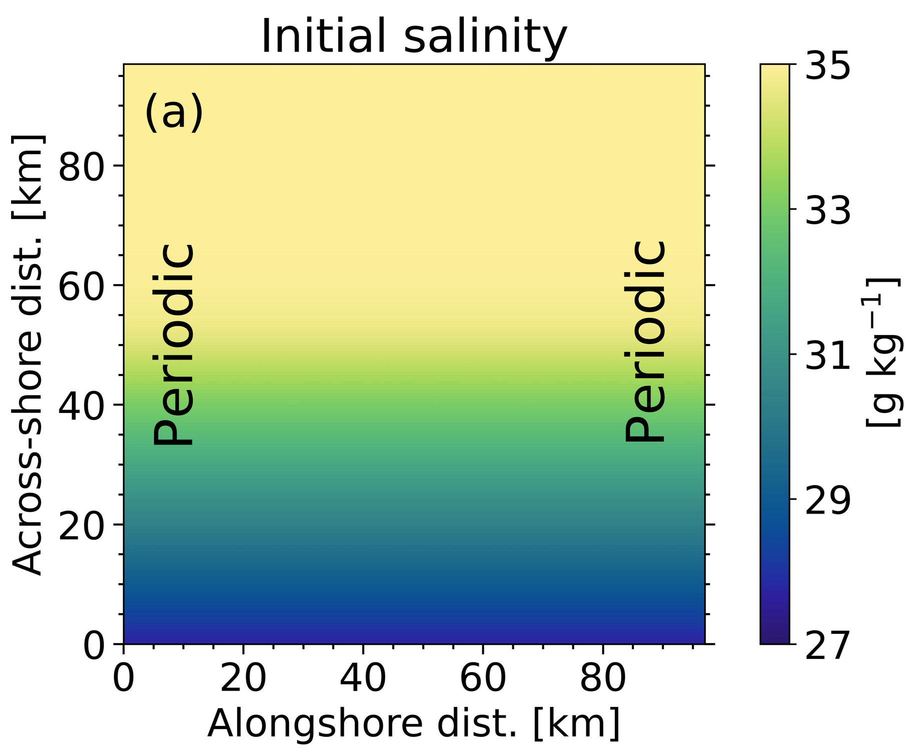
Numerical mixing suppresses submesoscale baroclinic instabilities over sloping bathymetry

Dylan Schlichting[1,2], Robert Hetland[1,3], and Spencer Jones[1]

1. Department of Oceanography, Texas A&M University. 2. Los Alamos National Laboratory. 3. Pacific Northwest National Laboratory | dylan.schlichting@tamu.edu

