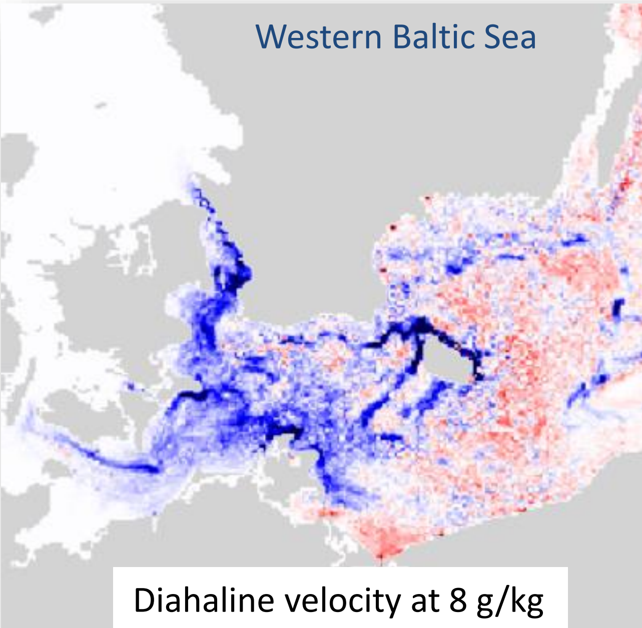
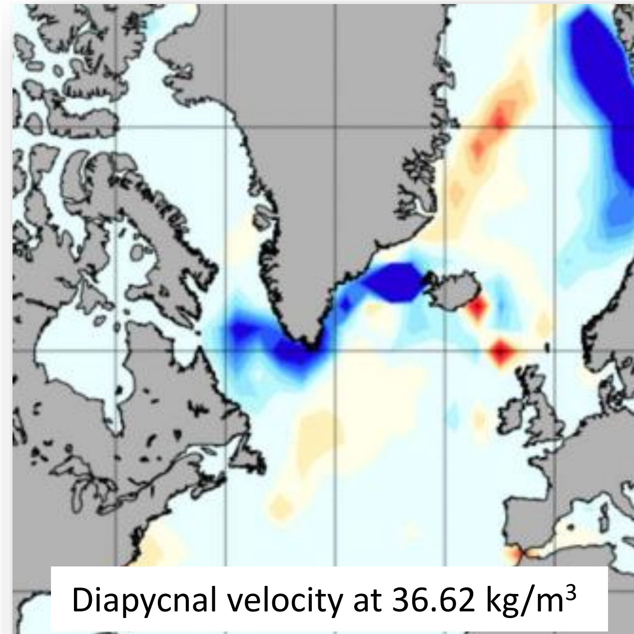
Estuarine mixing and exchange flow in an isohaline framework



Henell et al. (submitted)



Sidorenko et al. (2020)

manuscript submitted to *JGR: Oceans*

Spatial composition of the diahaline overturning circulation in a fjord–type, non–tidal estuarine system

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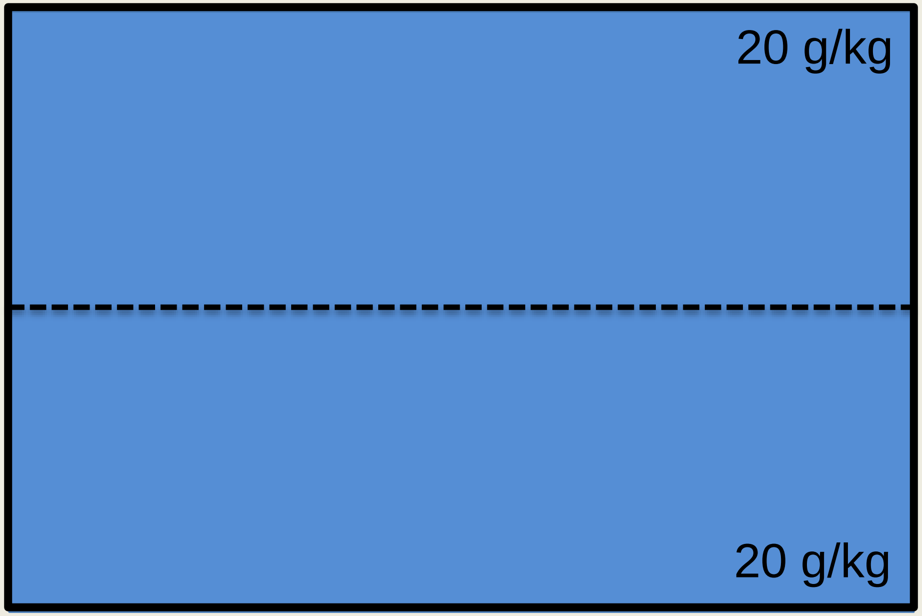
What is mixing?



Variance before mixing: $\mathrm{Var}\,(s) = V\left\{\frac{1}{2}(s_1-\bar{s})^2+\frac{1}{2}(s_2-\bar{s})^2\right\} = 100\ (\mathrm{g/kg})^2\ V$

Variance after mixing: $\mathrm{Var}\,(s) = V\left\{\frac{1}{2}(s_1-\bar{s})^2+\frac{1}{2}(s_2-\bar{s})^2\right\} = 0\ (\mathrm{g/kg})^2\ V$

Rate of variance loss: $100\ (\mathrm{g/kg})^2\ V\ /\ \Delta T$

This is identical to the loss in integrated salinity square.

Salinity mixing *M* is rate of loss of salinity variance or of integrated salinity square.

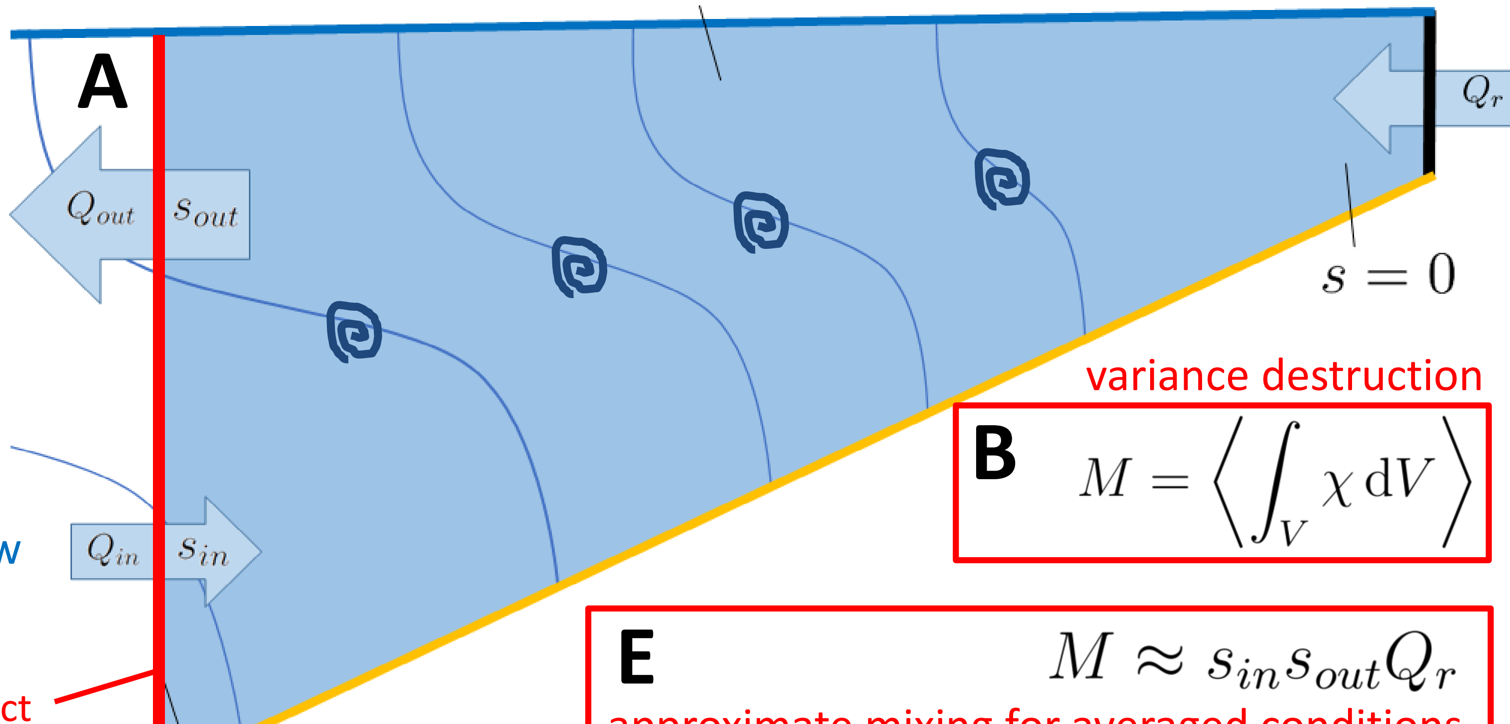
Average mixing in volume bounded by fixed transect

