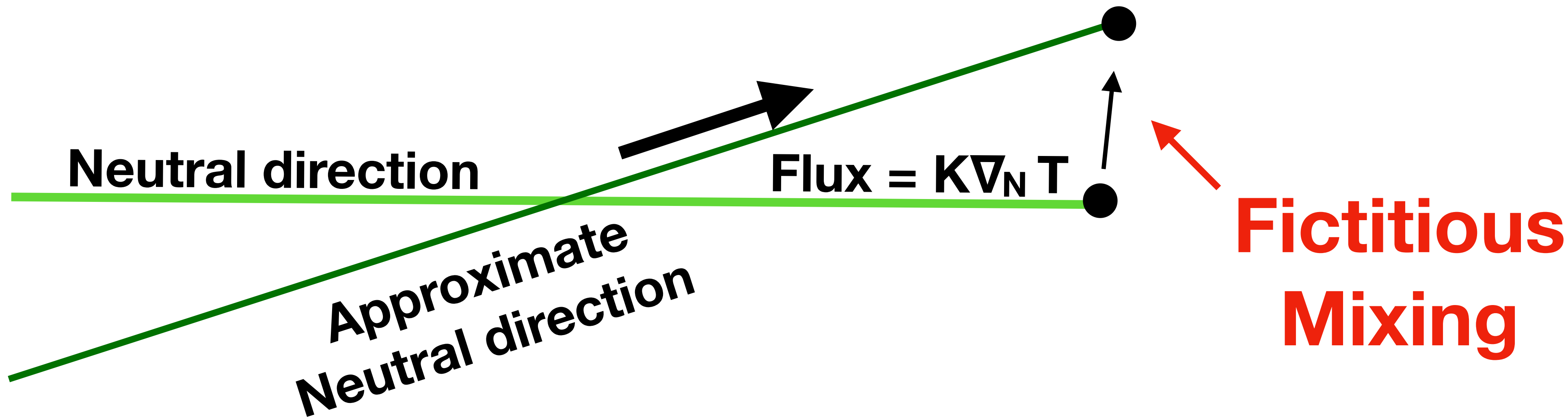
-Small-Scale Mixing

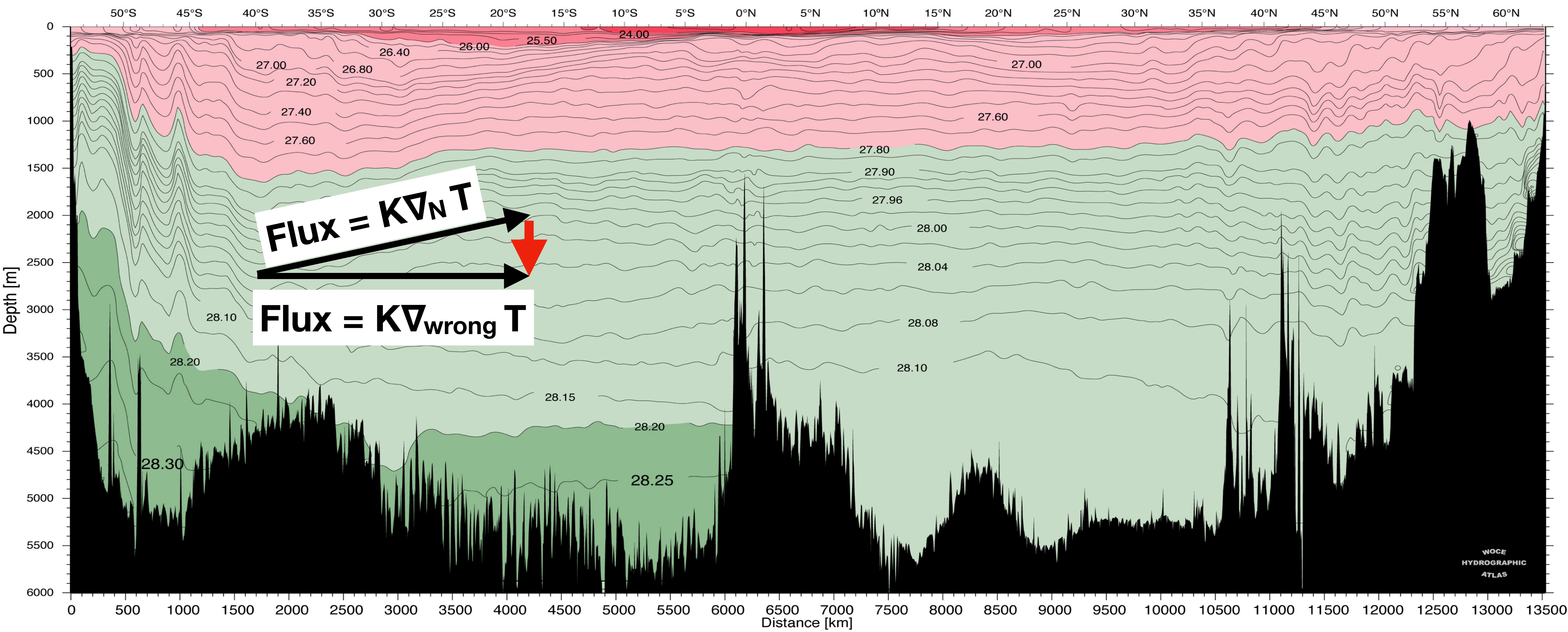
-Cabbeling and Thermobaricity

(see also: McDougall, Groeskamp and Griffies (2014, 2017, 2019 - in prep)



Representing mixing in numerical ocean models

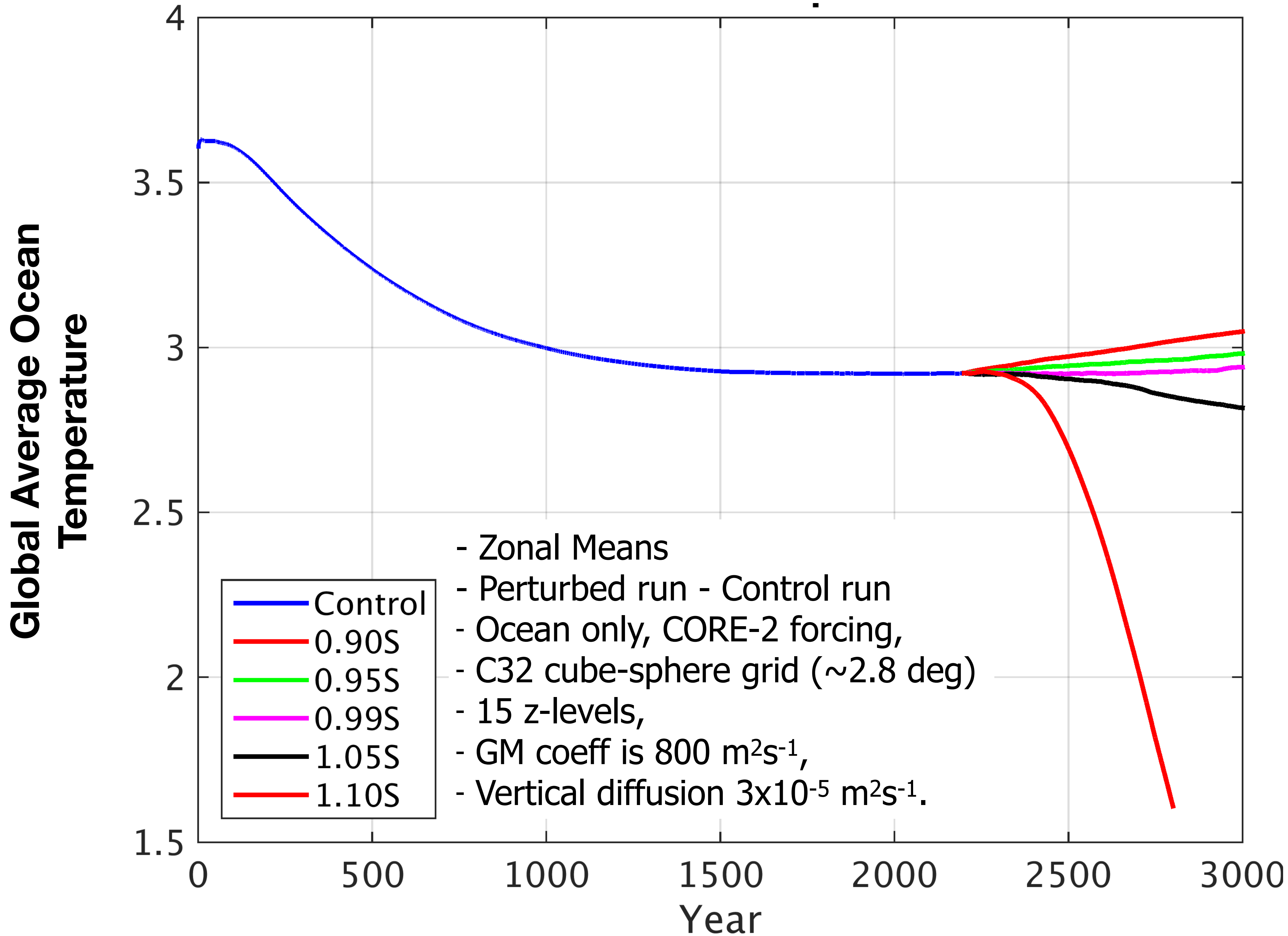




Representing mixing in numerical ocean models

Global Mean Ocean Temperature

Collaboration with **D. Ferreira** (University of Reading)



Why care?
It Matters for things that matter!

Gent-McWilliams Parametrization

$$\Upsilon^{GM} = K_{GM}\,\mathbf{S} = K_{GM}\,(S_x, S_y)$$

Redi-Diffusion

$$\mathbf{K}\ \nabla_N\ \mathbf{T}$$

Influences Tracer transport (GM) and diffusion (Redi):
Heat
Carbon
Nutrients
Oxygen

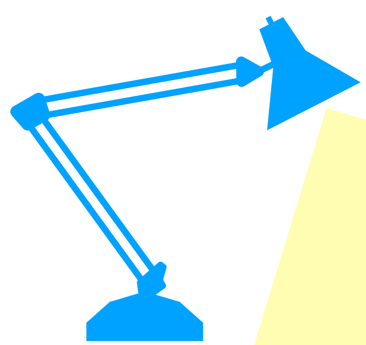
This significantly affects state of ocean and climate.