I. Idealized ROMS model following Hetland 2017 *JPO*



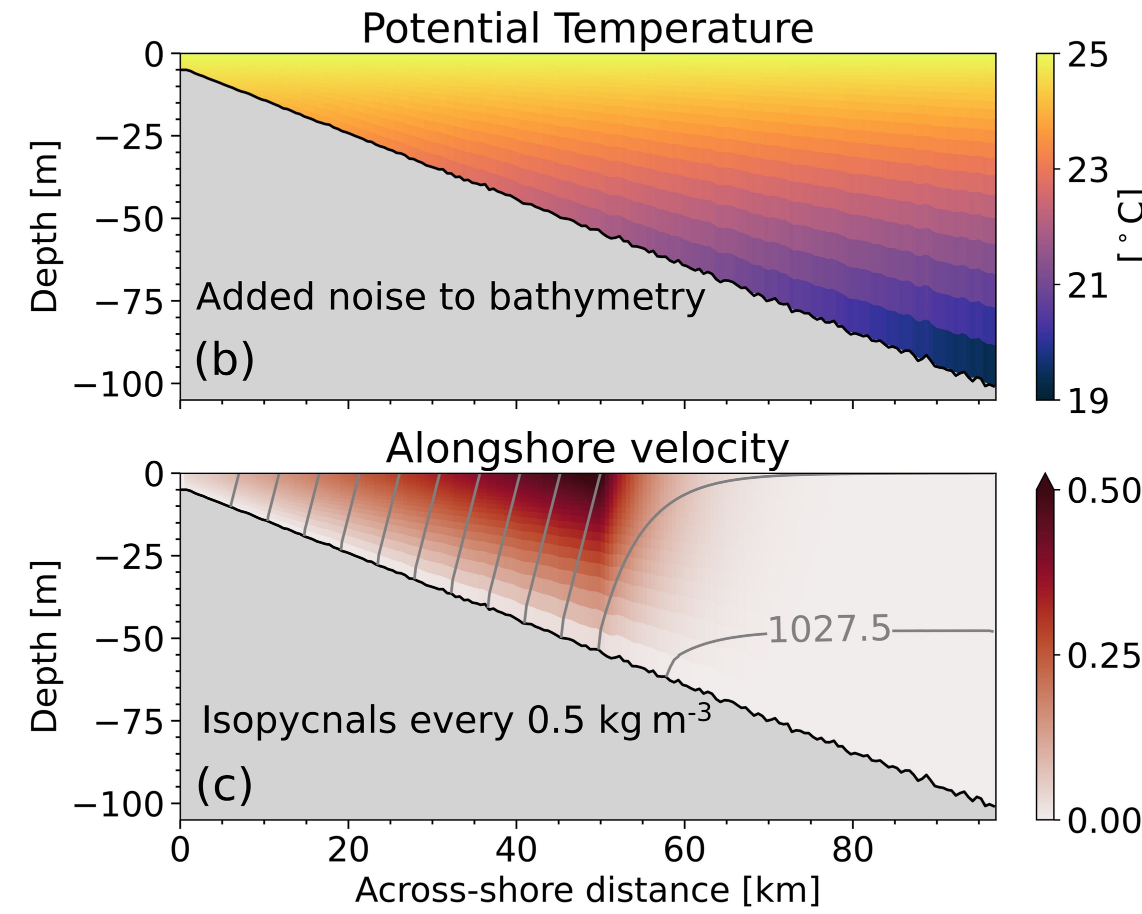


Fig 1: Plan view of initial surface salinity (a). Cross-sections of initial potential temperature (b) and alongshore velocity (c).

- $\mathcal{M}_{num} = (A\{s^2\} - A\{s\}^2)/\Delta t$ (Burchard & Rennau, 2008); $\mathcal{M}_{phy} = 2K_v(\partial_z s)^2$
- 500 m horizontal resolution; 30 vertical layers; f plane at 43°N; $k-\epsilon$ turb. closure
- 30-day simulations; wind stress $\tau^x = 0.1\sin(0.92ft)$; linear equation of state

How does numerical mixing impact larger scale flow and salinity field?