River discharge

Brackish water outflow

Salt water inflow

fixed transect



variance destruction

B

$$M = \left\langle \int_V \chi \, \mathrm{d}V \right\rangle$$

E

$$M \approx s_{in} s_{out} Q_r$$

approximate mixing for averaged conditions

C

Classical Knudsen volume and salt relations:

$$Q_{in} + Q_{out} + Q_r = 0 \qquad Q_{in} s_{in} + Q_{out} s_{out} = 0$$

$$Q_{in} = \frac{s_{out}}{s_{in} - s_{out}} Q_r \qquad Q_{out} = -\frac{s_{in}}{s_{in} - s_{out}} Q_r$$

Knudsen (1900)

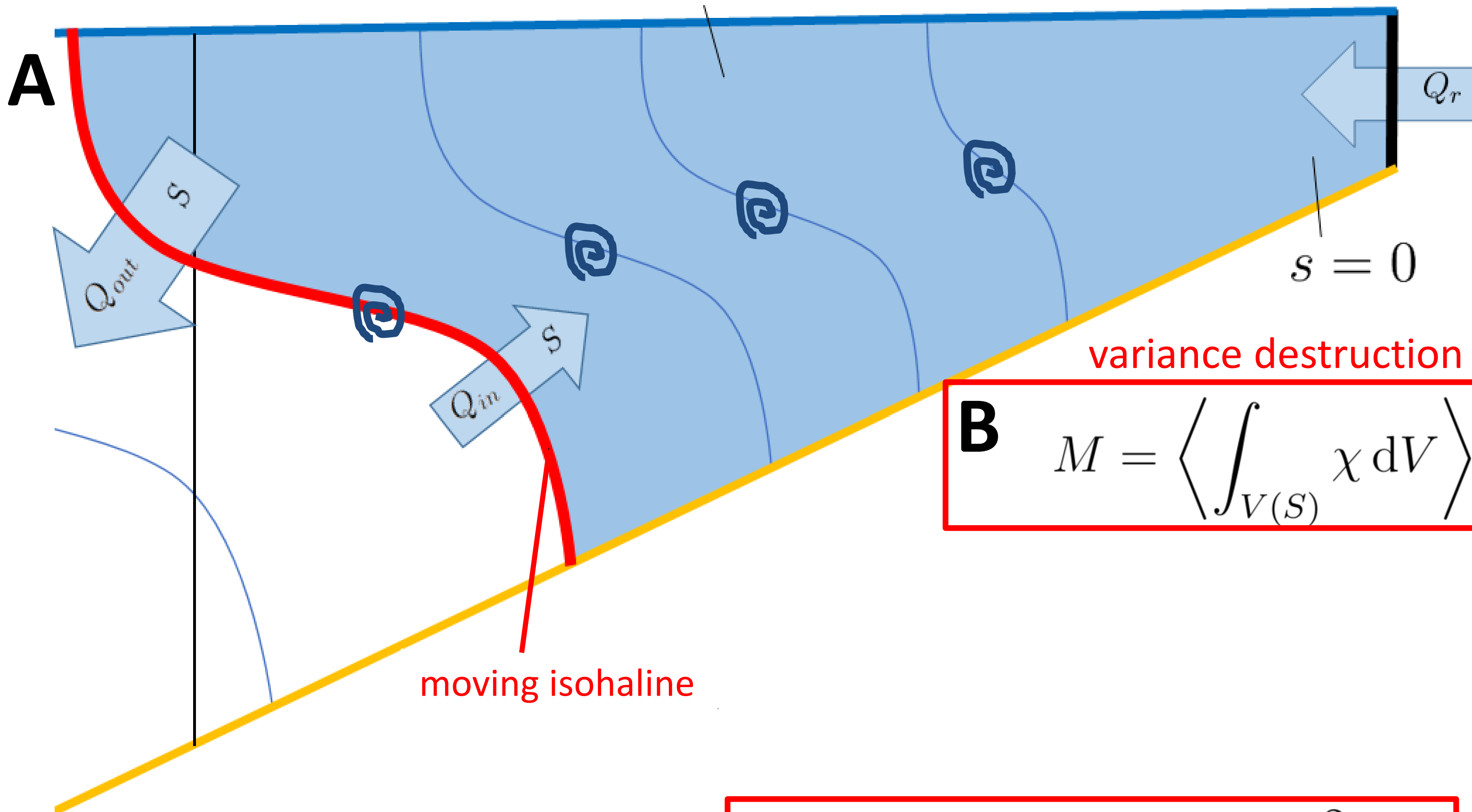
D

Knudsen mixing relation:

$$Q_{in} \left(s_{in}\right)^2 + Q_{out} \left(s_{out}\right)^2 = s_{in} s_{out} Q_r$$

MacCready et al. (2018)

Average mixing in volume bounded by moving isohaline



variance destruction

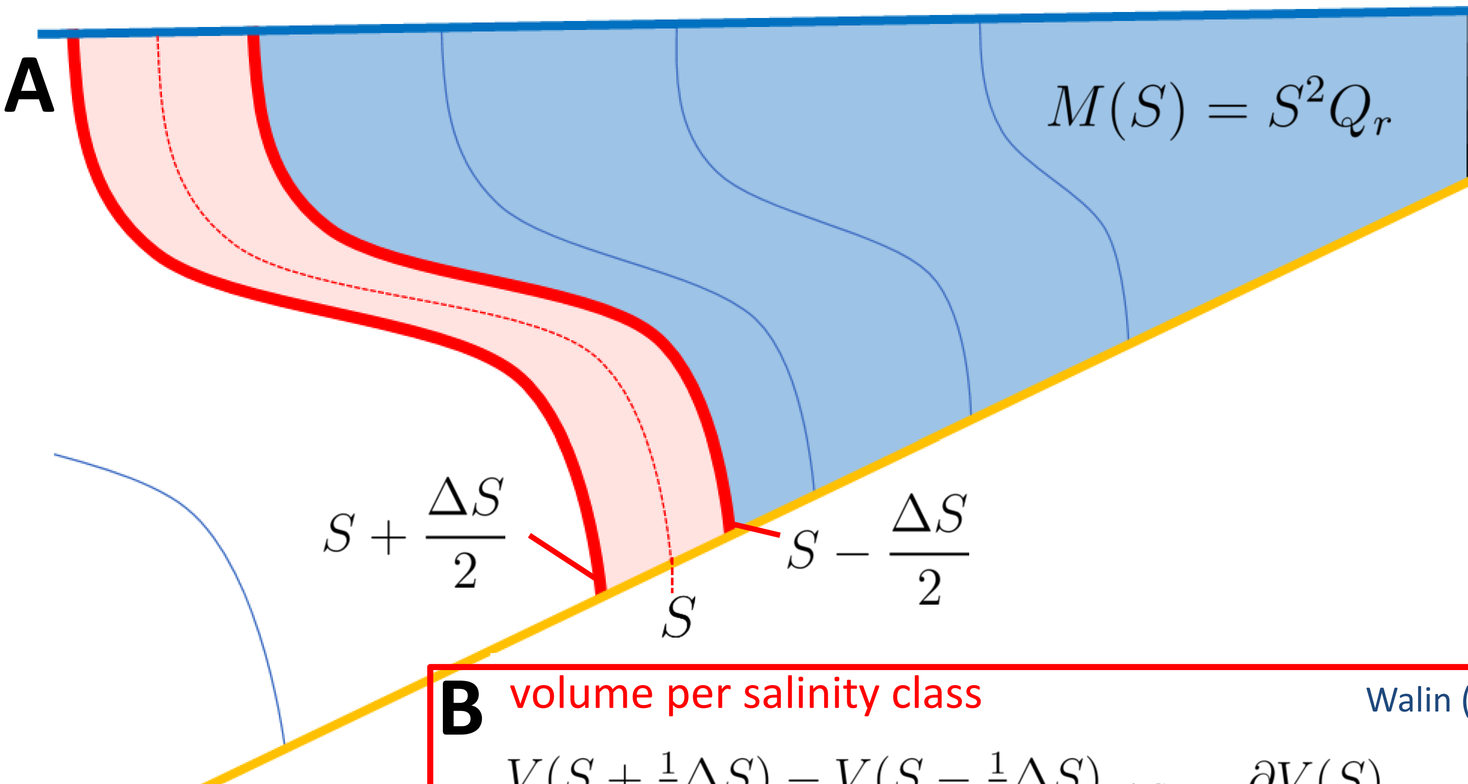
B $$M = \left\langle \int_{V(S)} \chi \, \mathrm{d}V \right\rangle$$

