Submesoscale Ocean Ventilation

Vertical fluxes conditioned on vorticity and strain reveal submesoscale ventilation

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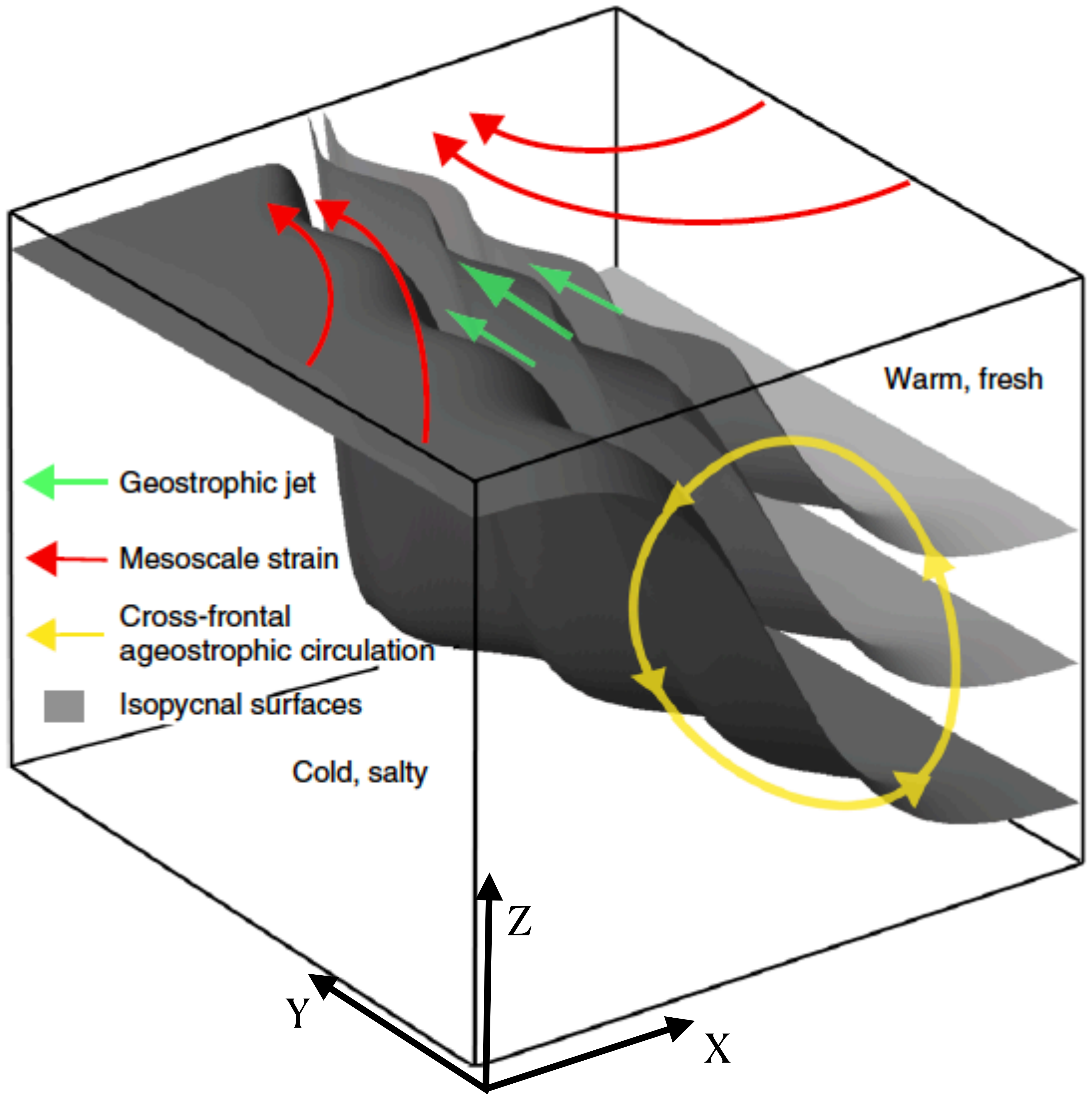
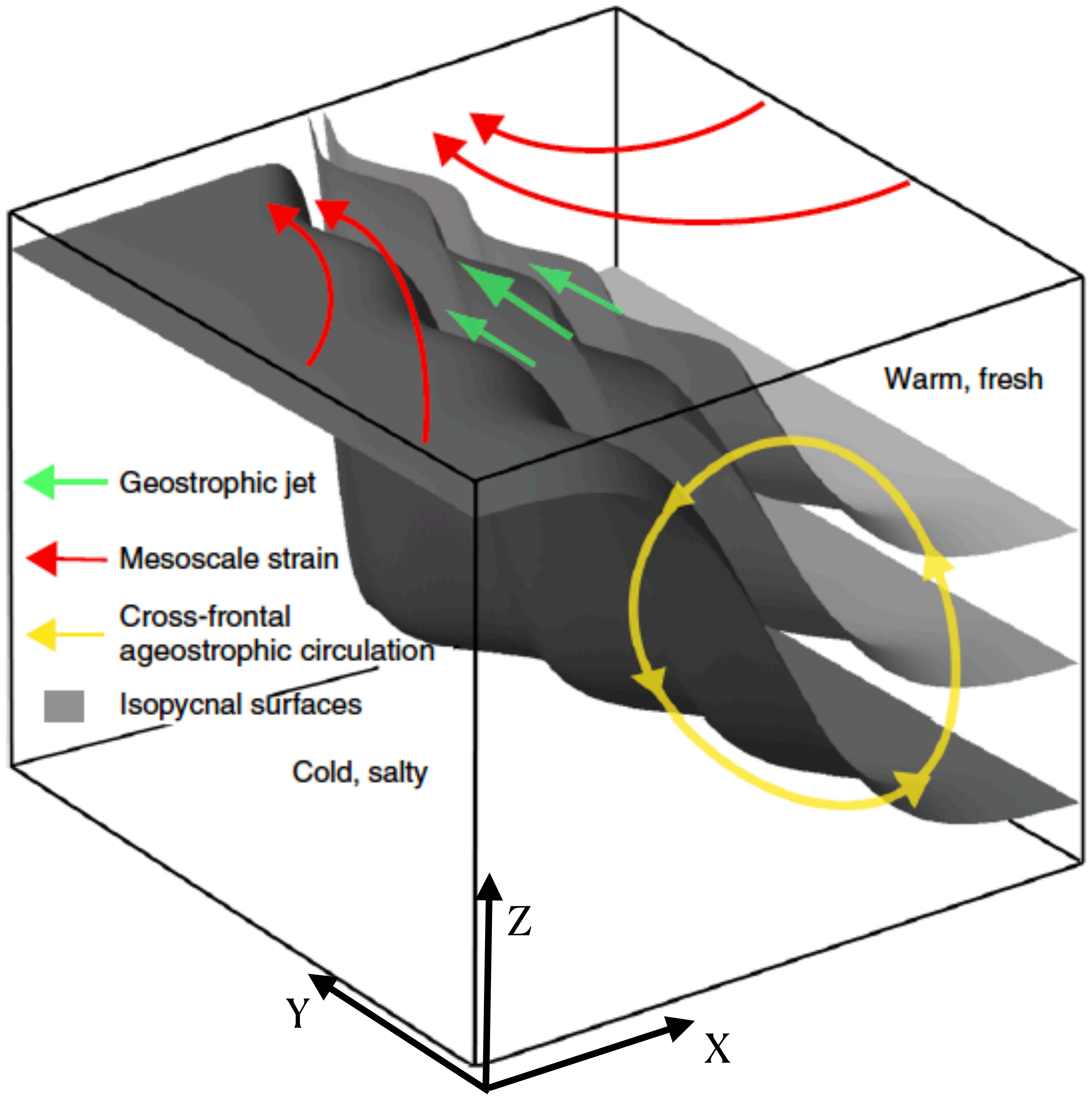
Thursday, 4 February 2021 | CESM Ocean Working Group Meeting