Outline and Conclusions:

There is an old method 

Now there is a new method

The new method is better 



This is very important

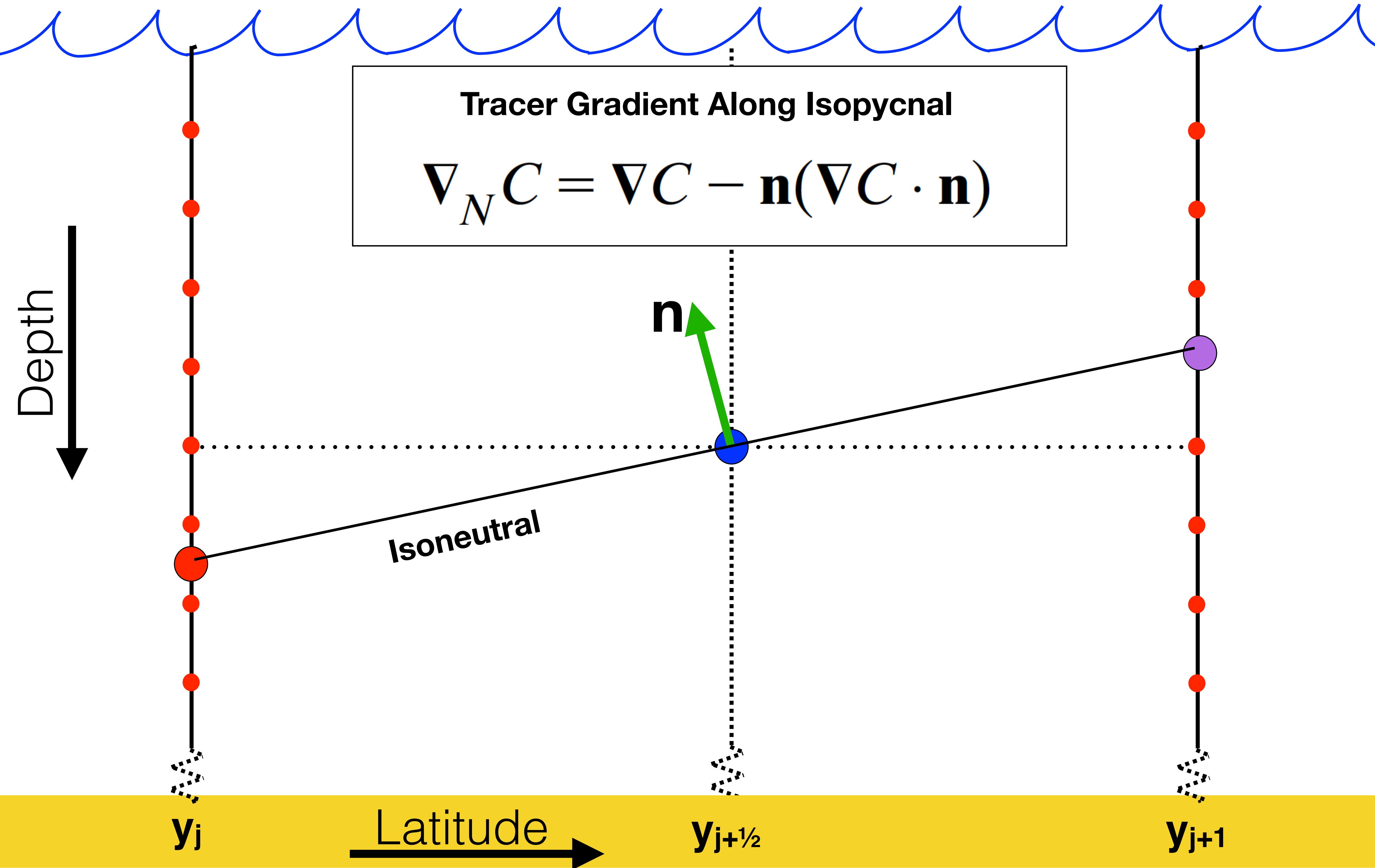
end

The “Local” Method

Based on: Redi 1982

Tracer Gradient Along Isopycnal

$$\nabla_N C = \nabla C - \mathbf{n}(\nabla C \cdot \mathbf{n})$$

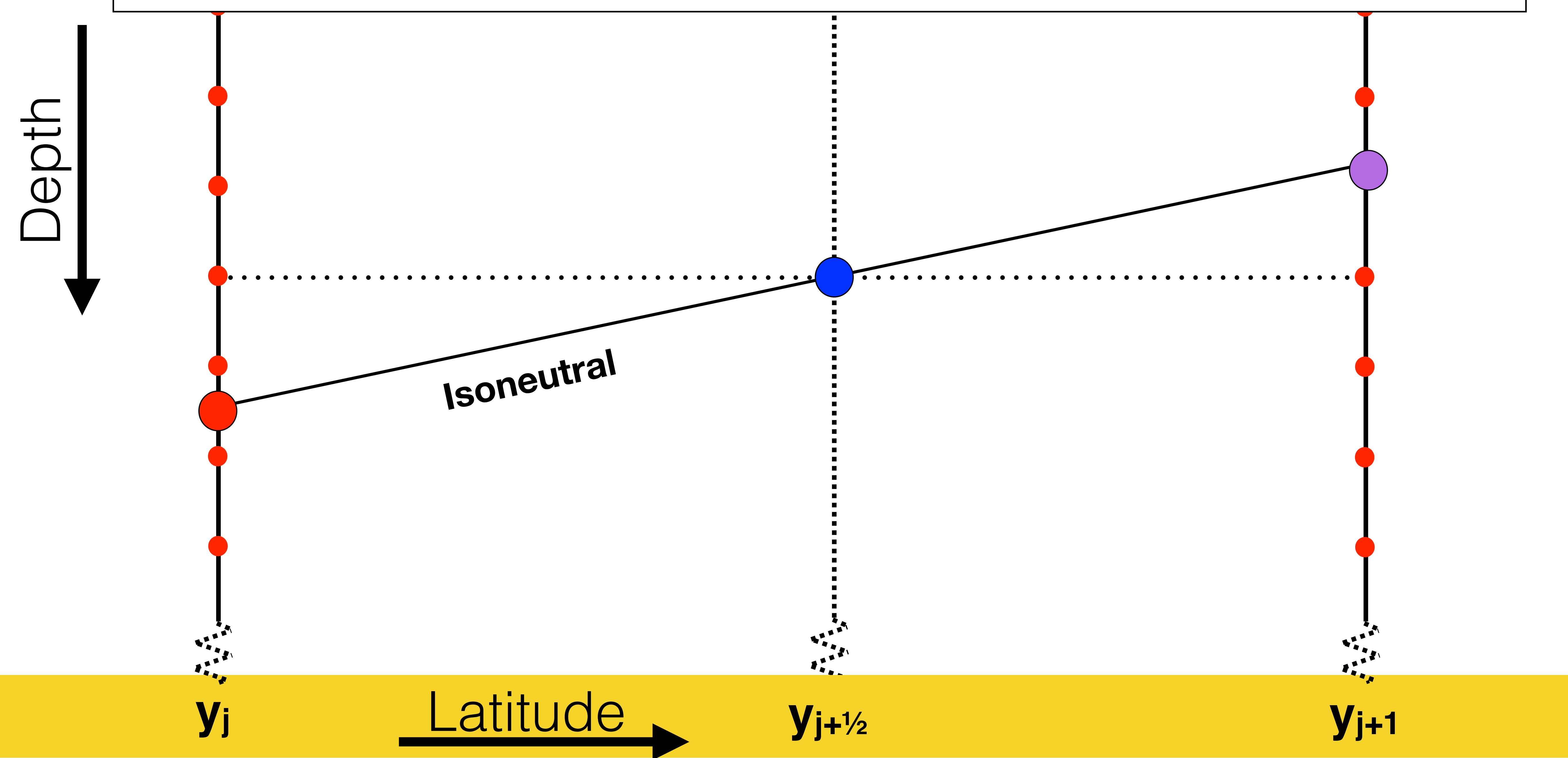


The “Local” Method

Based on: Redi 1982

Work it out:

$$\nabla_N \Theta \cdot \mathbf{j} = \left.\frac{\partial \Theta}{\partial y}\right|_N \quad =$$