C $$M(S) = S^2 Q_r$$

exact mixing for averaged conditions

Burchard (2020)

Defining properties per salinity class



B volume per salinity class — Walin (1977)

$$\frac{V(S+\frac{1}{2}\Delta S) - V(S-\frac{1}{2}\Delta S)}{\Delta S} \xrightarrow{\Delta S \to 0} \frac{\partial V(S)}{\partial S} = v(S)$$

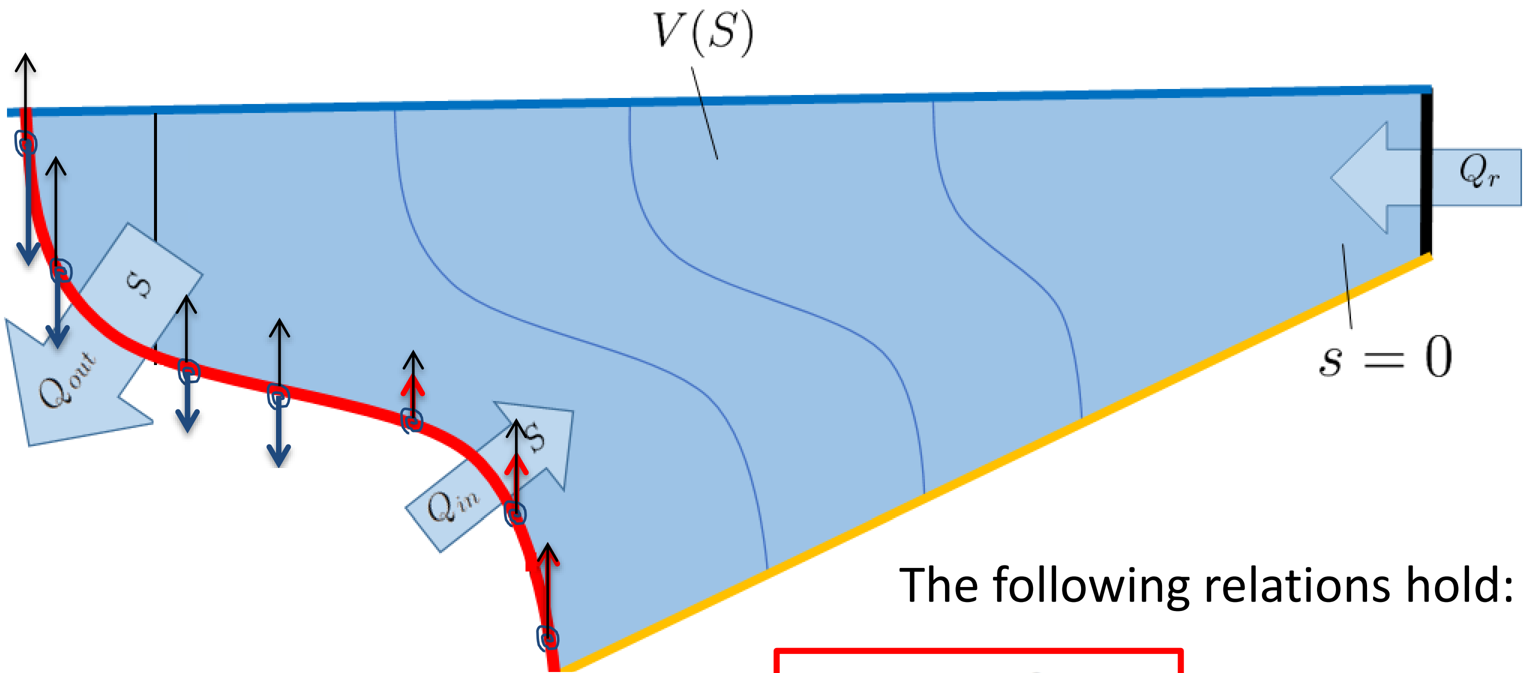
C mixing per salinity class — Burchard (2020)

$$\frac{M(S+\frac{1}{2}\Delta S) - M(S-\frac{1}{2}\Delta S)}{\Delta S} \xrightarrow{\Delta S \to 0} \frac{\partial M(S)}{\partial S} =$$

D universal law

Exact for
- long averages
- P-E=0
- S fully inside domain

Diahaline velocity & local mixing per salinity class



The following relations hold:

$$u_{\mathrm{dia,z}} = -\frac{\partial j_{\mathrm{dia,z}}}{\partial S},$$ Wang et al. (2017)

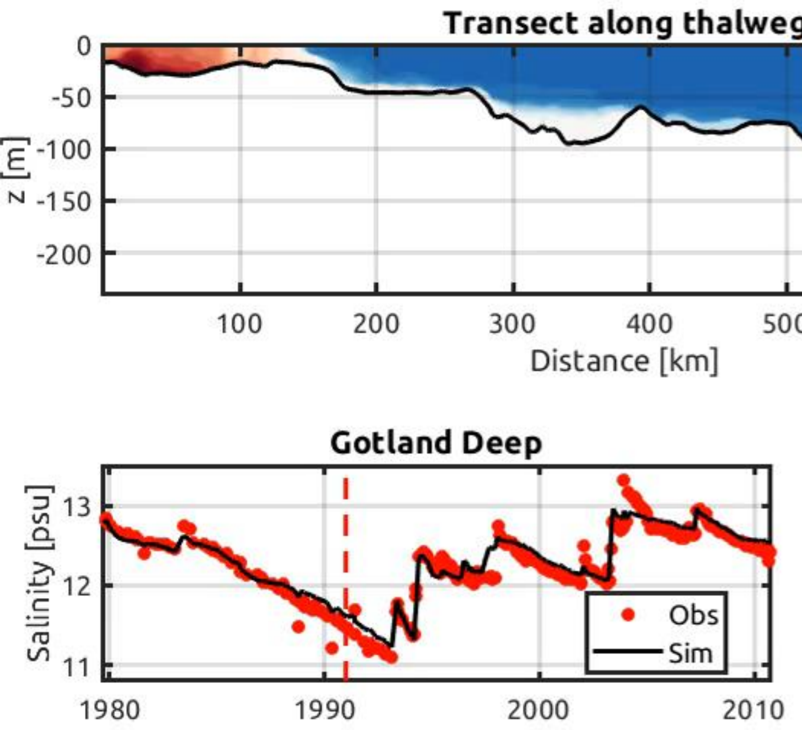
$$j_{\mathrm{dia,z}} = -\frac{1}{2} m_{\mathrm{xy}},$$ Li et al. (2022)