Schematic of a front,
Levy, Franks and Smith 2018

Observations suggest that tracers are transported from the mixed layer into the interior as thin filaments at fronts.



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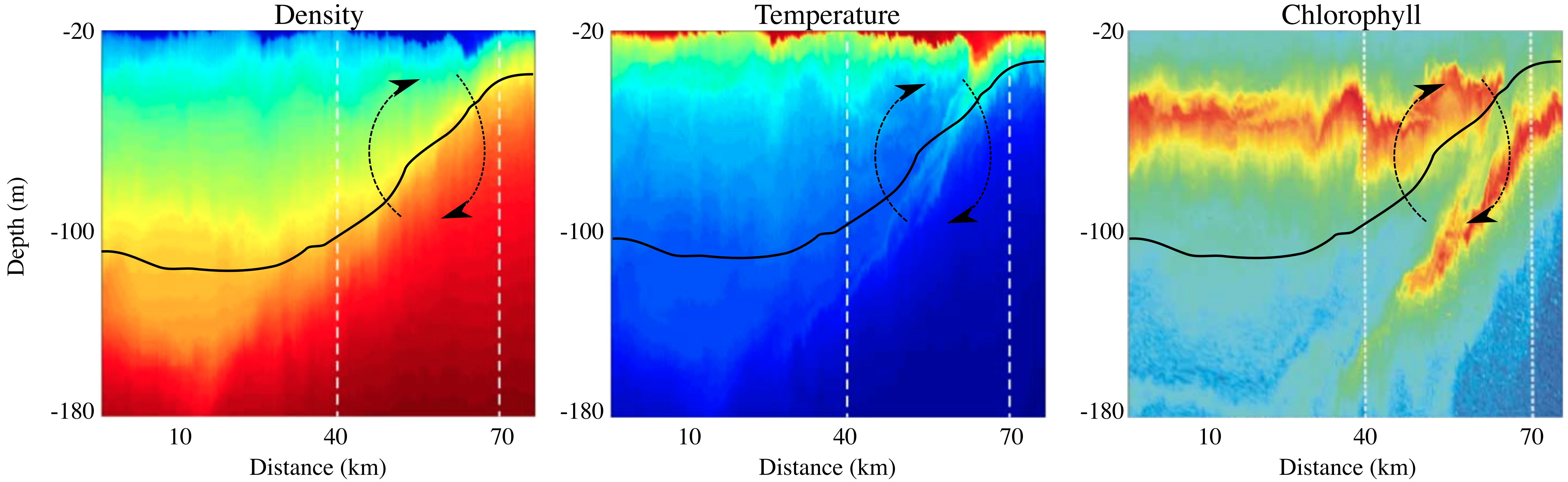
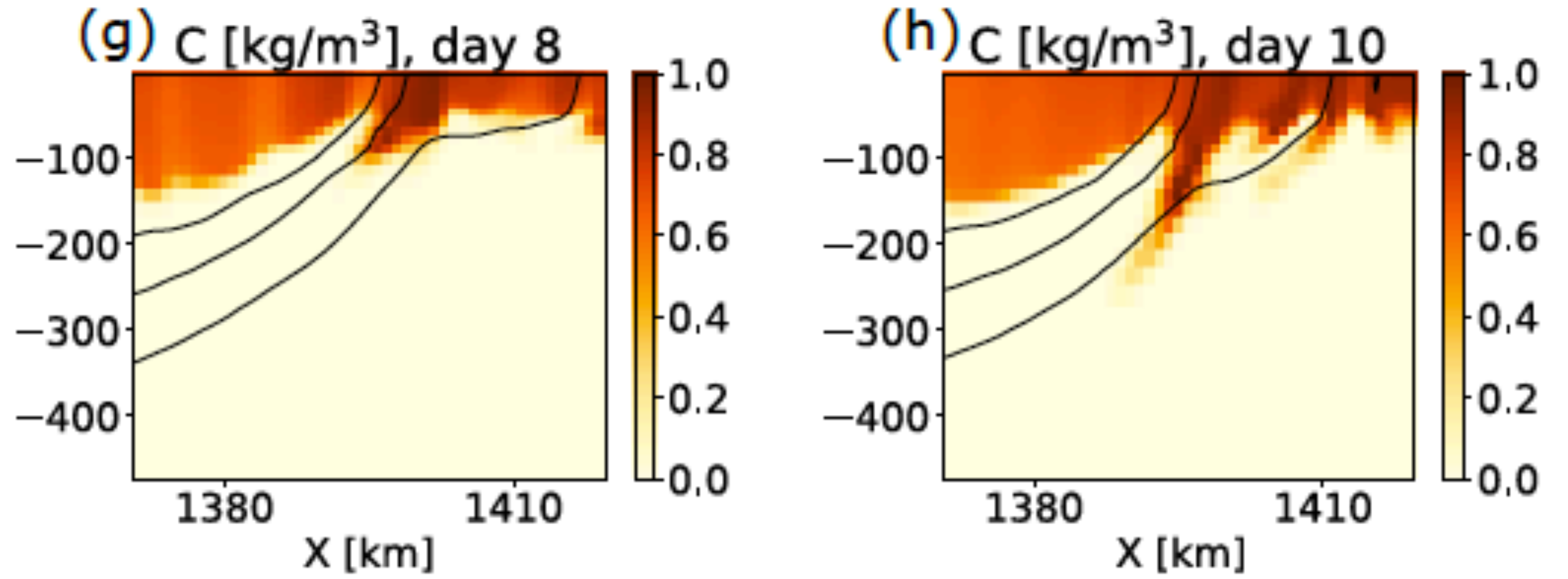