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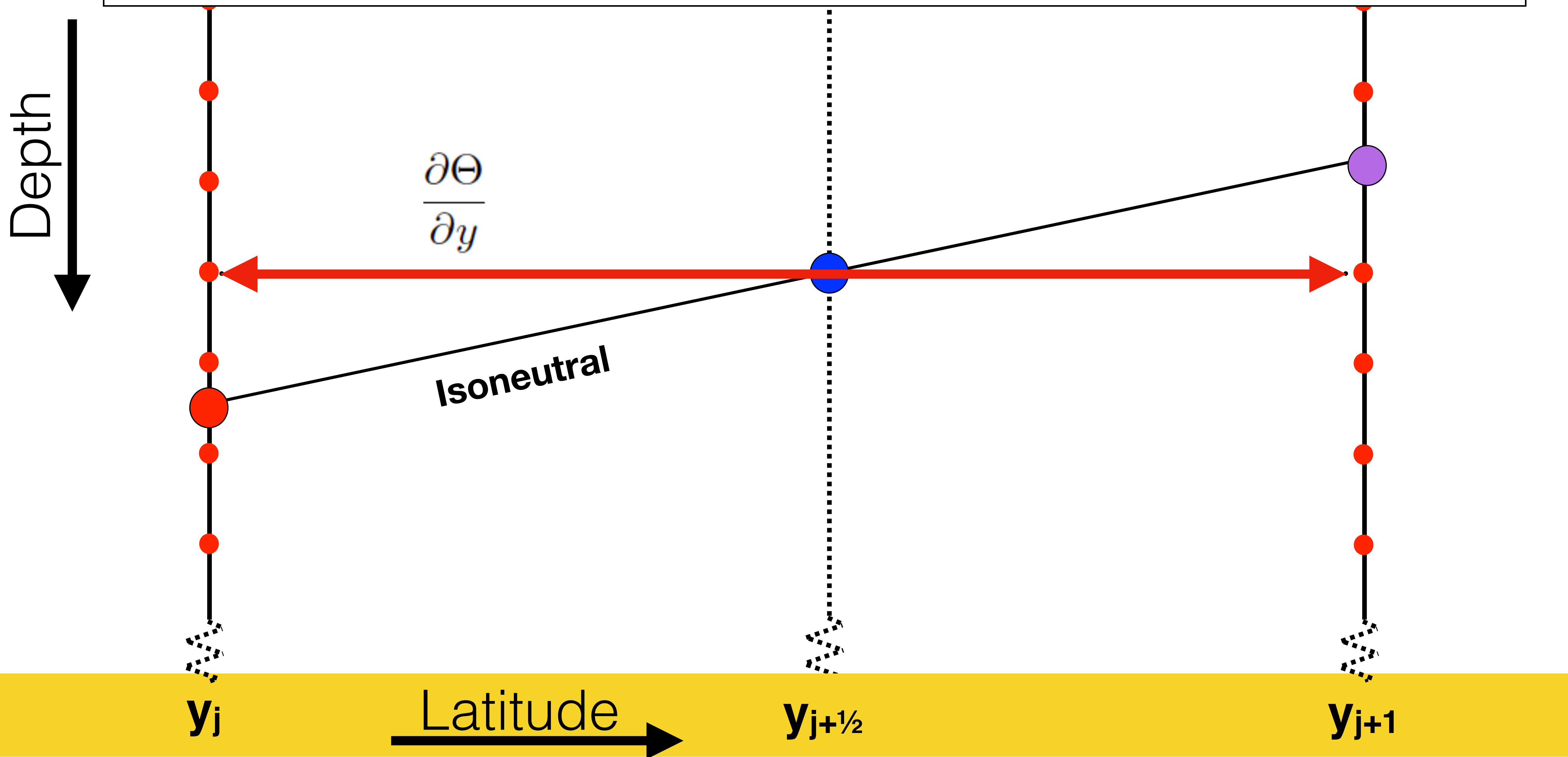
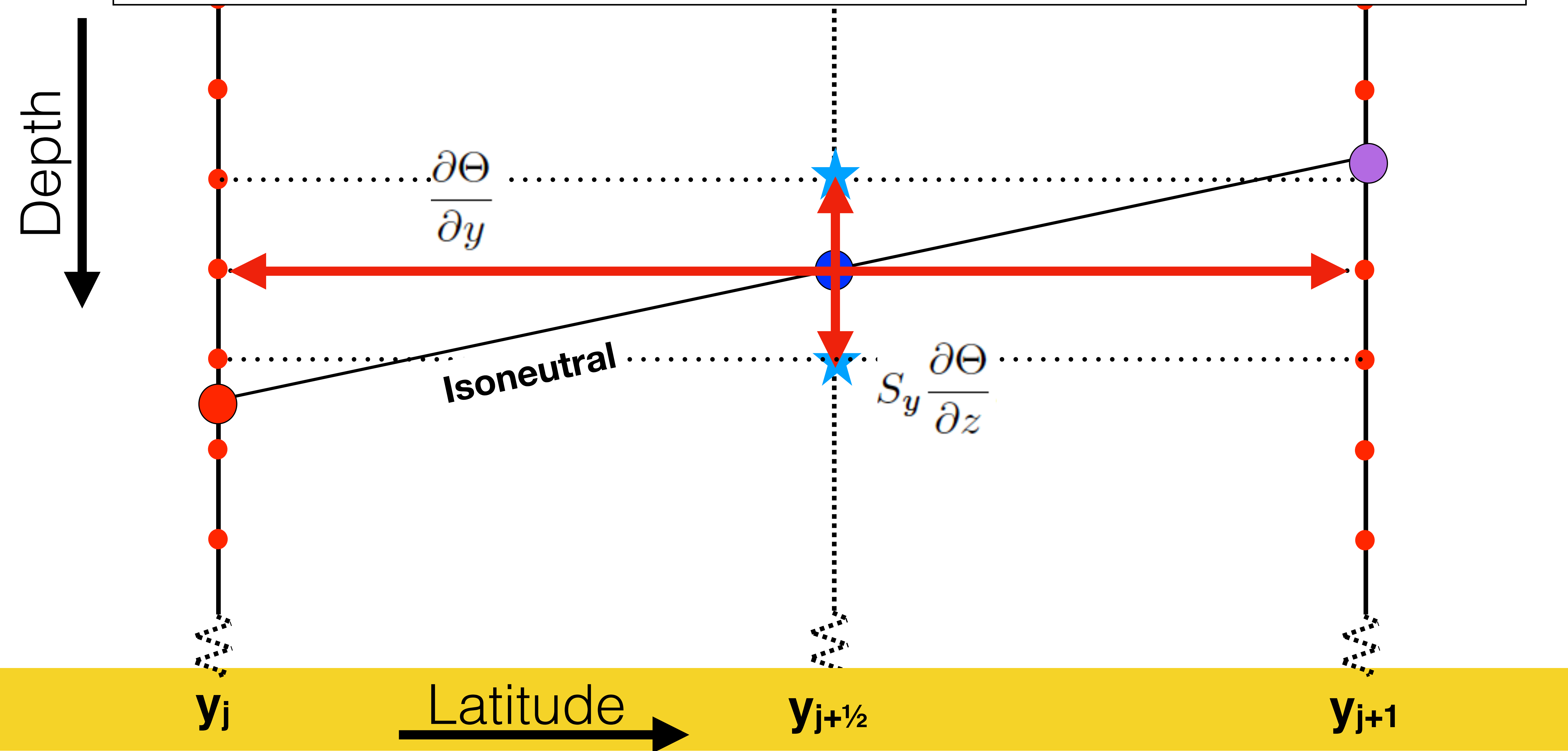


The “Local” Method

Based on: Redi 1982

Work it out:

$$\nabla_N \Theta \cdot \mathbf{j} = \left.\frac{\partial \Theta}{\partial y}\right|_N \quad = \quad \frac{\partial \Theta}{\partial y} + S_y \frac{\partial \Theta}{\partial z}$$