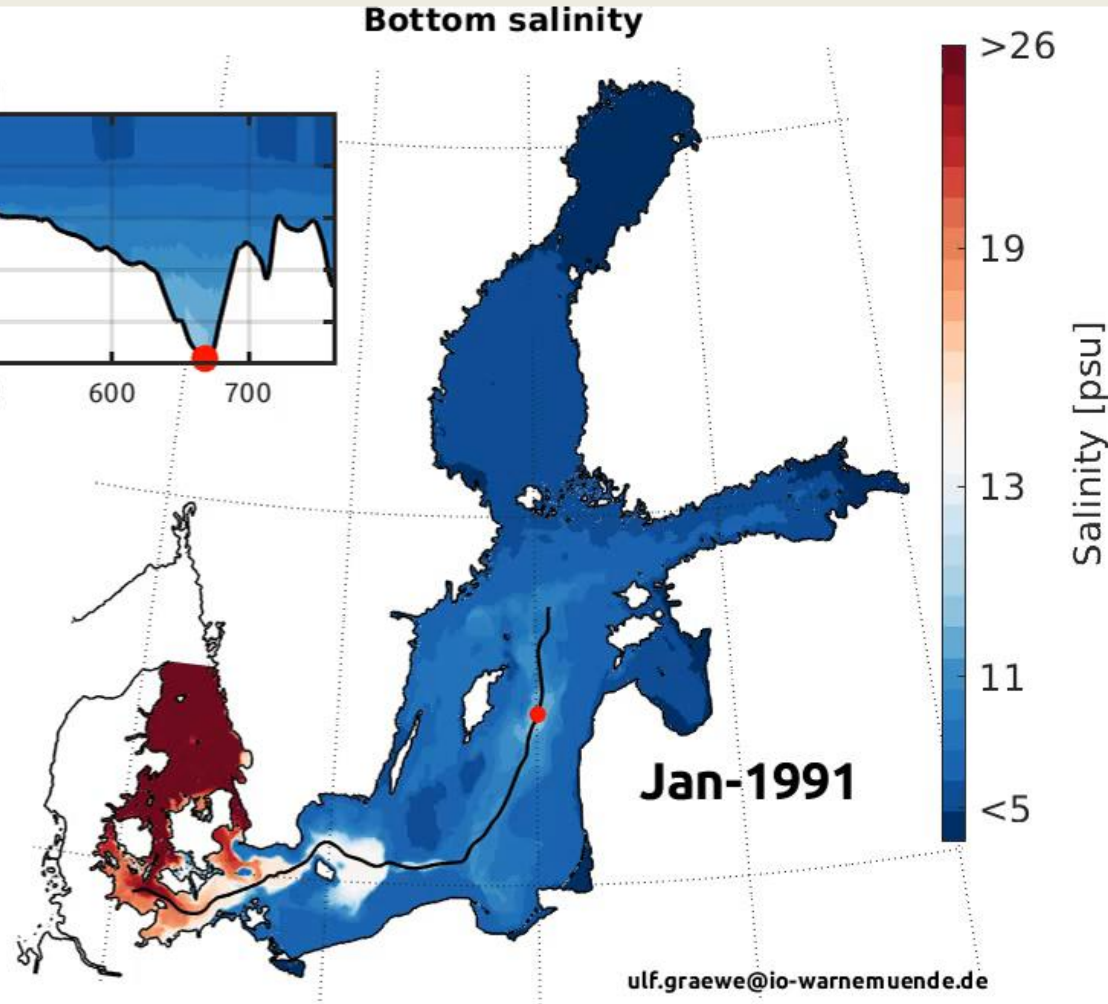
$$u_{\mathrm{dia,z}} = \frac{1}{2}\frac{\partial m_{\mathrm{xy}}}{\partial S},$$ Klingbeil & Henell (submitted)

- ↓↑ Vert. diahaline velocity $u_{\mathrm{dia,z}}$ (>0 for outgoing)
- Local mixing per salinity class m_{xy} (>0)
- ↑ Vert. diahaline salt flux $j_{\mathrm{dia,z}}$ (<0)