Glider section across a from in the Alboran Sea, Ruiz et al 2009



Section across a front in a 1km simulation,
Balwada, Xiao et al 2021

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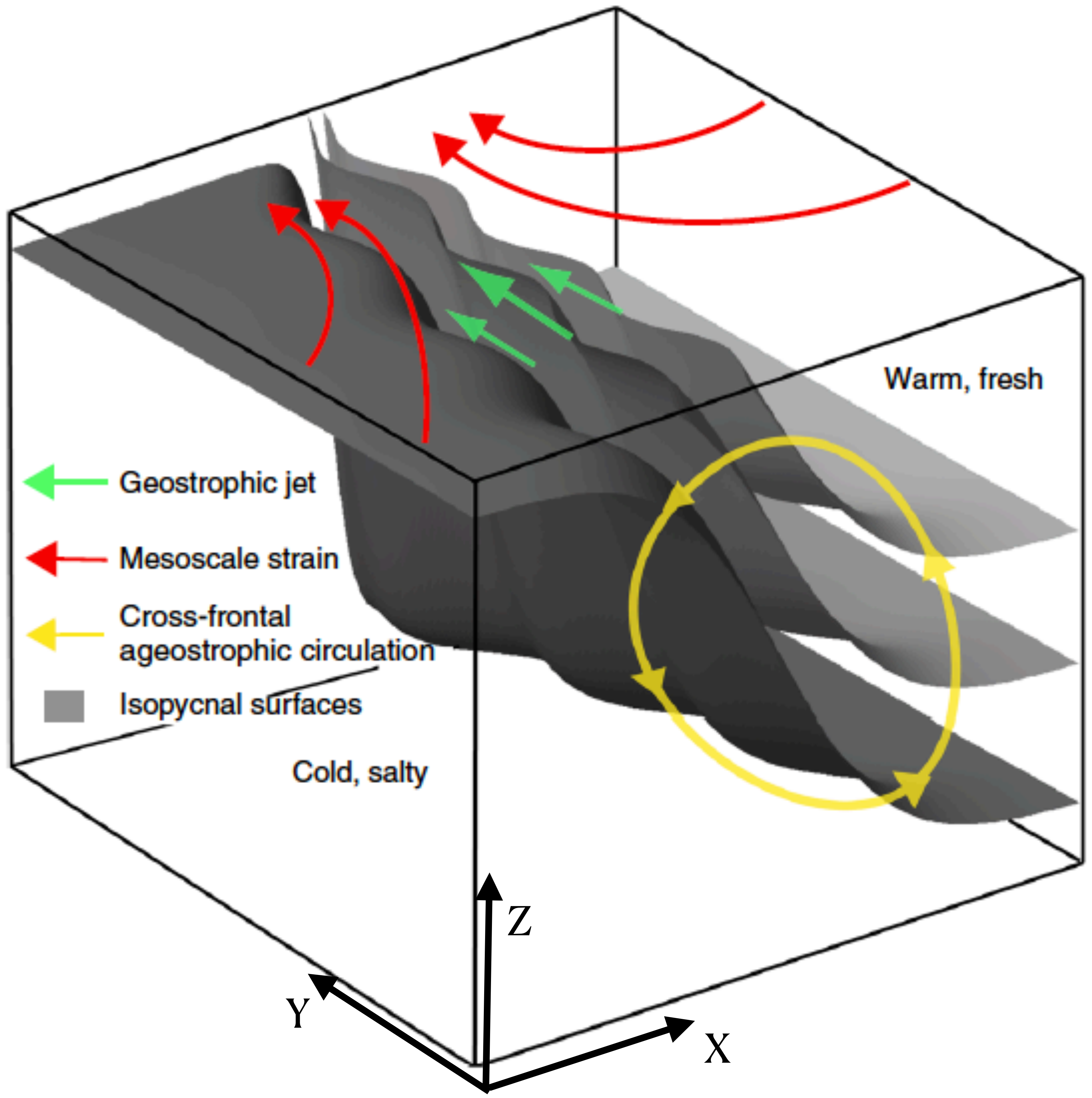