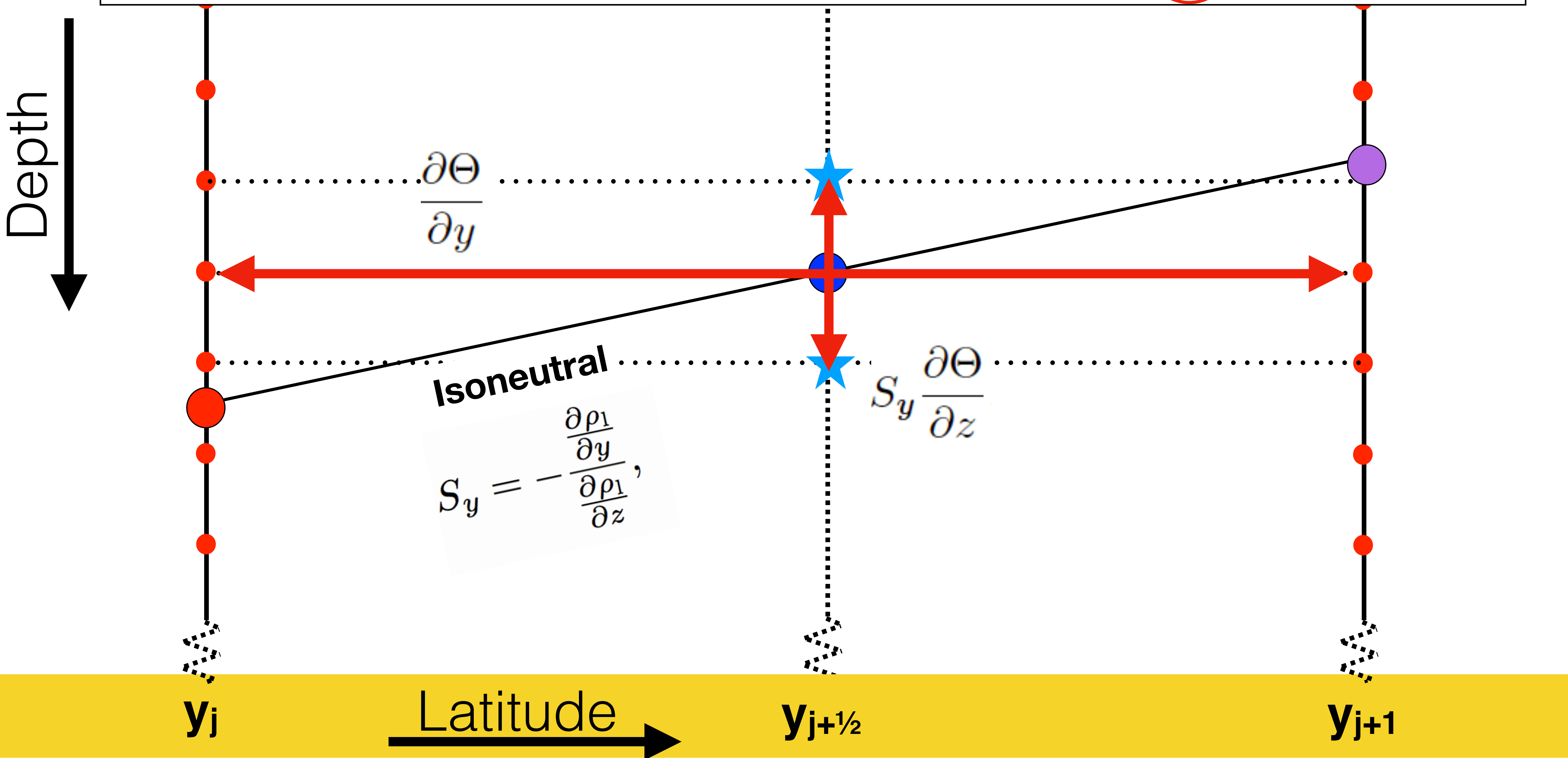
The "Local" Method

Based on: Redi 1982

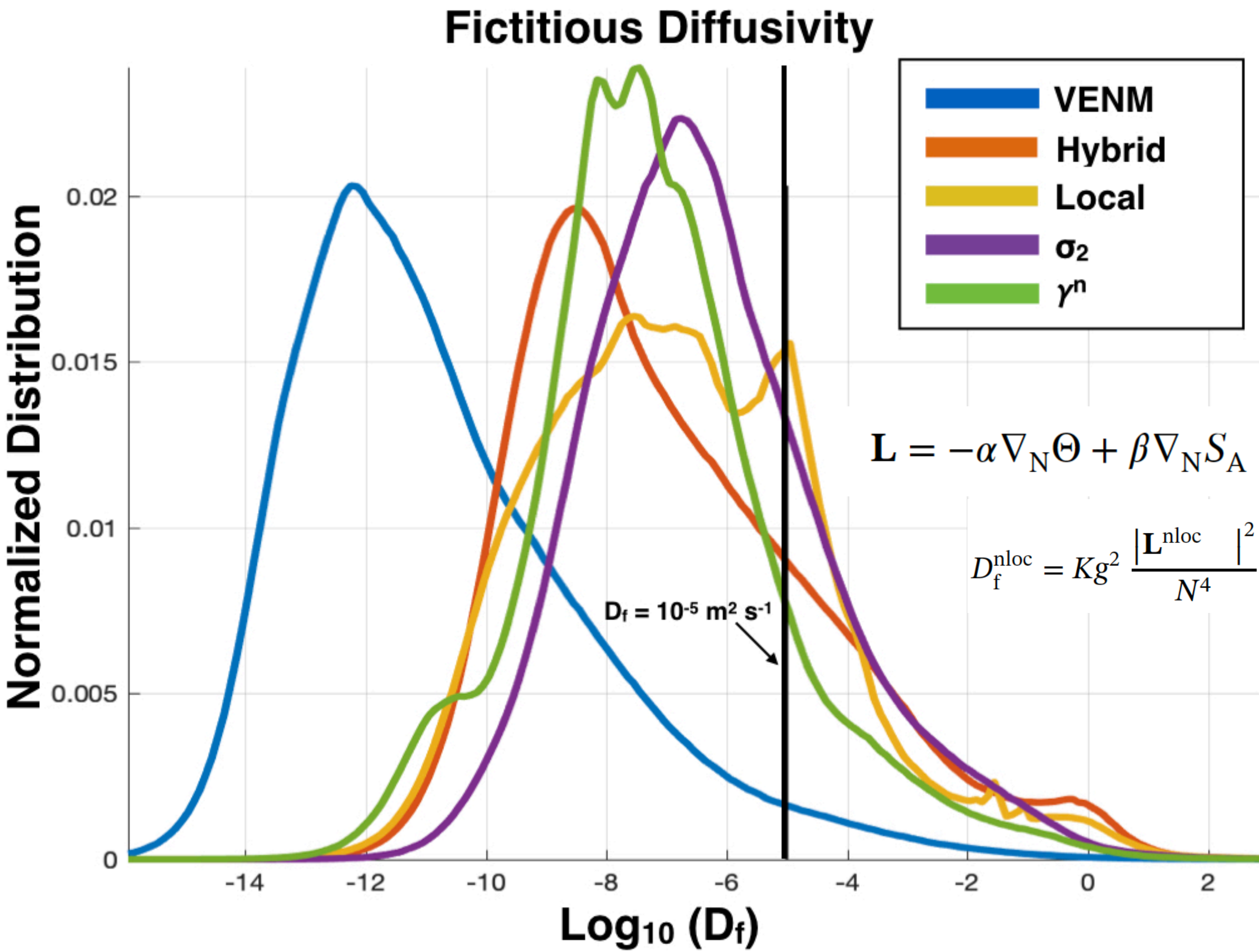
Local Method [with S_{max} = 0.01]

$$\nabla_N \Theta \cdot \mathbf{j} = \left.\frac{\partial \Theta}{\partial y}\right|_N = \frac{\partial \Theta}{\partial y} + S_y \frac{\partial \Theta}{\partial z} \qquad S_y = -\frac{\frac{\partial \rho_1}{\partial y}}{\frac{\partial \rho_1}{\partial z}},$$

Can go to zero



So far so good: you would think…



$$\mathbf{L} = -\alpha \nabla_N \Theta + \beta \nabla_N S_A = 0.$$

$$D_f^{nloc} = K g^2 \frac{\left|\mathbf{L}^{nloc}\right|^2}{N^4},$$

Talk about this paper

AGU100 ADVANCING EARTH AND SPACE SCIENCE

JAMES Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2019MS001613

VENM: An Algorithm to Accurately Calculate Neutral Slopes and Gradients

Sjoerd Groeskamp[1], Paul M. Barker[1], Trevor J. McDougall[1], Ryan P. Abernathey[2], and Stephen M. Griffies[3]

[1]School of Mathematics and Statistics, University of New South Wales, Sydney, New South Wales, Australia, [2]Lamont-Doherty Earth Observatory, Columbia University, New York City, NY, USA, [3]NOAA Geophysical Fluid Dynamics Laboratory and Princeton University Program in Atmospheric and Oceanic Sciences, Princeton, NJ, USA

Key Points:
- We provide a vertically nonlocal method (VENM) to calculate neutral slopes and gradients
- A VENM-like method is numerically and physically more accurate than most used methods
- VENM can fundamentally improve physics for data analyses and numerical modeling

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Citation:
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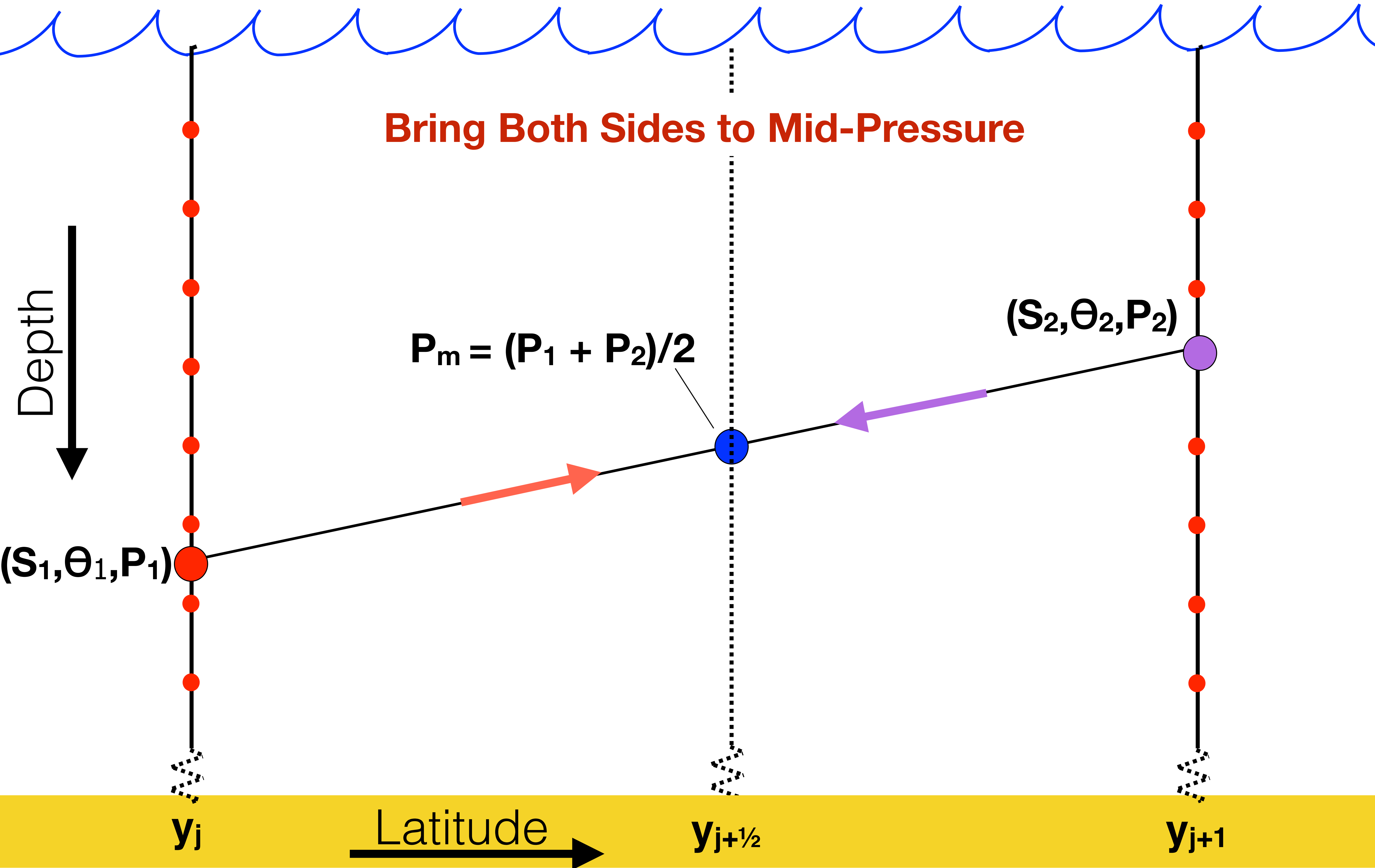
Abstract

Mesoscale eddies stir along the neutral plane, and the resulting neutral diffusion is a fundamental aspect of subgrid-scale tracer transport in ocean models. Calculating neutral diffusion traditionally involves calculating neutral slopes and three-dimensional tracer gradients. The calculation of the neutral slope traditionally occurs by computing the ratio of the horizontal to vertical locally referenced potential density derivative. However, this approach is problematic in regions of weak vertical stratification, prompting the use of a variety of ad hoc regularization methods that can lead to rather nonphysical dependencies for the resulting neutral tracer gradients. Here we use a VErtical Non-local Method "VENM," a search algorithm that requires no ad hoc regularization and significantly improves the numerical accuracy of calculating neutral slopes, neutral tracer gradients, and associated neutral diffusive fluxes. We compare and contrast VENM against a more traditional method, using an independent objective neutrality condition combined with estimates of spurious diffusion, heat transport, and water mass transformation rates. VENM is more accurate, both physically and numerically, and should form the basis for future efforts involving neutral diffusion calculations from observations and possibly numerical model simulations.