Leibniz Institute for Baltic Sea Research Warnemünde

Baltic Sea simulations using GETM

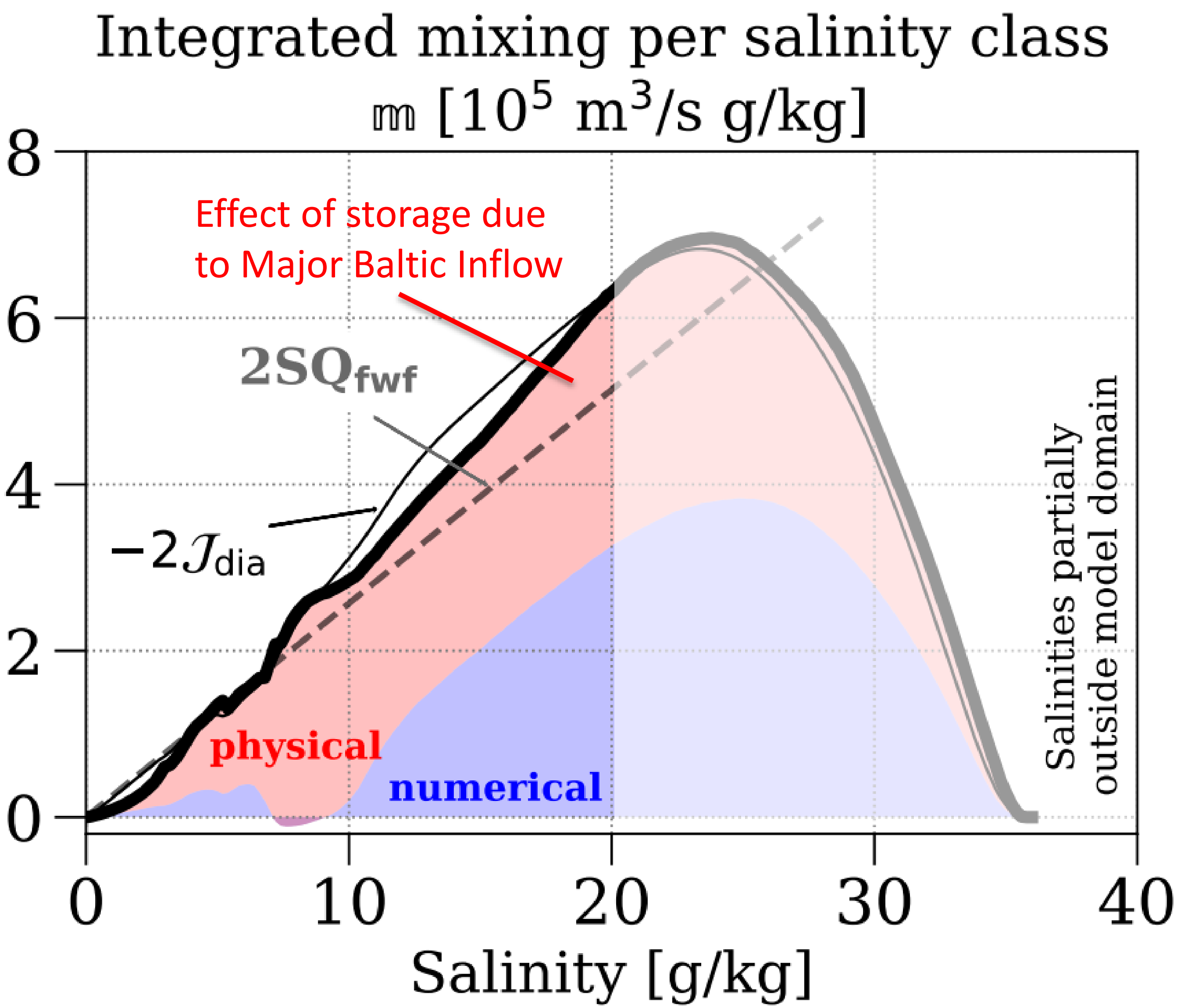




Baltic Sea as model ocean

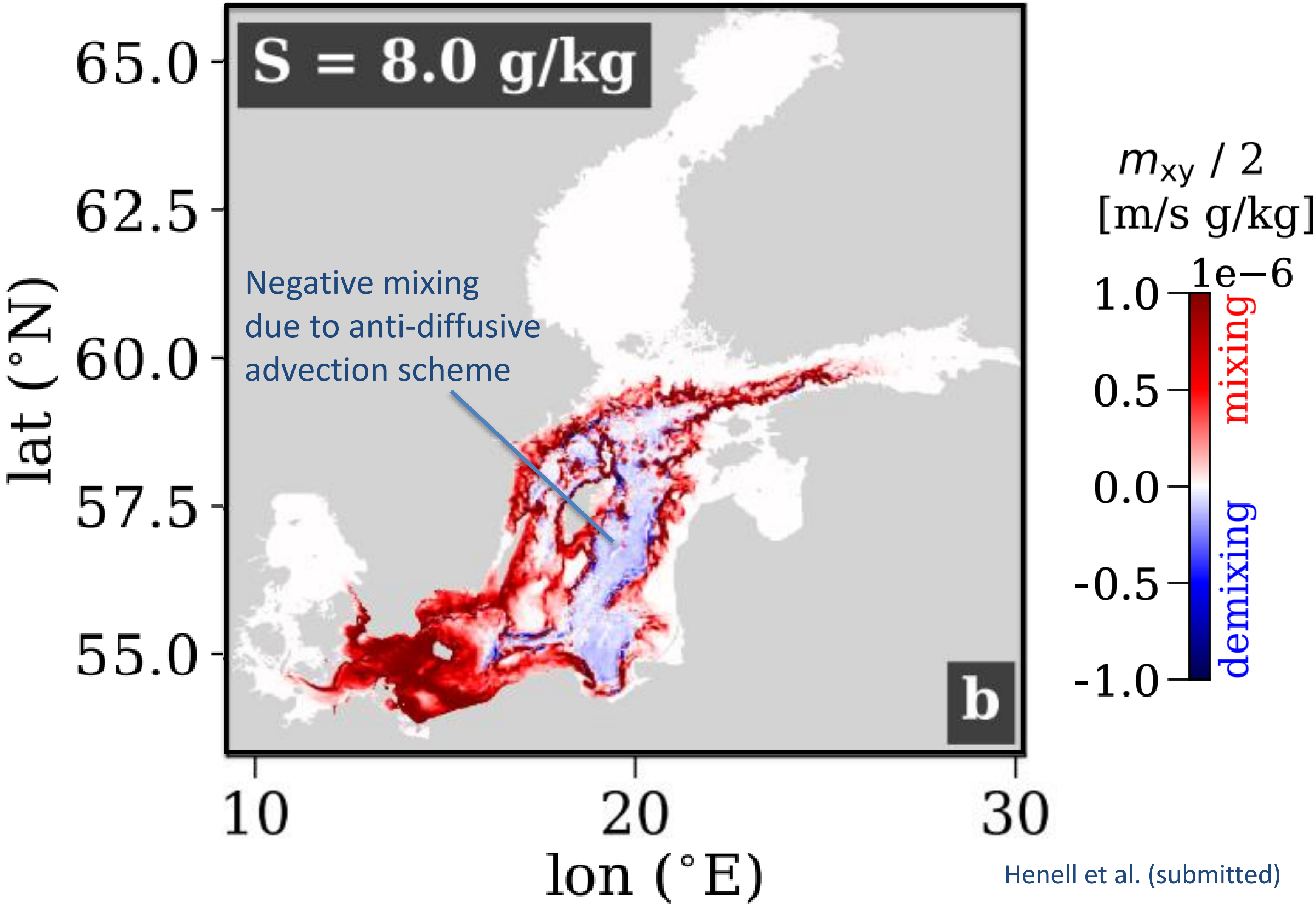
We analyse the years 2014 & 2015 and show bi-annual averages.

Mixing per salinity class



Henell et al. (submitted)