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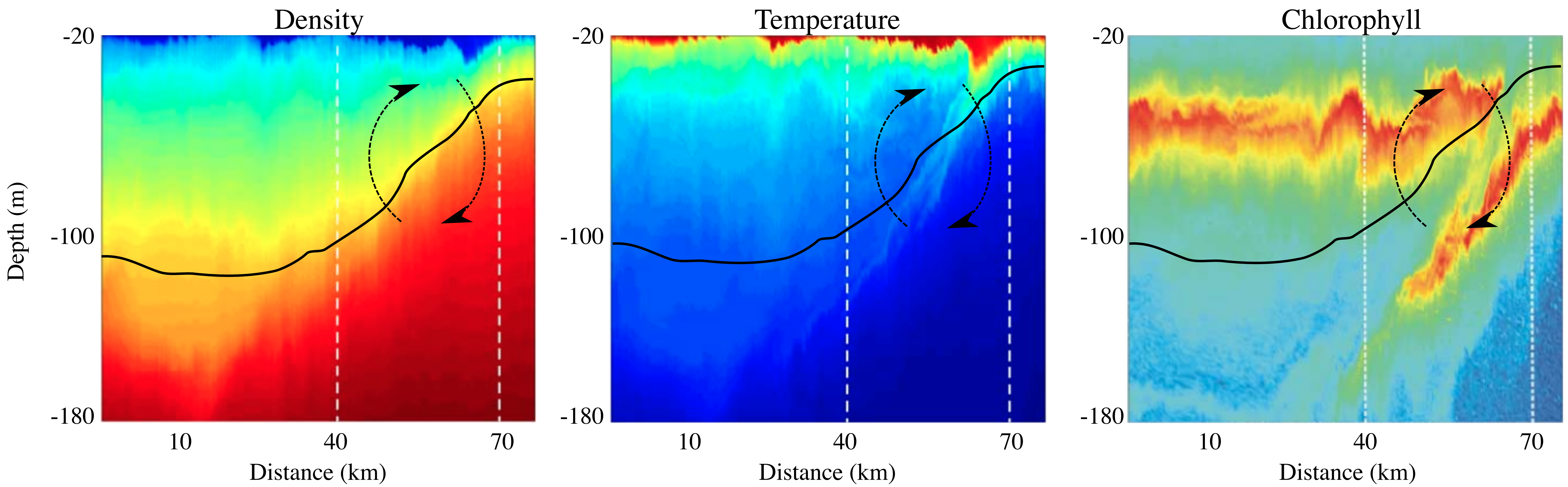
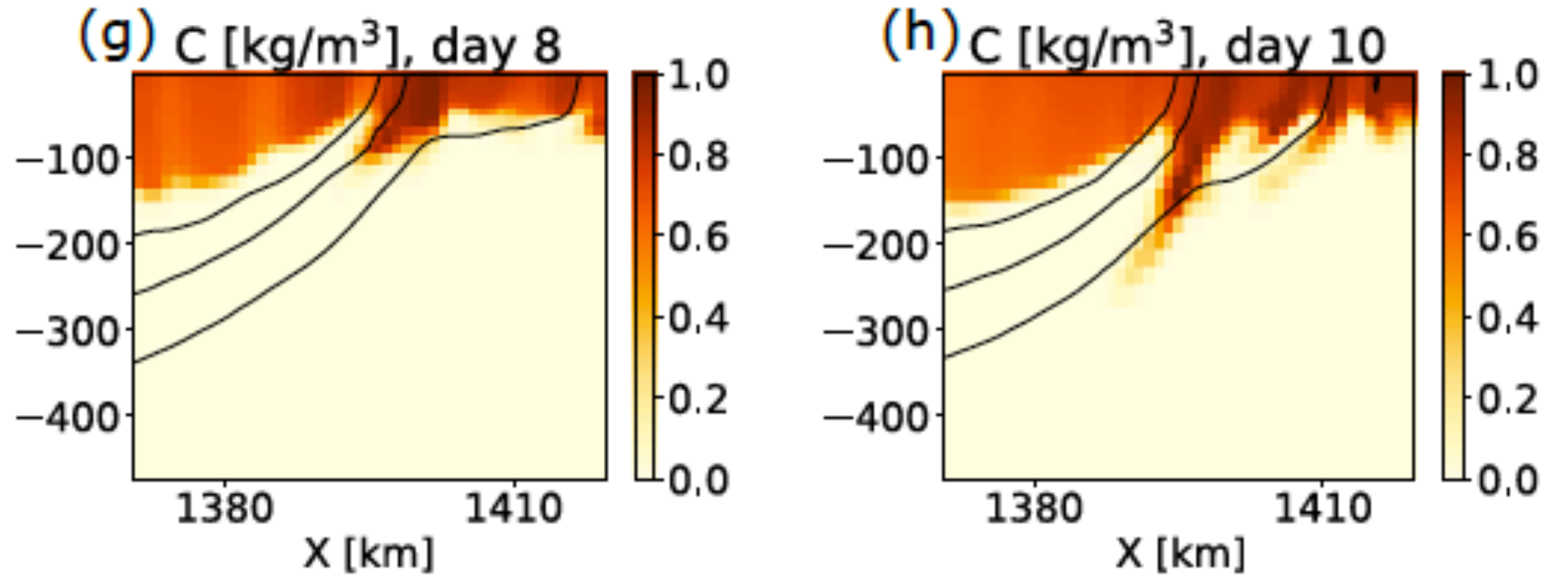