VENM

VENM: VErtically Nonlocal Method

Based on: Jacket and McDougall 1997



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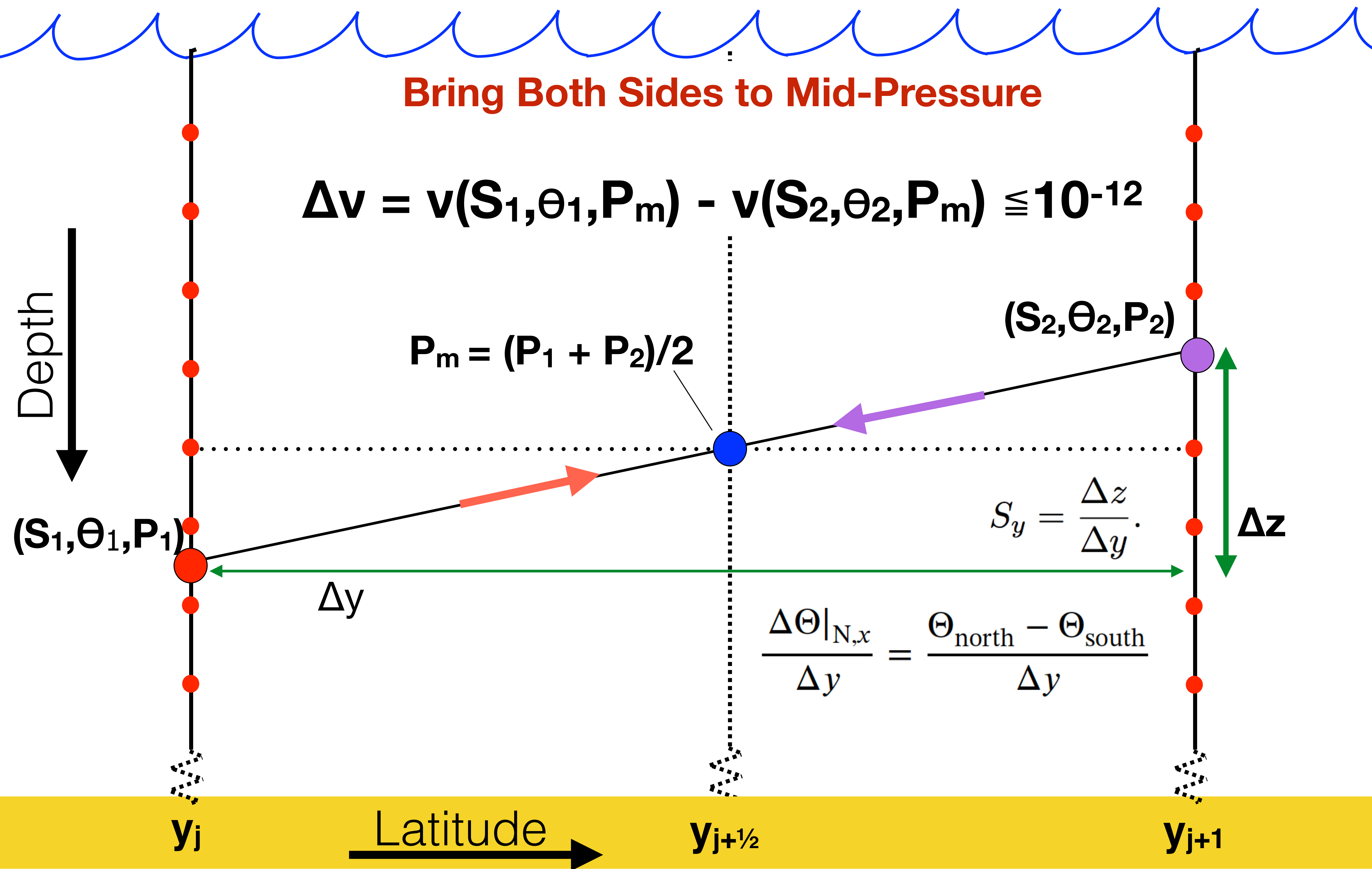


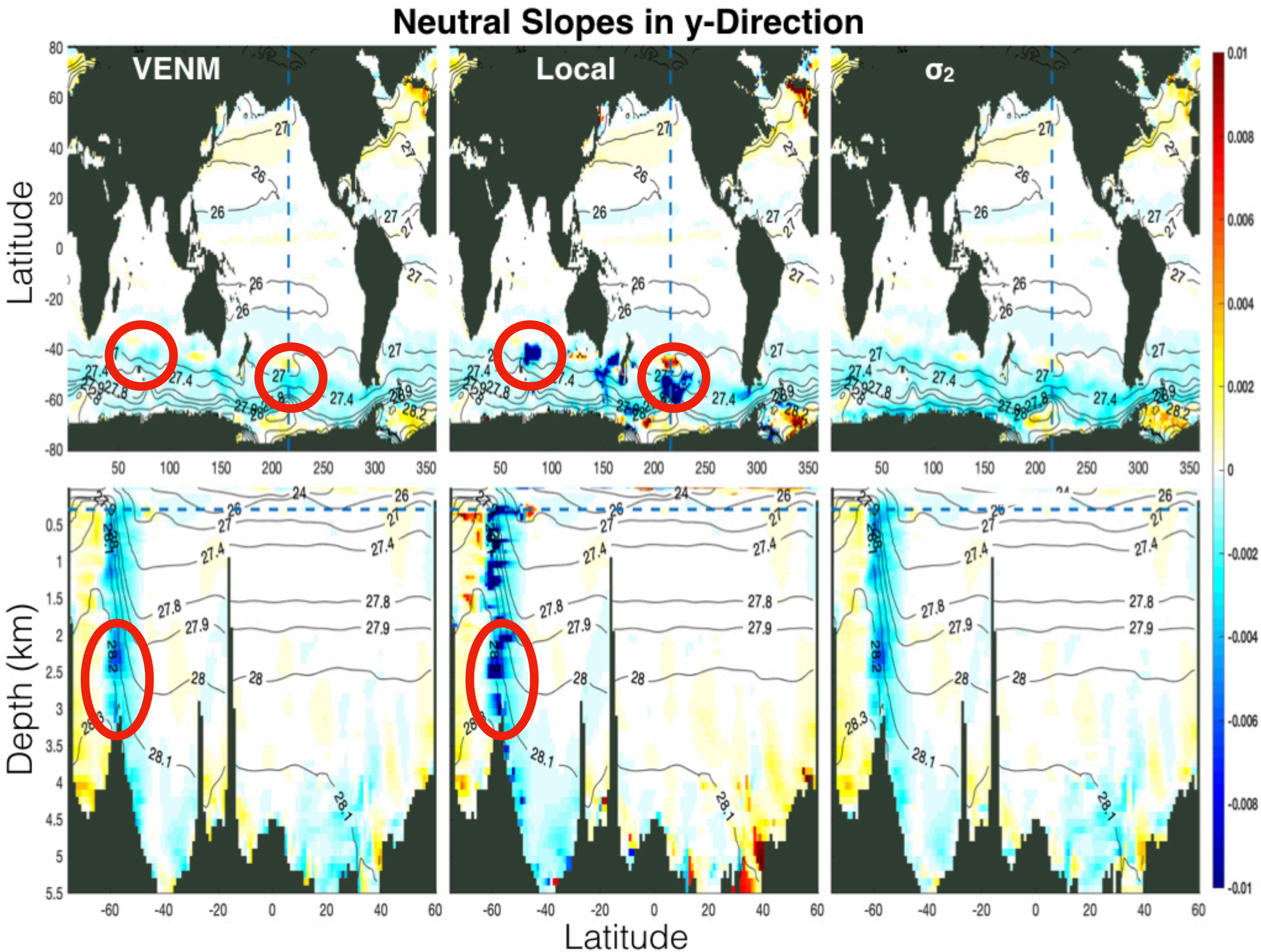
Calculating Diffusive and advective Eddy Fluxes from ocean observations