II. Mixing in frontal zones is numerically driven

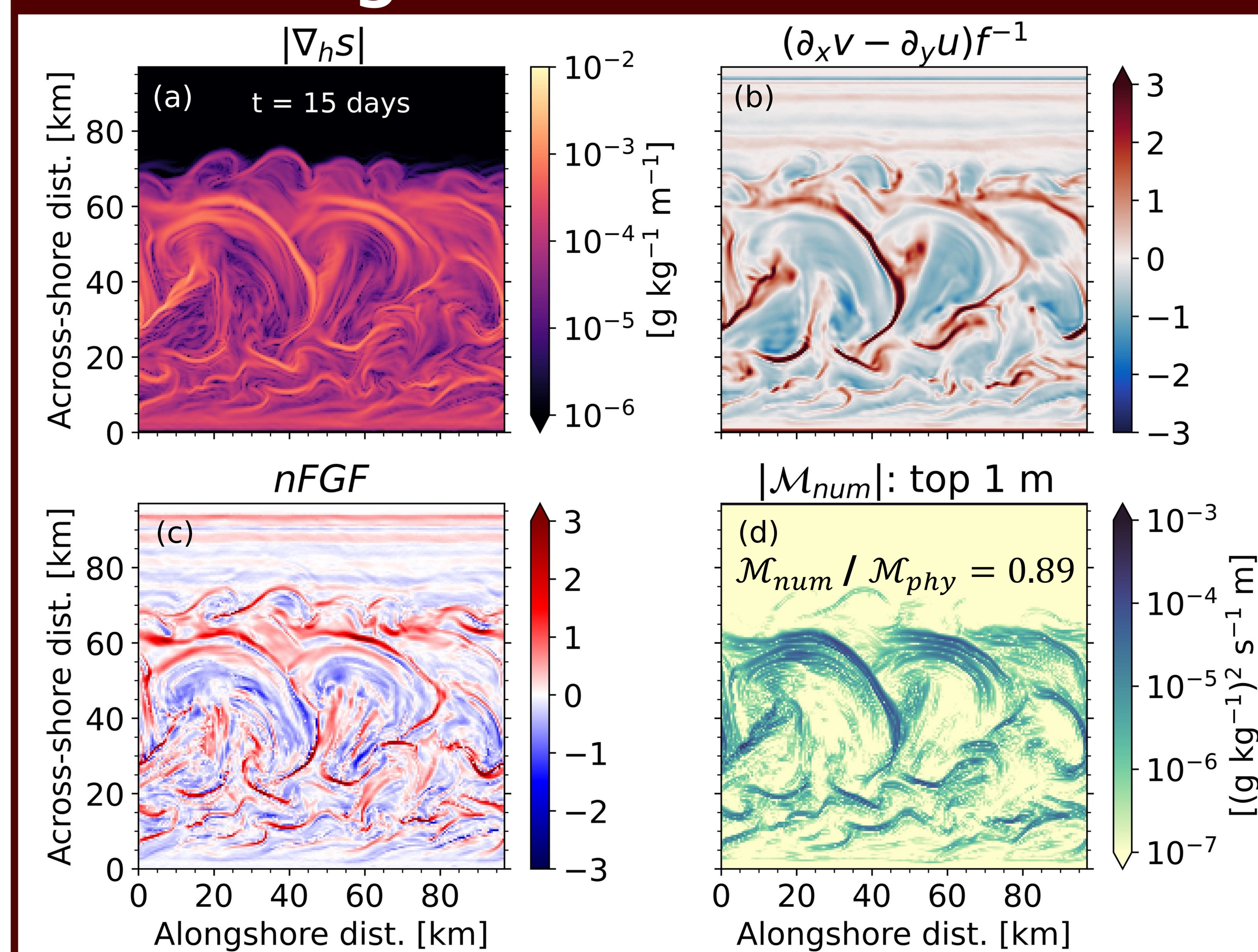


Fig 2: Day 15 hourly averages of surface horizontal salinity gradient magnitude (a), relative vorticity (b), $nFGF$ (c), and $\mathcal{M}_{num}$ integrated over the top 1 m of the water column (d).

$$nFGF = [2f(\nabla_h s)^2]^{-1} \frac{D}{Dt}(\nabla_h s)^2 \begin{cases} nFGF > 0 \text{ frontogenesis.} \\ nFGF < 0 \text{ frontolysis.} \end{cases}$$