Glider section across a from in the Alboran Sea, Ruiz et al 2009

- **While locally significant, do fronts play a major role in large scale tracer budgets?**
- **What are the dominant scales and processes involved in ocean ventilation?**



Section across a front in a 1km simulation,
Balwada, Xiao et al 2021

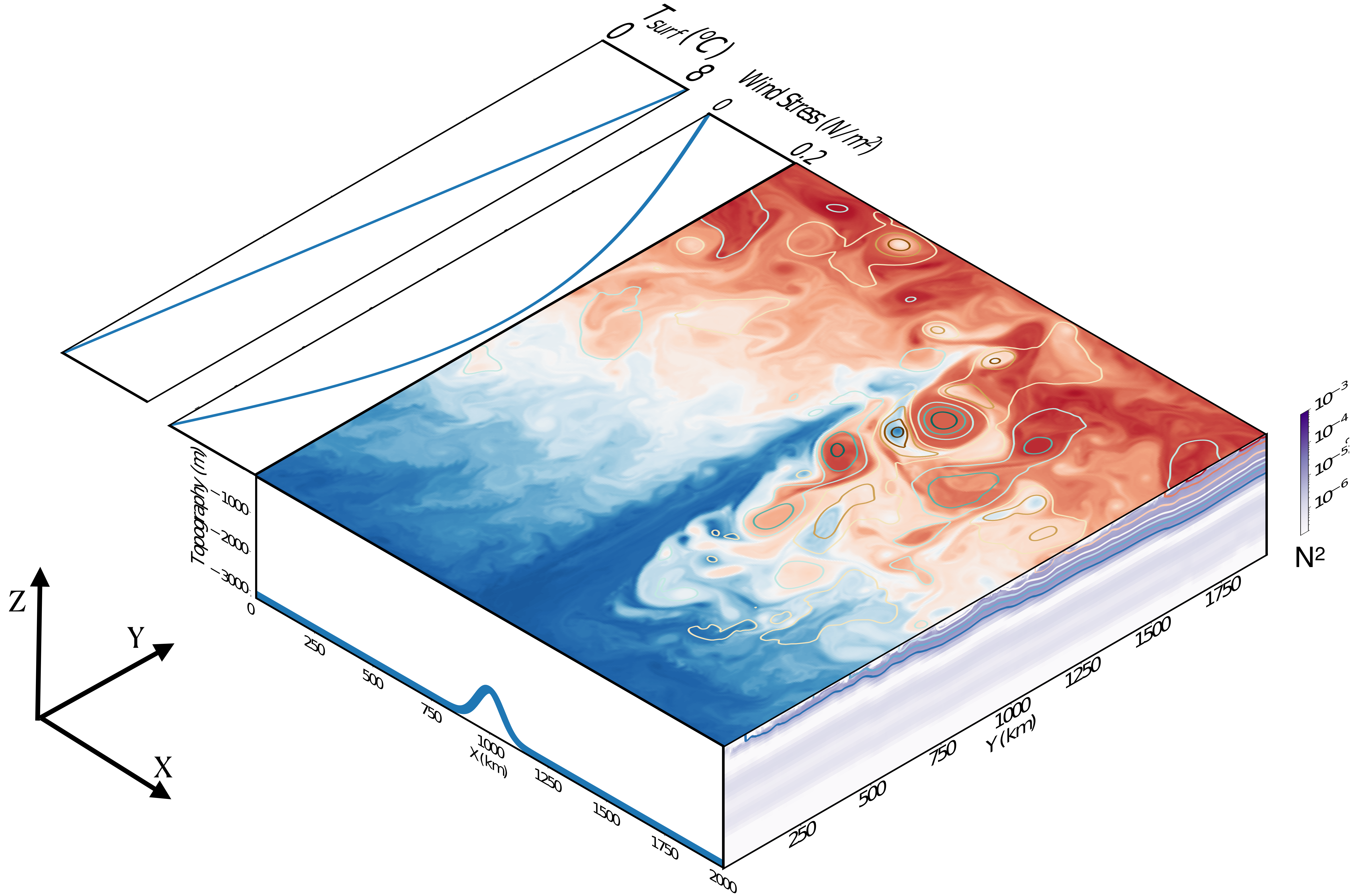
A simulation suite to study mesoscale & submesoscale transport