Applied to World Ocean Atlas

Observationally based gridded climatology

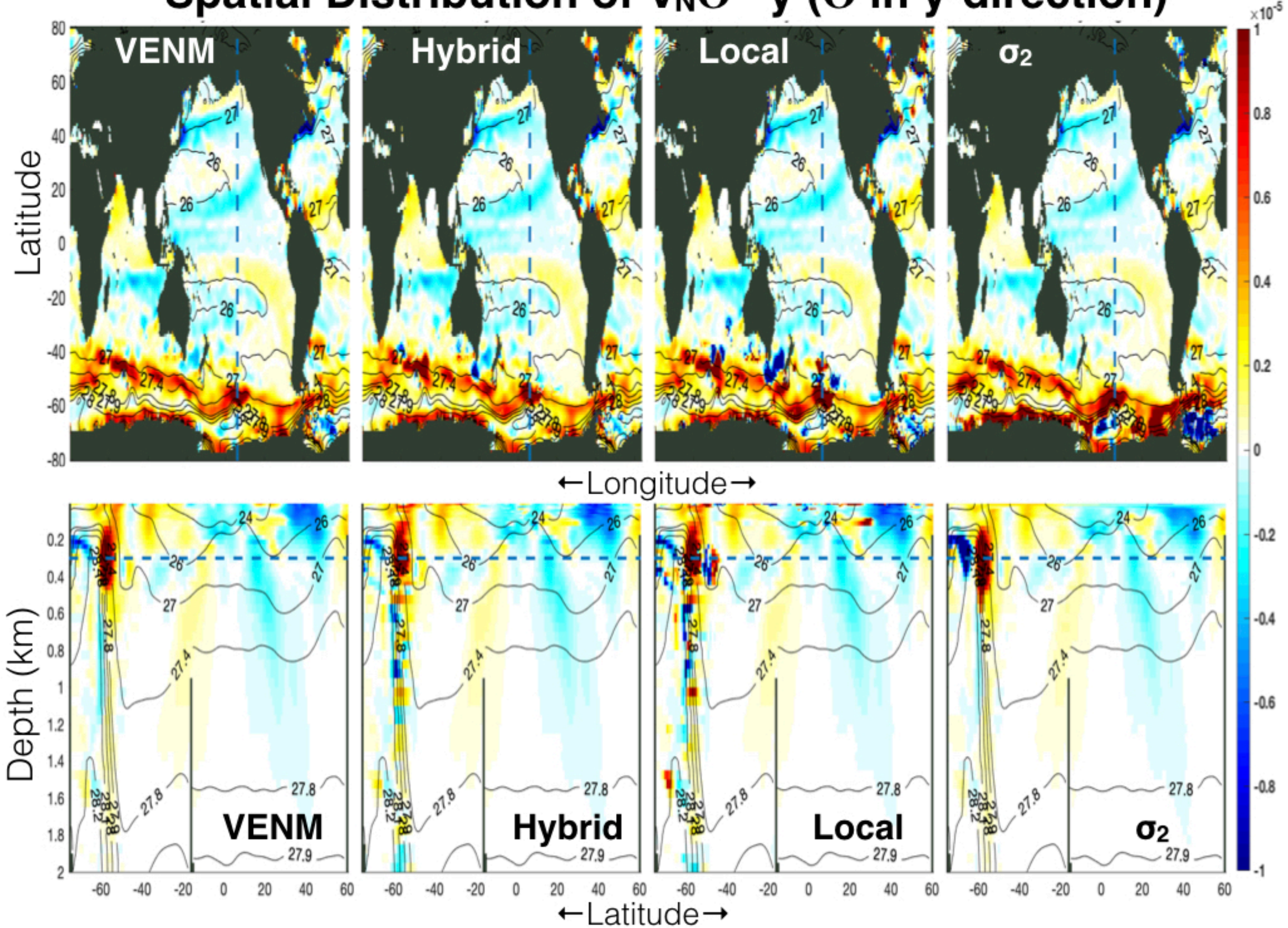
(S, T, P)

VENM - Results



VENM - Results

Spatial Distribution of $\nabla_N\Theta \cdot \hat{y}$ (Θ in y-direction)



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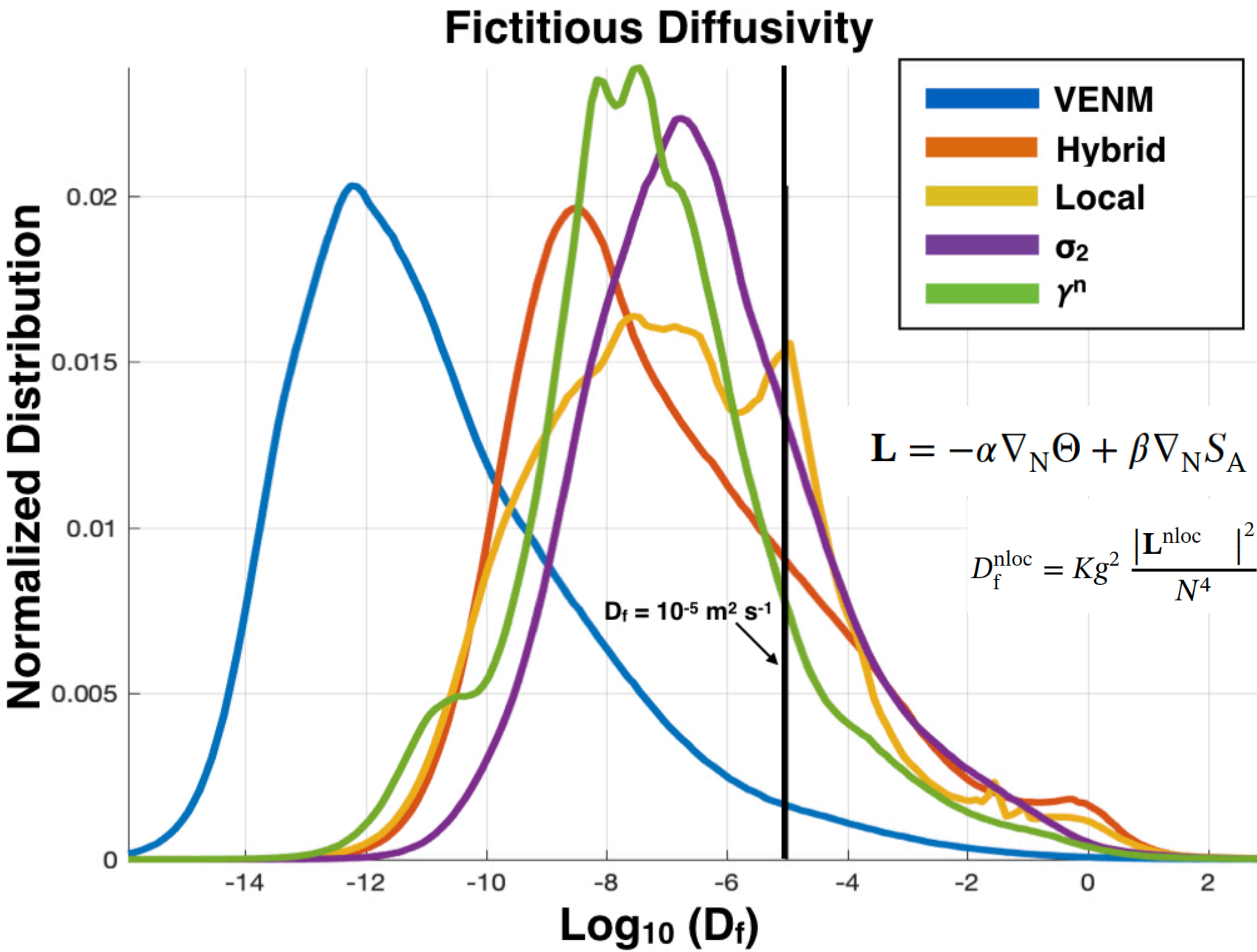