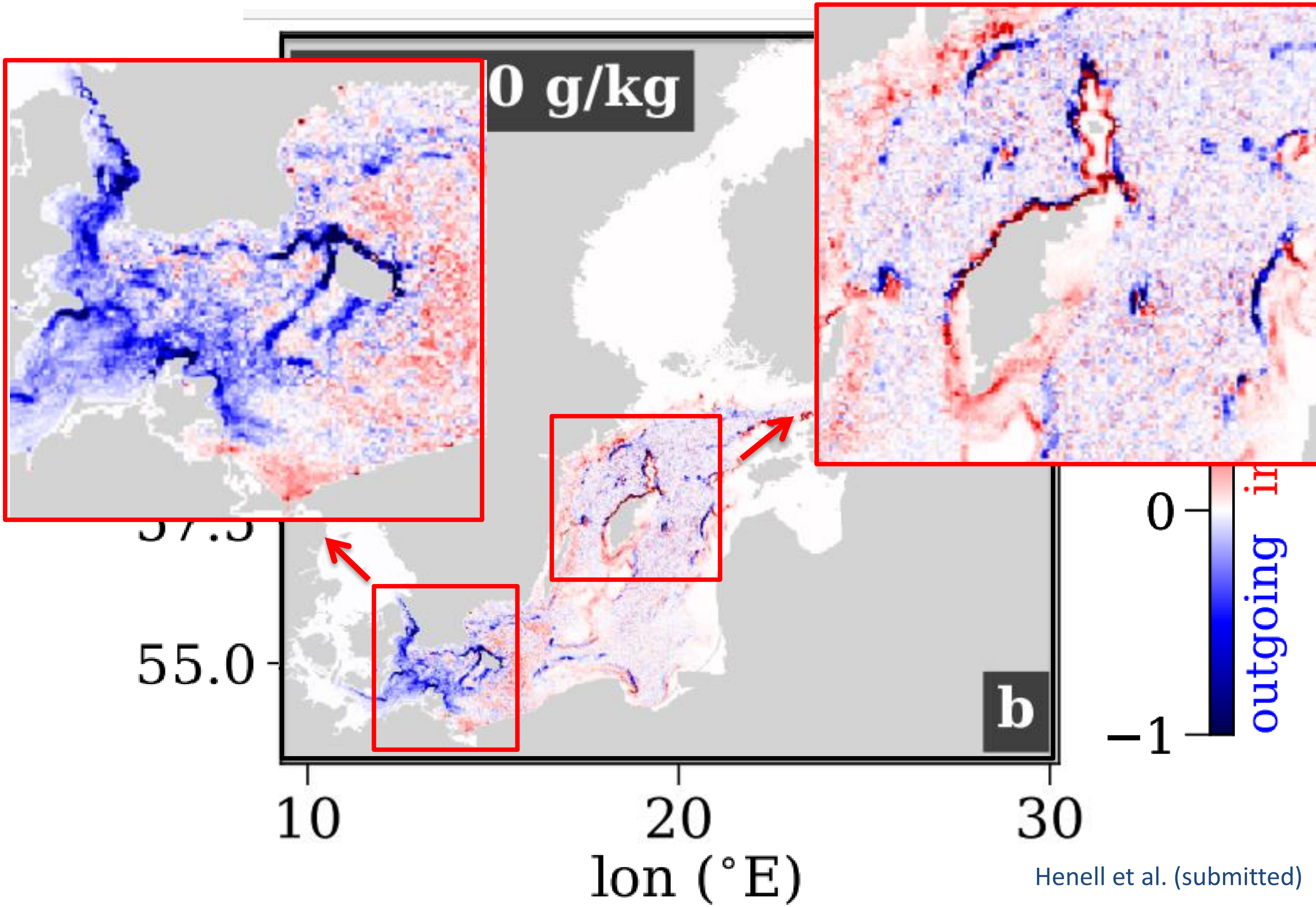
Mixing per salinity class @ 8 g/kg



Negative mixing due to anti-diffusive advection scheme

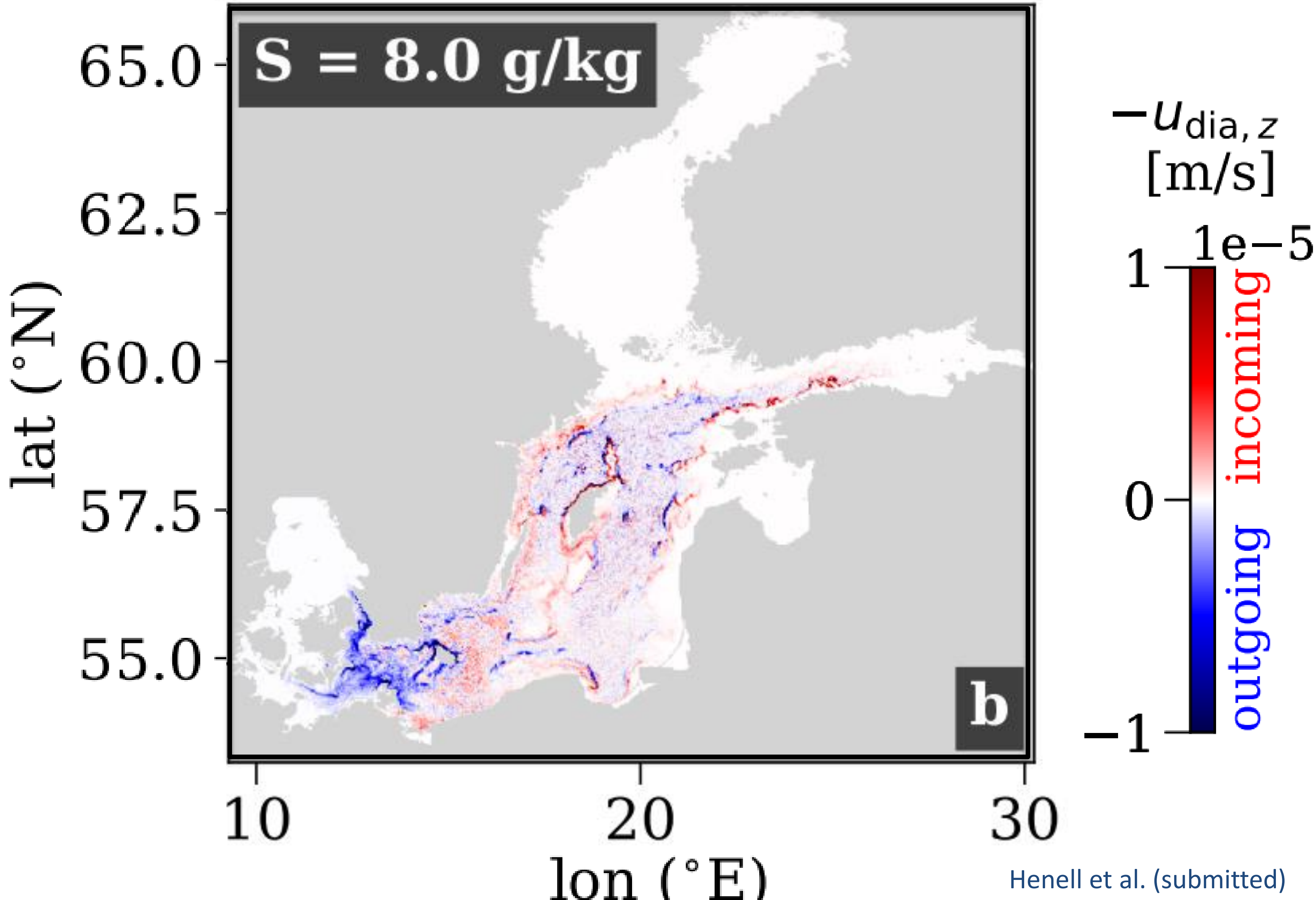
Henell et al. (submitted)

Diahaline velocity @ 8 g/kg



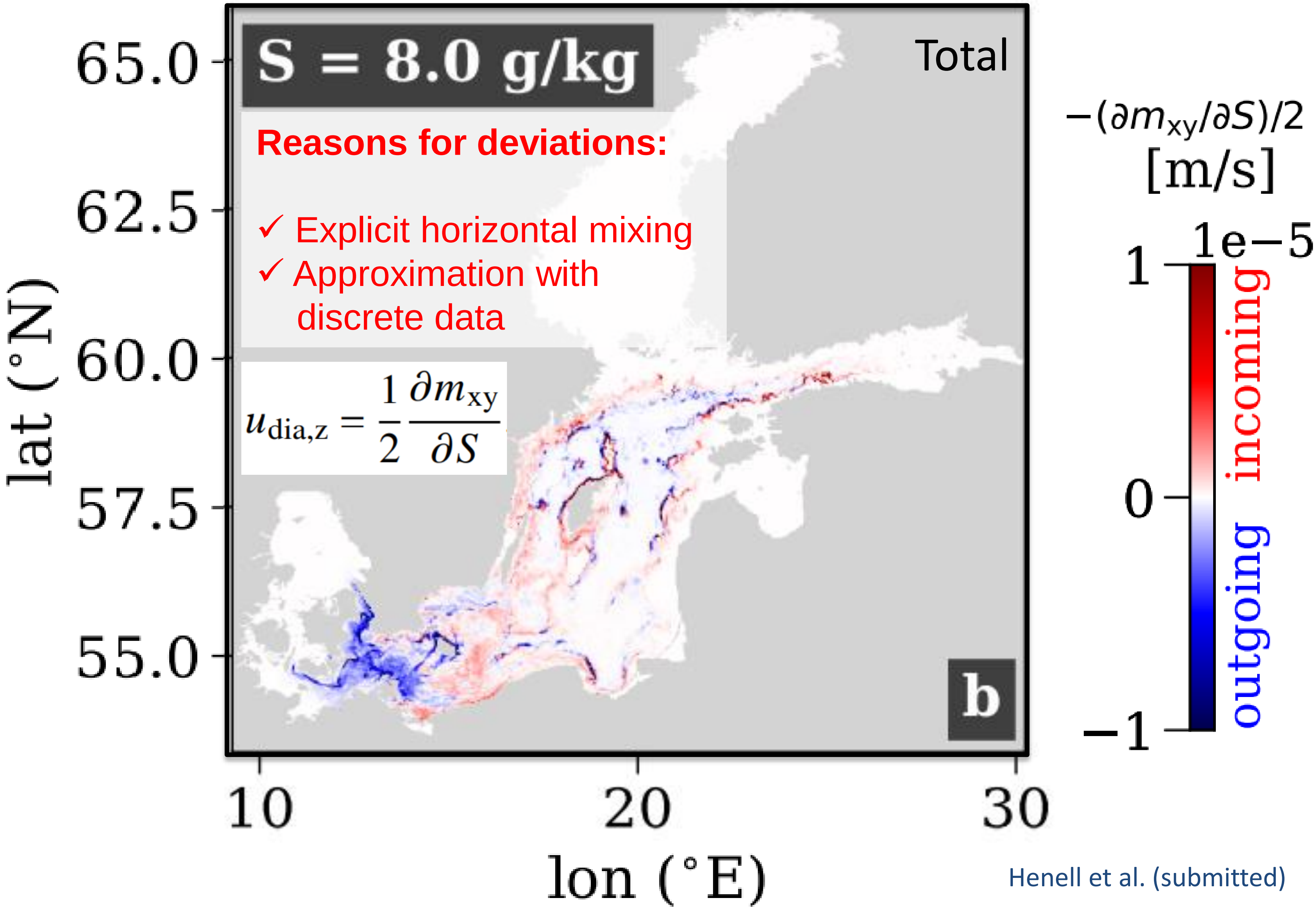
Henell et al. (submitted)

Diahaline velocity @ 8 g/kg



Henell et al. (submitted)

S-derivative of total local mixing per salinity class @ 8 g/kg



Reasons for deviations:

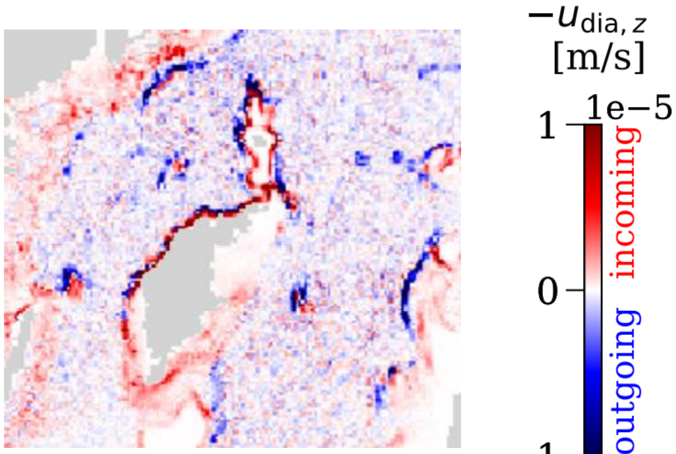
- ✓ Explicit horizontal mixing
- ✓ Approximation with discrete data