Barkan et al. 2019 *JPO*

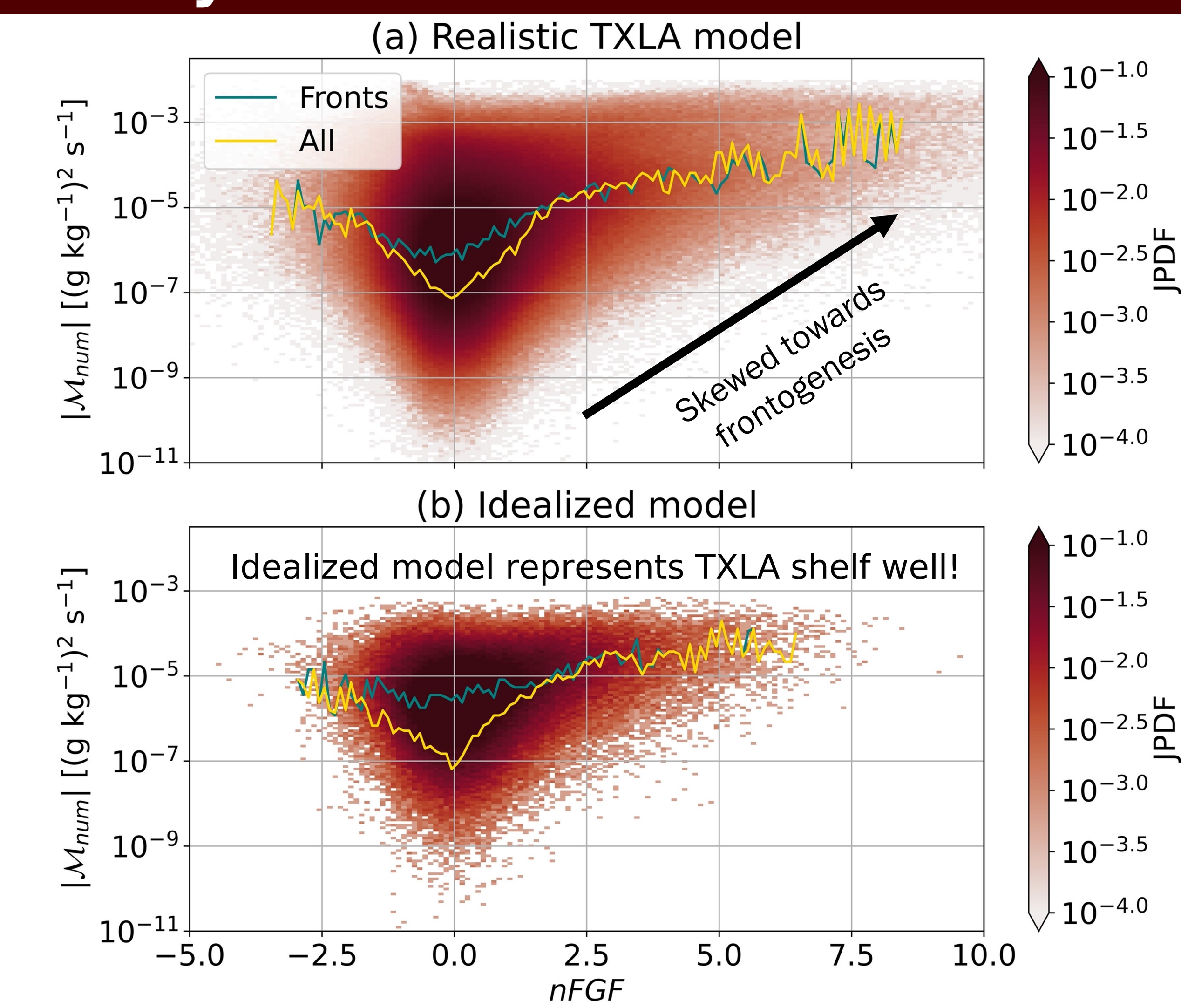


Fig 3: (a) surface layer joint probability density functions of $nFGF$ and $|\mathcal{M}_{num}|$ for the realistic TXLA model (Schlichting et al. 2023 *JAMES*) from June 20-26, 2010. Same as (a), but with the idealized model from days 7.5-15 (b).

III. Advection scheme ensemble shows $\mathcal{M}_{num}$ suppresses the release of APE by damping instabilities

- Three advection schemes: MPDATA, HSIMT, U3HC4
- Analysis tools: Eddy kinetic energy, available potential energy, isohaline & isopycnal variability
- Ensemble: 8 runs / scheme with variable 1% random bathymetry noise so ICs don't bias solution
- More developed eddies = more EKE, less APE, instabilities spread further offshore

$$\boldsymbol{u} = \overline{\boldsymbol{u}} + \boldsymbol{u}', \quad \overline{\boldsymbol{u}} = \frac{1}{L}\int_0^L \boldsymbol{u}\, dx$$

$$EKE = 0.5(u'^2 + v'^2), \quad MKE = 0.5(\bar{u}^2 + \bar{v}^2)$$ Normalized by initial MKE

$APE = \rho_0 b' z$ ⟶ Normalized by initial values

$$b' = b - b_{ref}, \quad b = -g\,(\rho_0 - \rho)/\rho_0$$

<>=16 hour rolling mean, ¯ =ensemble mean

Tab. 1: Ensemble-averaged bulk mixing statistics integrated up to 97 km across-shore.