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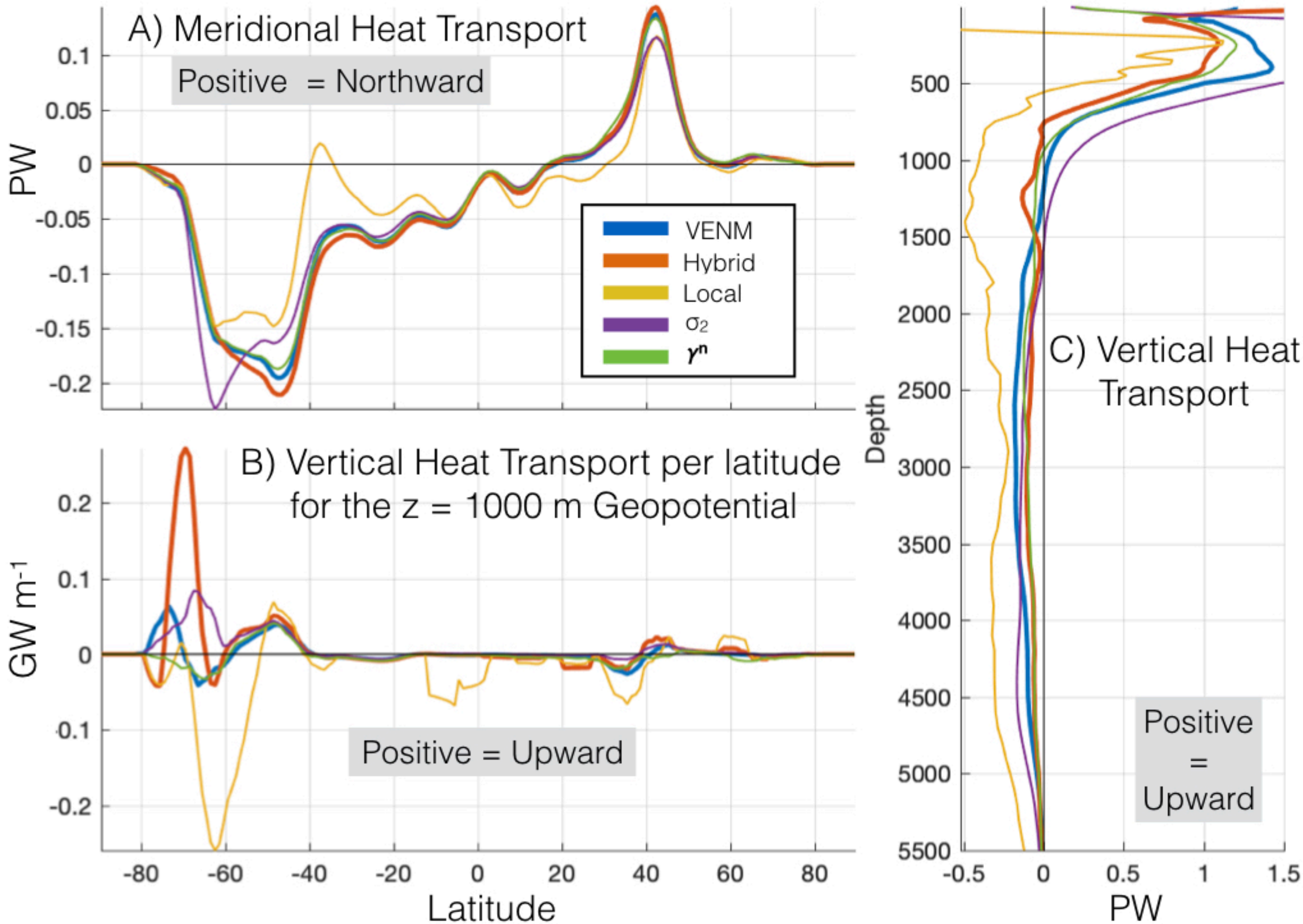
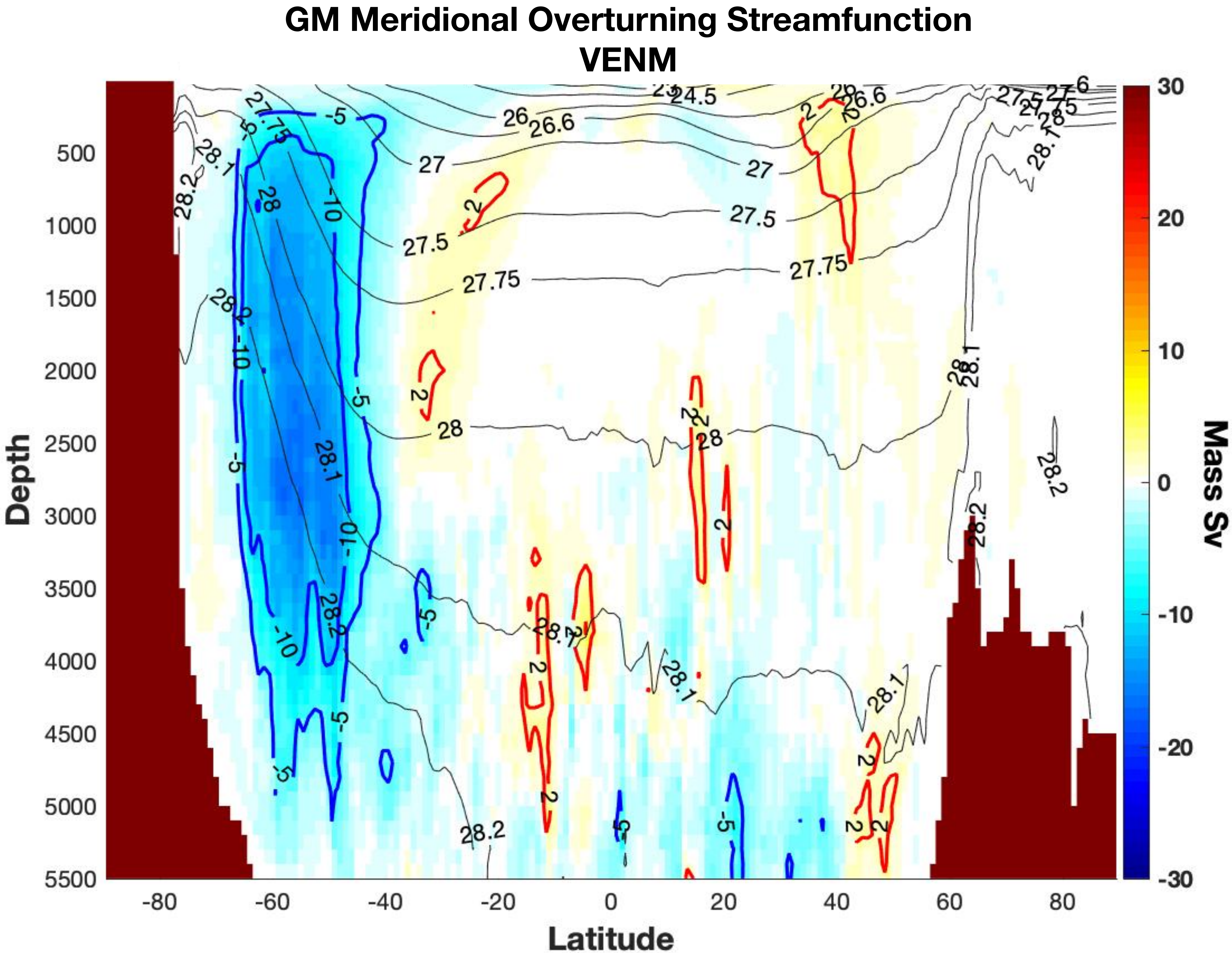
$$D_f^{nloc} = K g^2 \frac{\left| \mathbf{L}^{nloc} \right|^2}{N^4},$$

VENM - Results

Meridional and Vertical Heat Transports



VENM - Results



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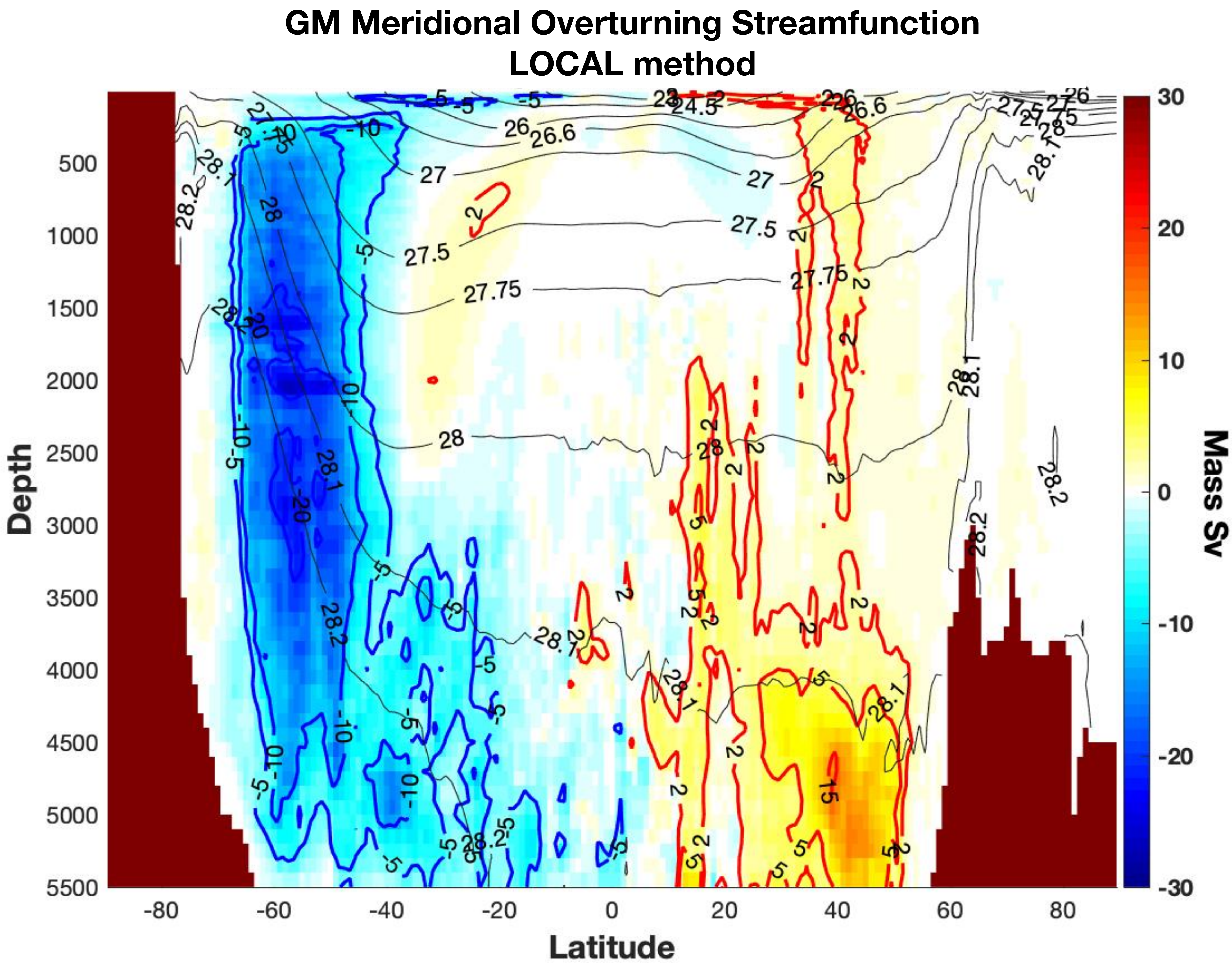
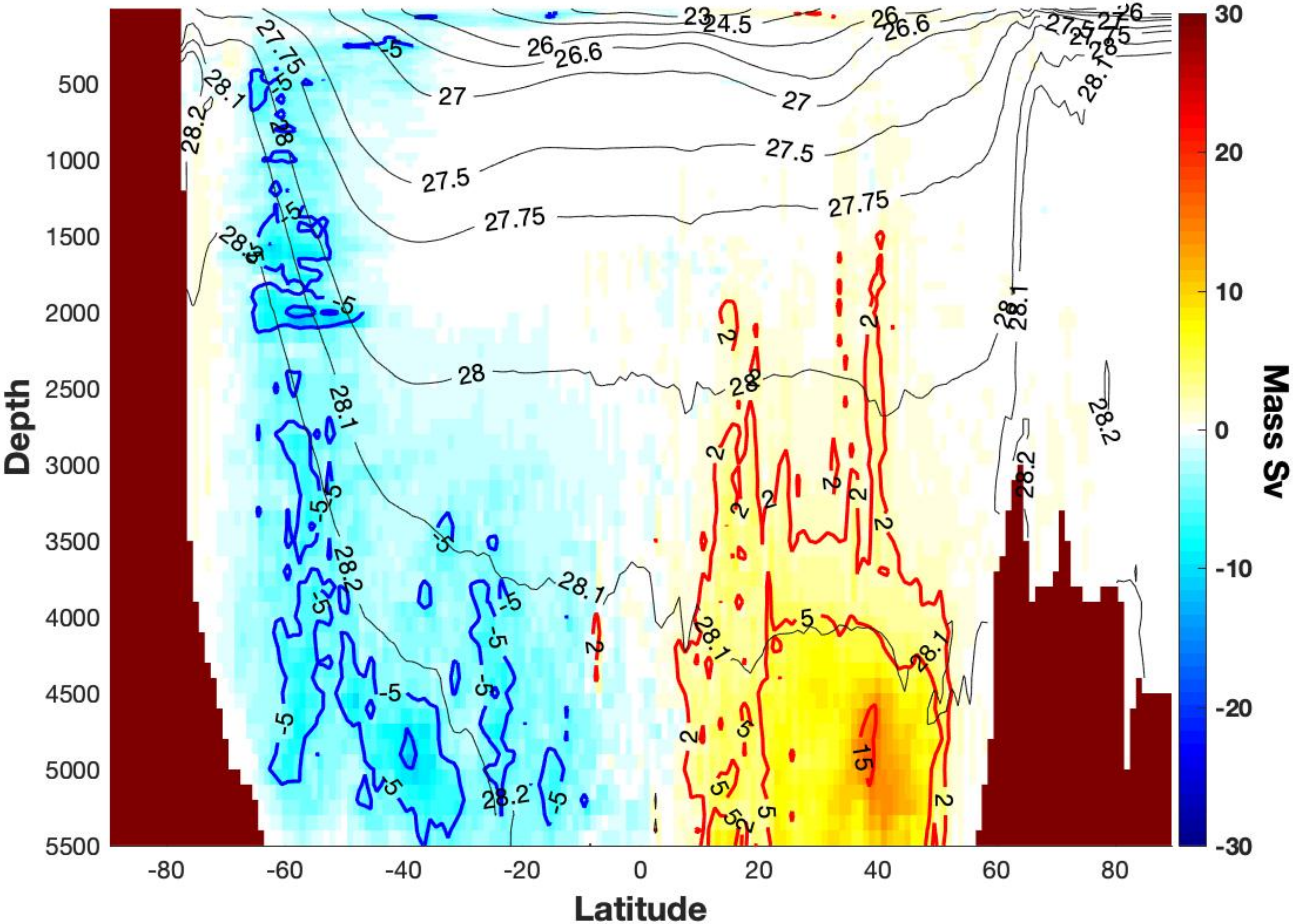