$$u_{\mathrm{dia,z}} = \frac{1}{2}\frac{\partial m_{xy}}{\partial S}$$

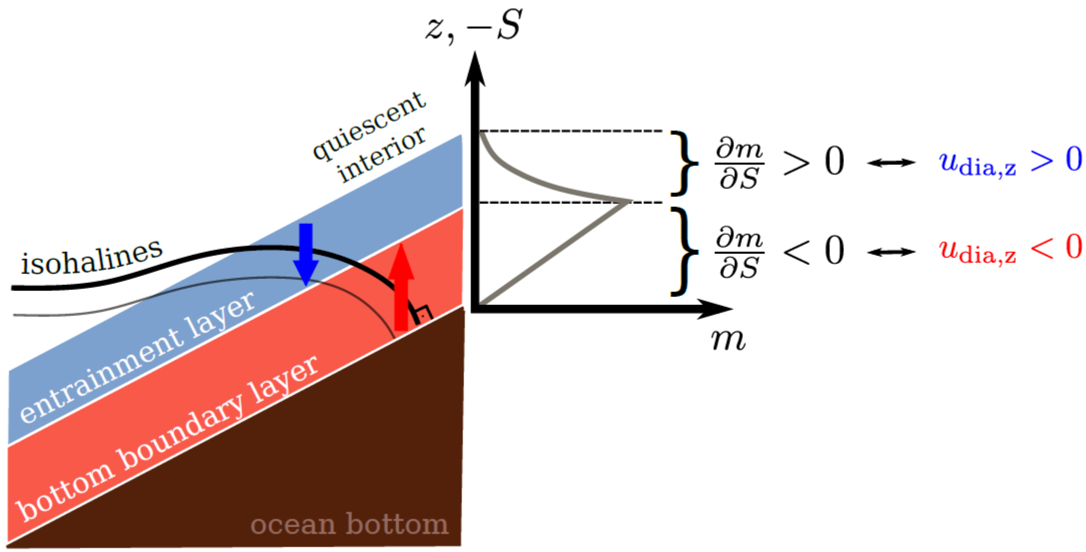
Henell et al. (submitted)

Synthesis

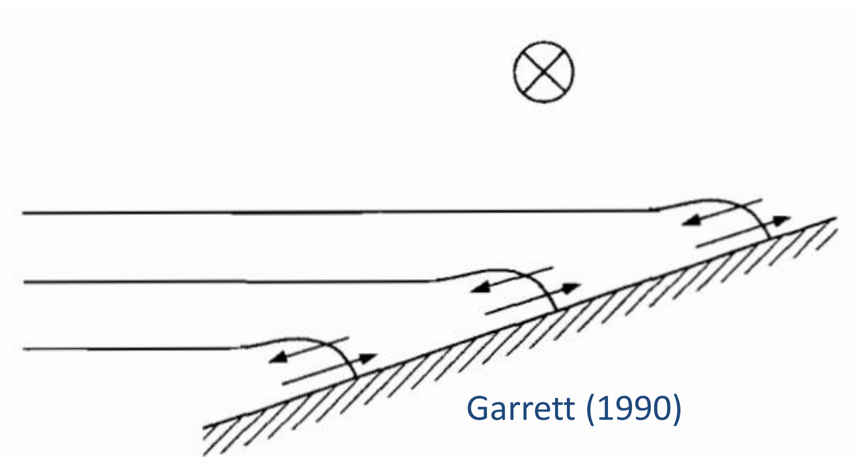
The relation $u_{\text{dia,z}} = \frac{1}{2}\frac{\partial m_{\text{xy}}}{\partial S}$ is the local link between mixing and exchange flow.



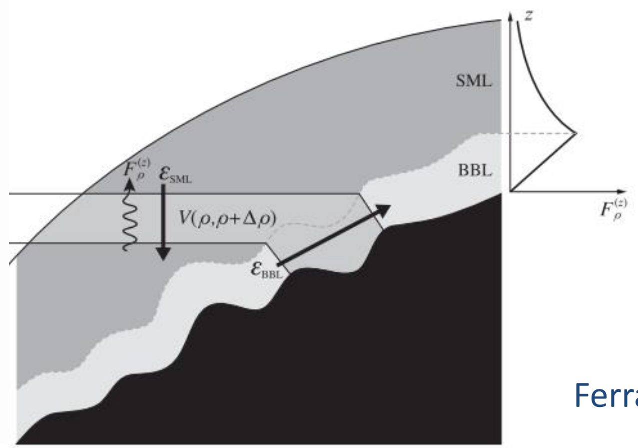
Henell et al. (submitted)



(strongly) modified after Ferrari et al. (2016) by Henell et al. (submitted)

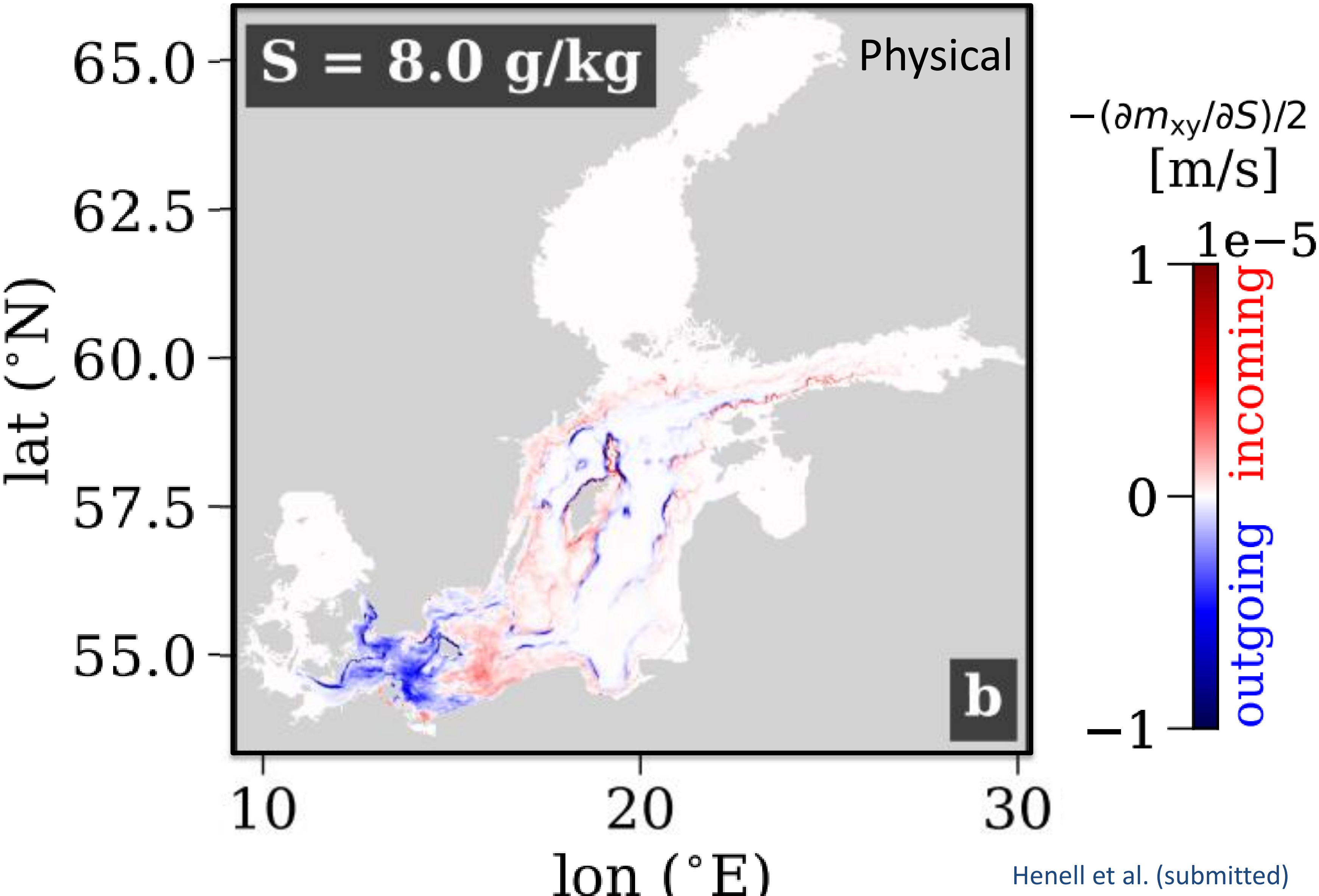


Garrett (1990)