Scheme	$\mathcal{M}_{num}/\mathcal{M}_{tot}$	$\mathcal{M}_{phy}/\mathcal{M}_{tot}$	$\mathcal{M}_{num}/\mathcal{M}_{phy}$
MPDATA	0.14	0.86	0.16
U3HC4	0.17	0.83	0.21
HSIMT	0.34	0.66	0.50

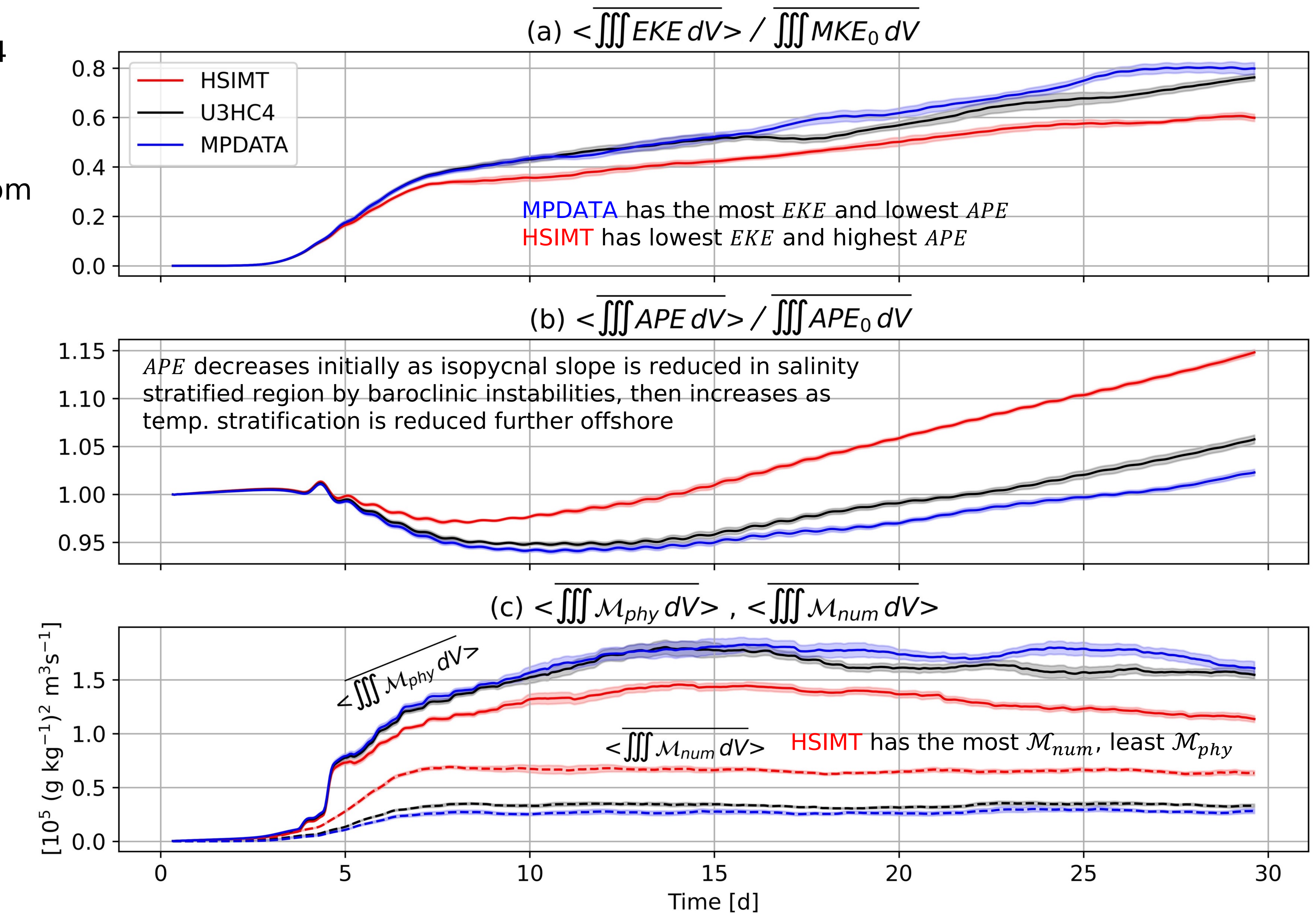


Fig 4: Ensemble-averaged, convolved, volume-integrated EKE(a), APE(b), and $\mathcal{M}_{phy}$ and $\mathcal{M}_{num}$(d) up to 97 km offshore. The shaded areas represent values within the 95% confidence intervals about the ensemble average. 16-hour convolution is performed to remove influence of near-inertial, oscillatory wind forcing.