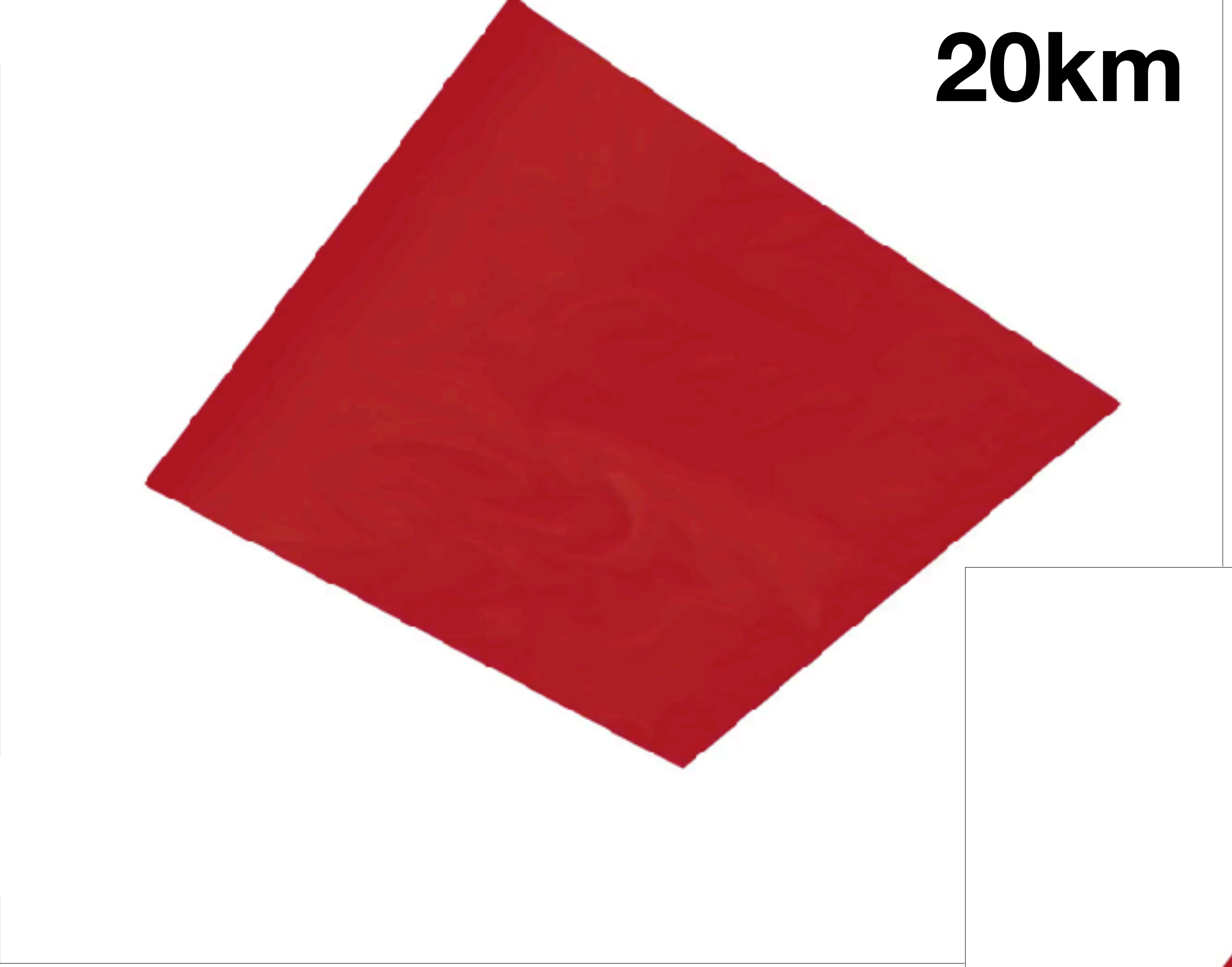
Physical Setup

- Zonally periodic channel in MITgcm.
- 2000km X 2000km X 3km.
- Beta plane with central latitude ~ 35°S
- Horizontal grid size of 20, 5 and 1km.
- Vertical grid size of 1m near the surface, with 76 levels.
- Forced by winds and buoyancy restoring.
- 1km high meridional ridge to add some realism.
- Meridional boundaries are no flow walls, implying no deep overturning circulation.
- KPP parameterization for mixed layer.
- QG Leith for small scale dissipation.