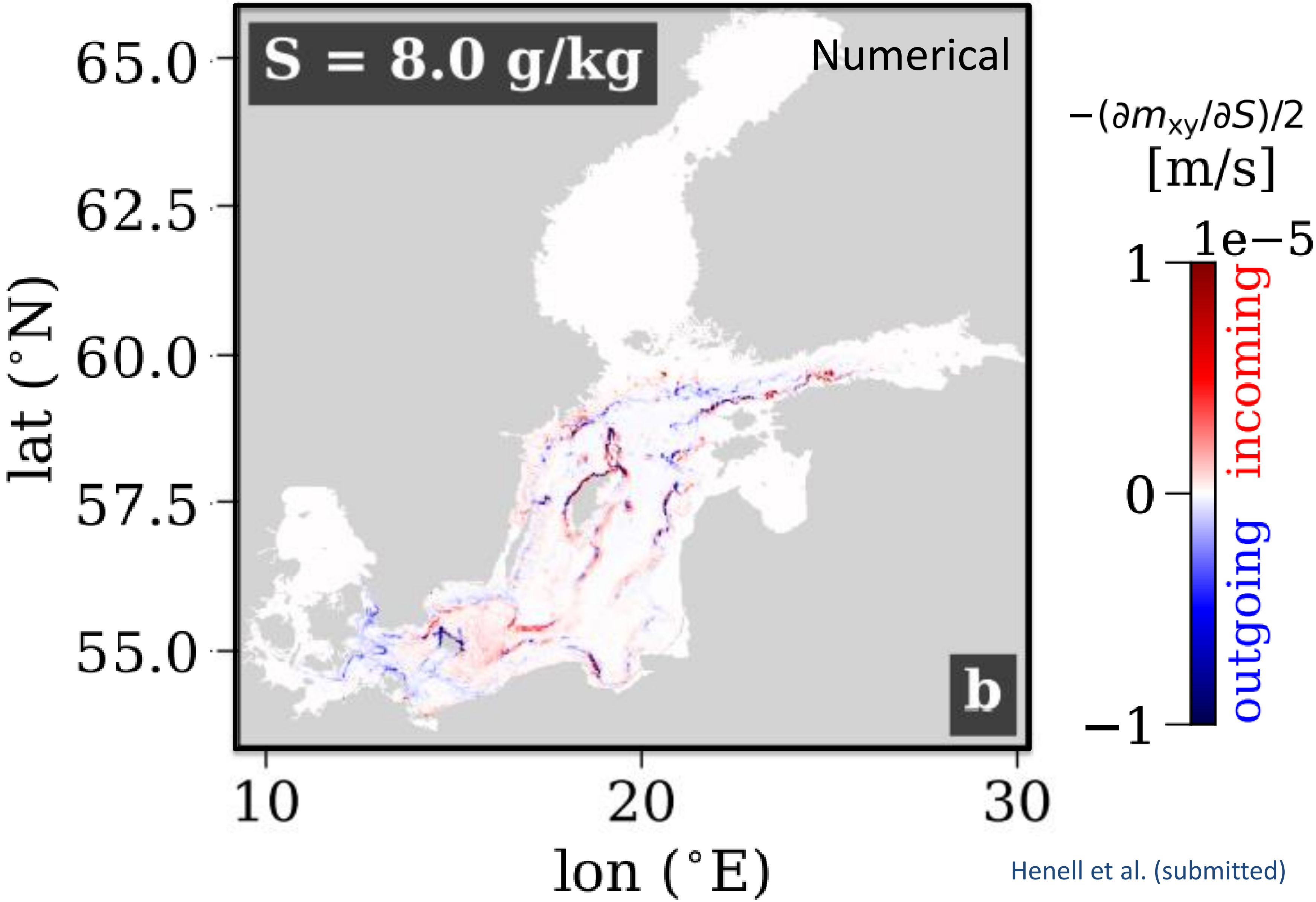
Ferrari et al. (2016)

S-derivative of physical local mixing per salinity class @ 8 g/kg



Henell et al. (submitted)

S-derivative of numerical local mixing per salinity class @ 8 g/kg

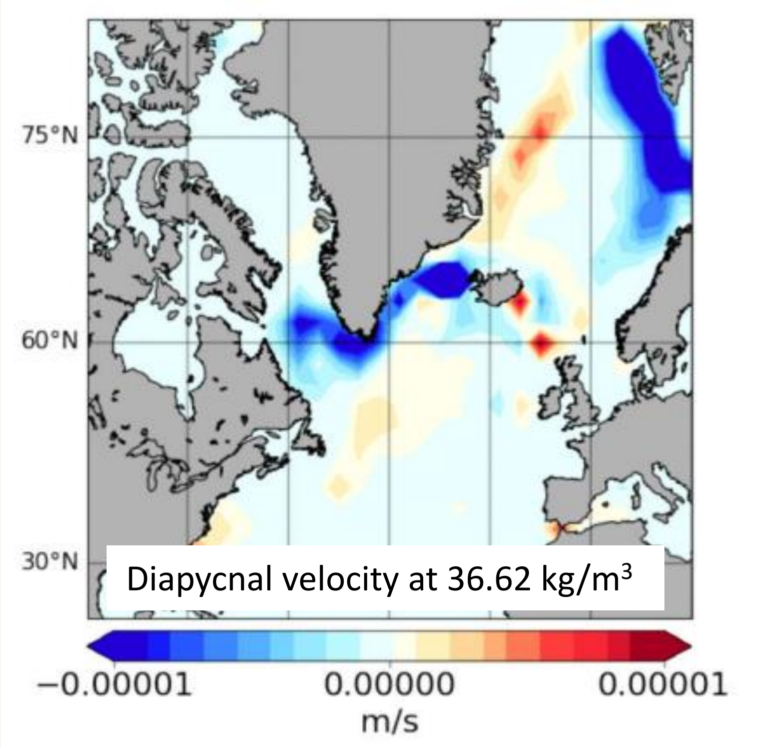


Henell et al. (submitted)

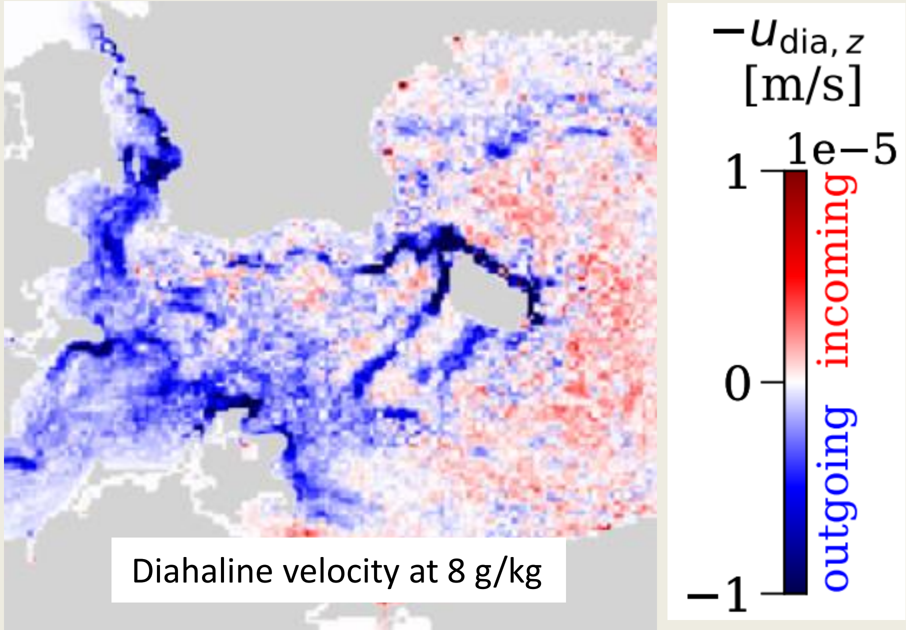
Plan for TRR 181 Phase III

✓Diagnose diahaline/diapycnal overturning in world ocean and relate it to local mixing

✓Separate between physically and numerically driven global overturning circulation?



Sidorenko et al. (2020)



Henell et al. (submittted)