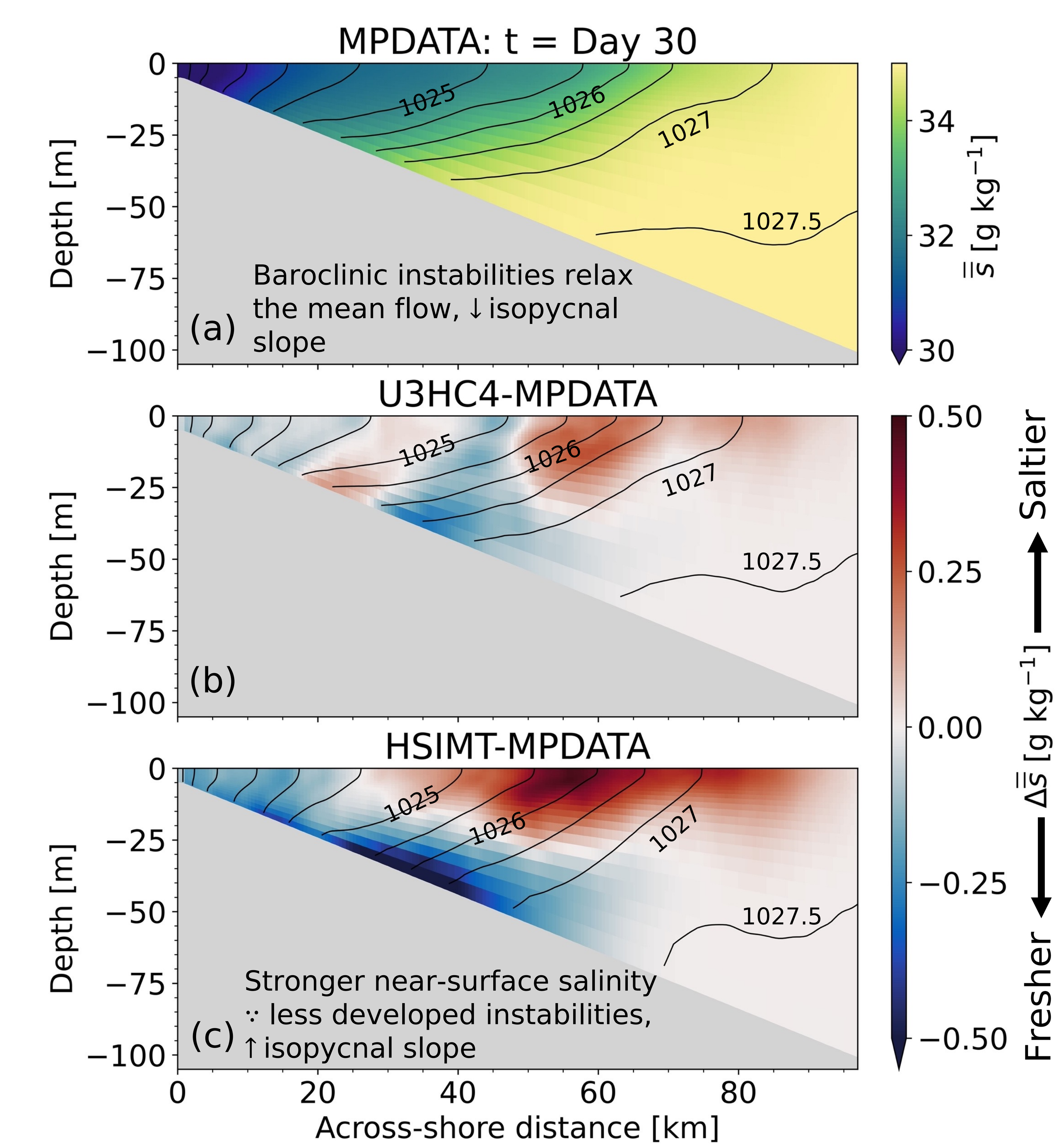


Fig 5: Cross-sections of alongshore- and ensemble- averaged salinity (denoted by ═) for MPDATA on day 30 (a). Relative differences between the same quantities for U3HC4 (b) and HSIMT (c), which are denoted by Δ. Isopycnals overlaid every 0.5 kg m^{-3}.

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