VENM - Results

GM Meridional Overturning Streamfunction
Difference: LOCAL - VENM



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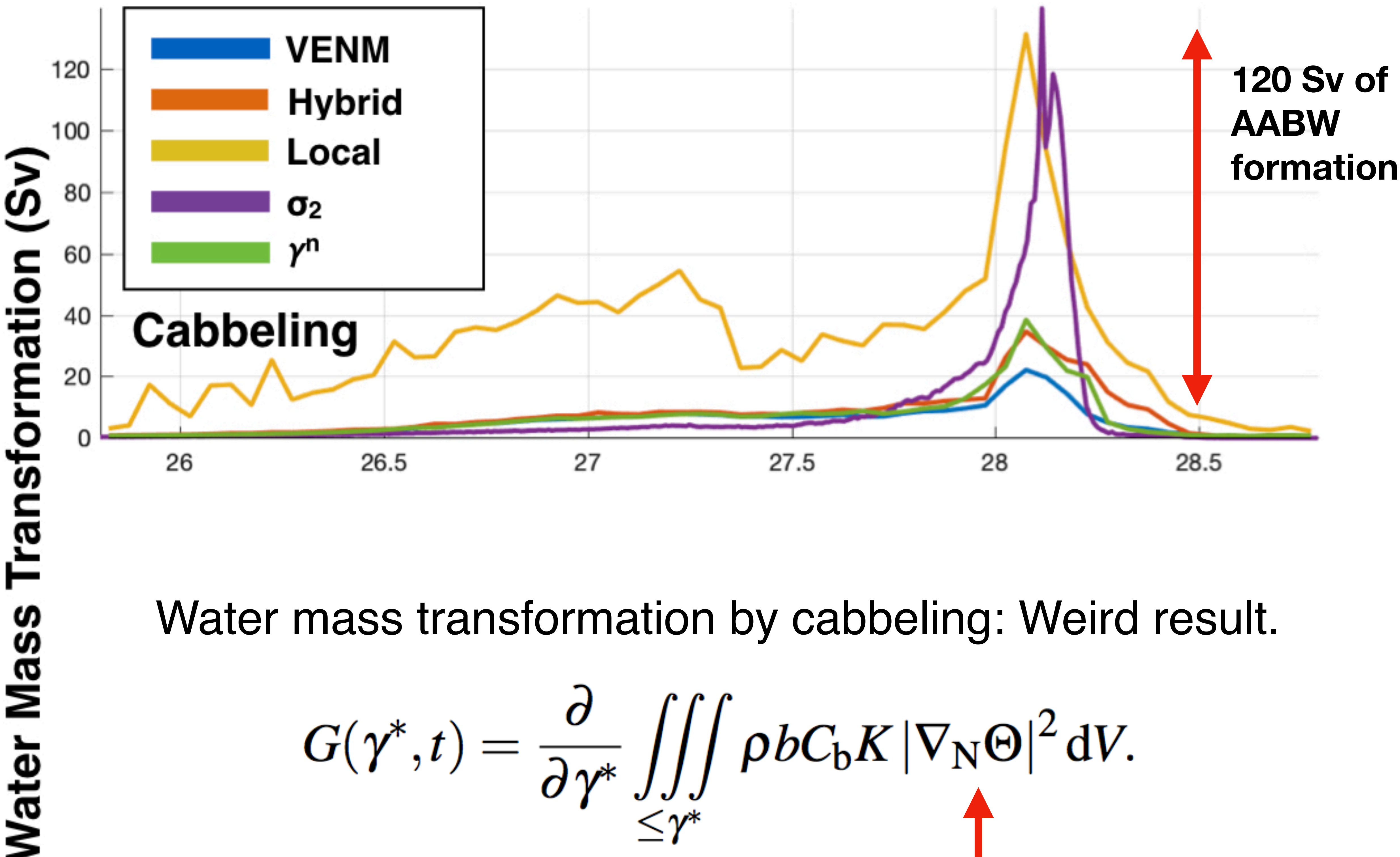


Water mass transformation by cabbeling: Weird result.

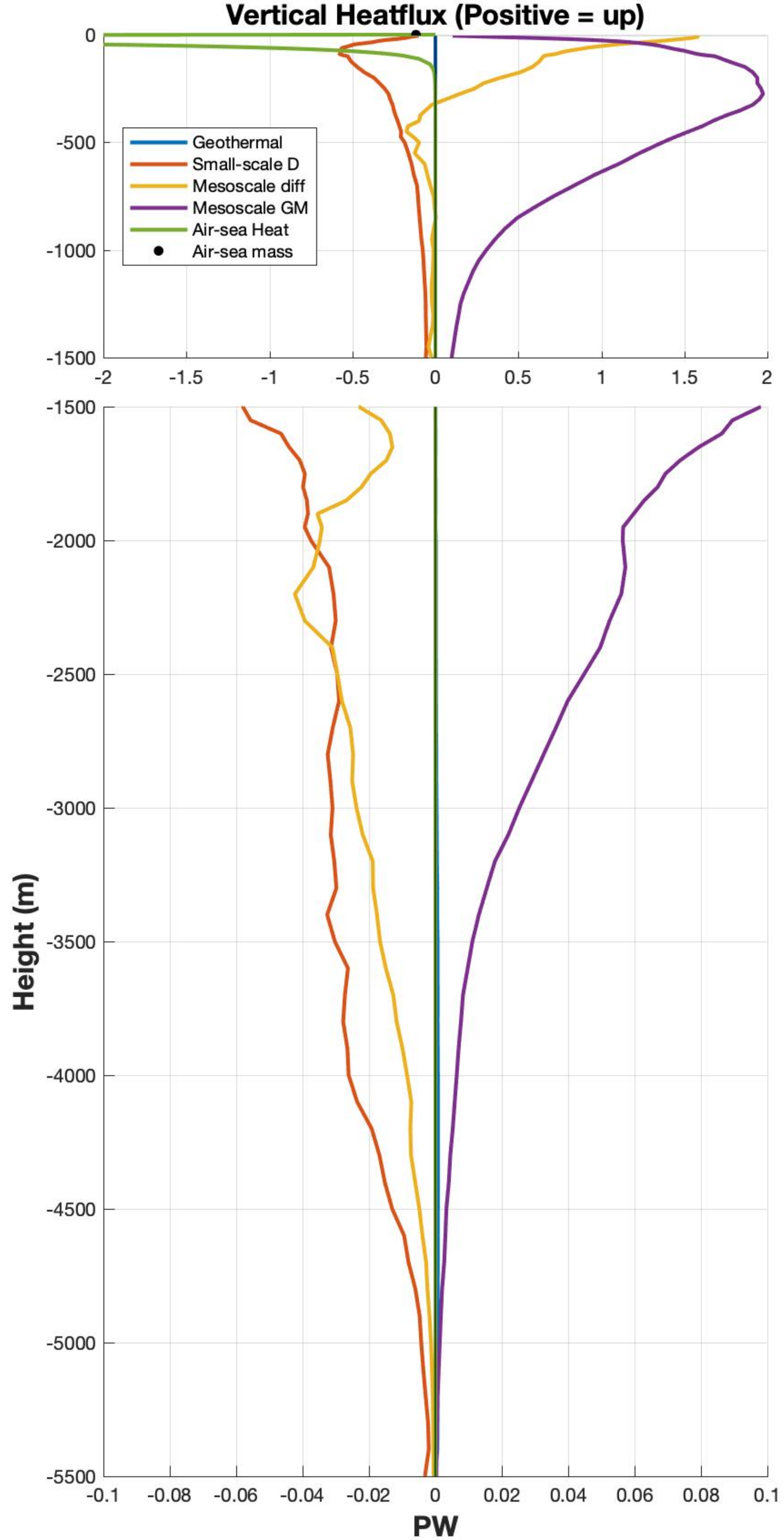
$$G(\gamma^*, t) = \frac{\partial}{\partial \gamma^*} \iiint_{\leq \gamma^*} \rho b C_b K \left| \nabla_N \Theta \right|^2 \mathrm{d}V.$$

Sensitive to gradient

VENM - Results

VENM:

- Numerically more stable and accurate.
- Self-Regularization (H / Δx)
- Significantly improves representation of fundamental physical processes
- Computationally more expensive, but:
- Andrew Shao et al is implementing VENM-like code into MOM6 and NEMO.
- Sigma2 does not improve compared to local method
- Impact on Eddy Parameterization (GM90) and transport/diffusion of heat, carbon, etc.
- Likely to change climate predictions.



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