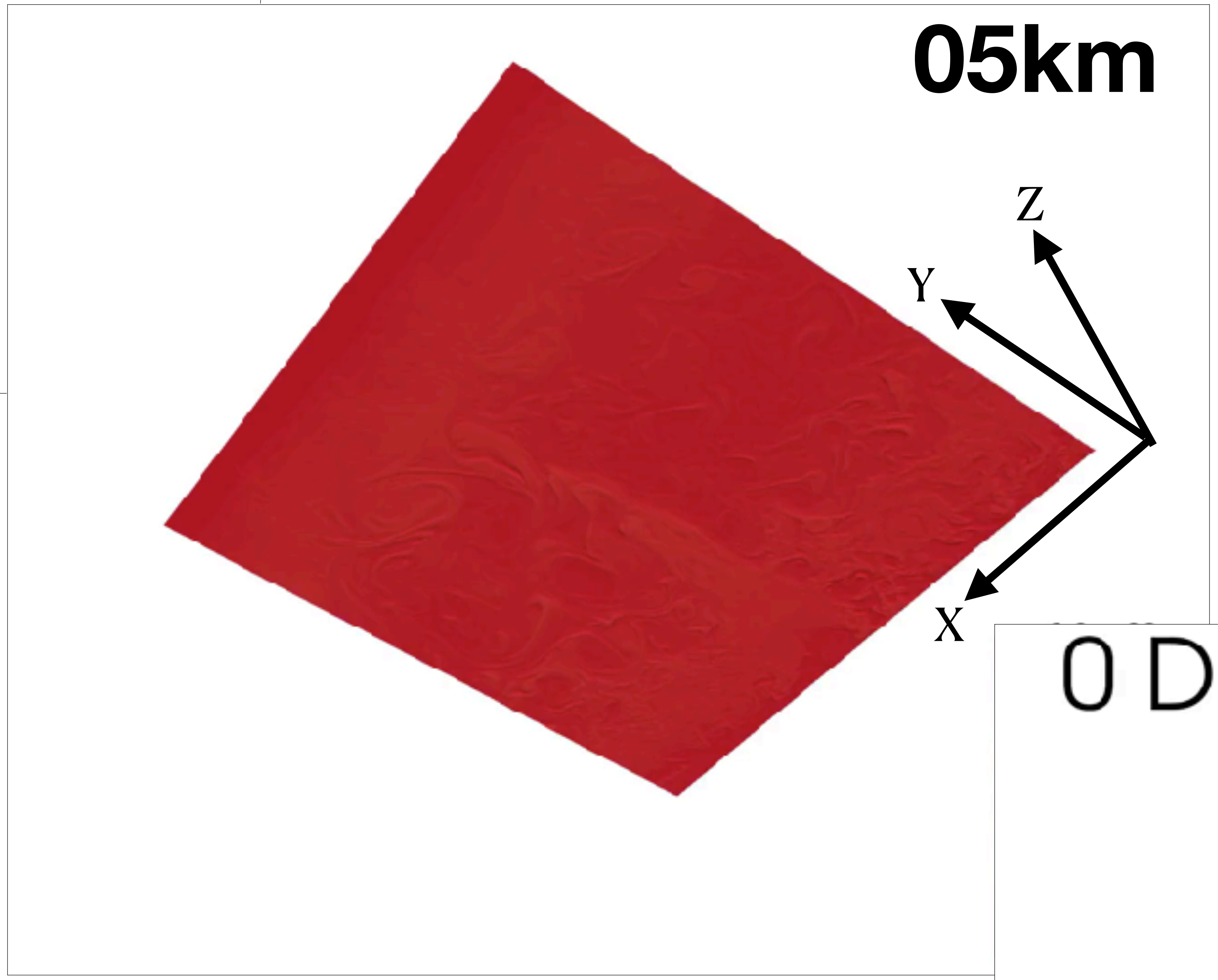
Tracer Setup

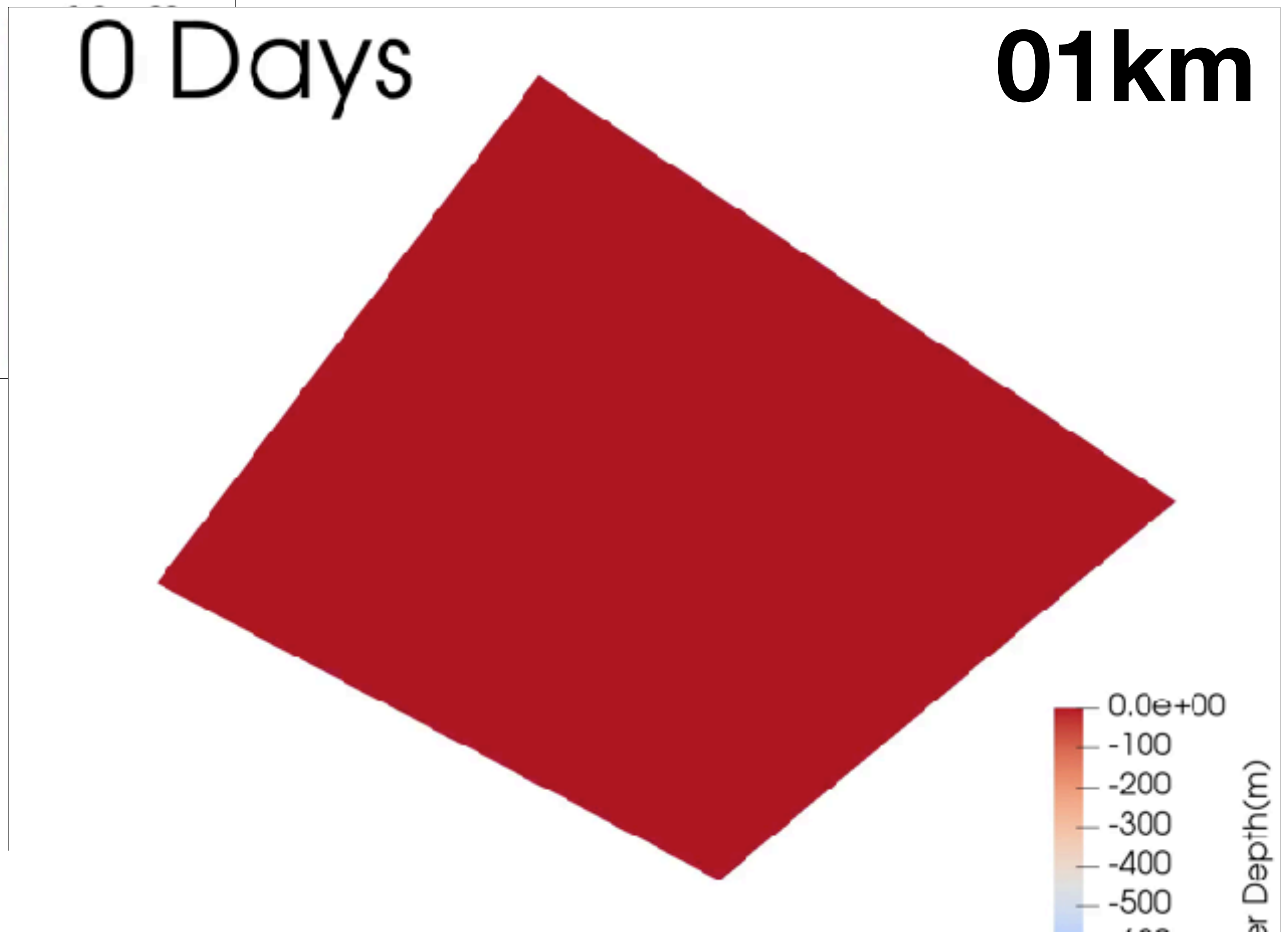
- Surface restoring to a constant value with a time scale of 72mins (very rapid, similar gas transfer velocity to moderate wind conditions in Southern Ocean).
- Started after the flow is in equilibrium.





Increasing resolution
Smaller scale fronts
Shallower mixed layers
Tracer transported deeper & faster!



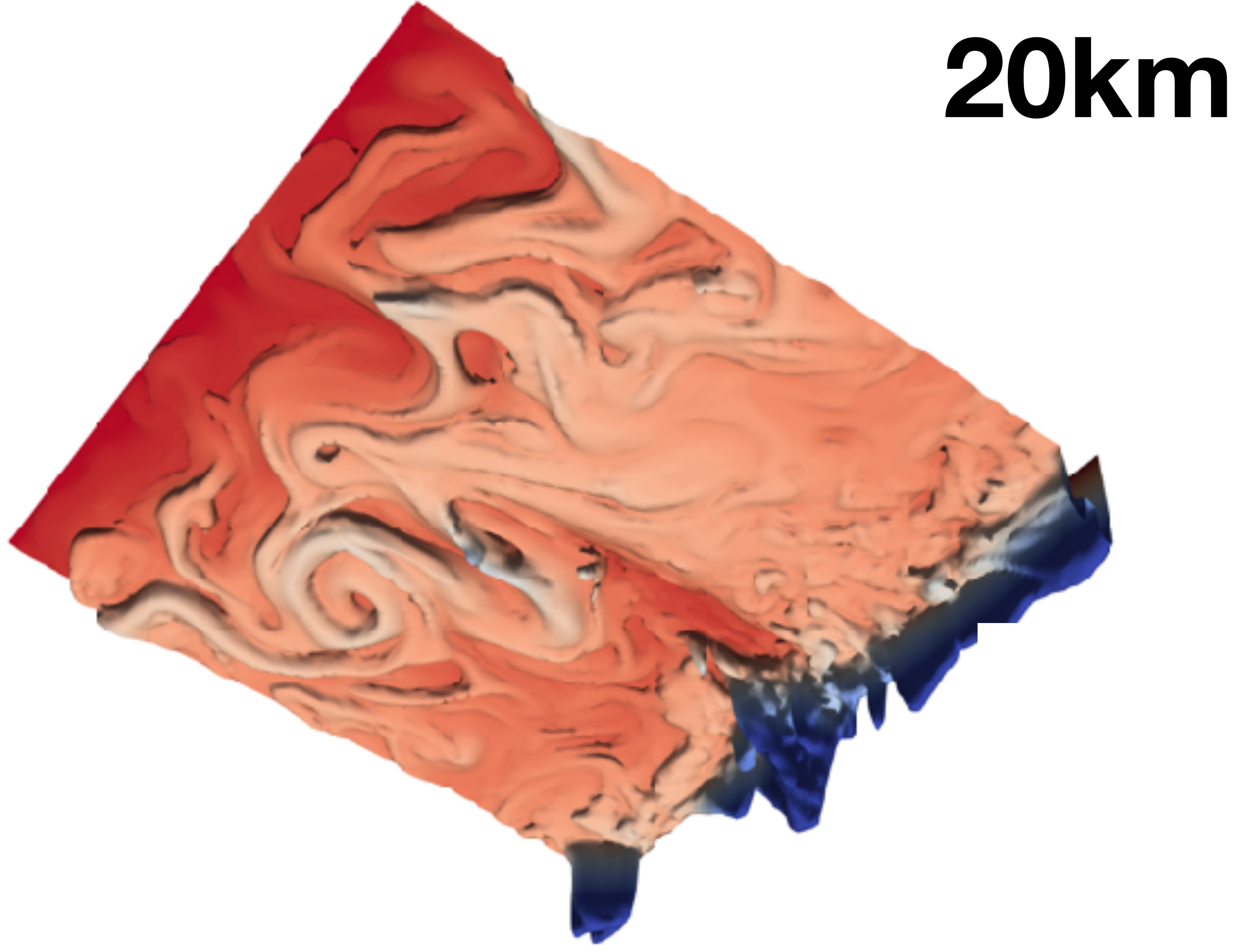


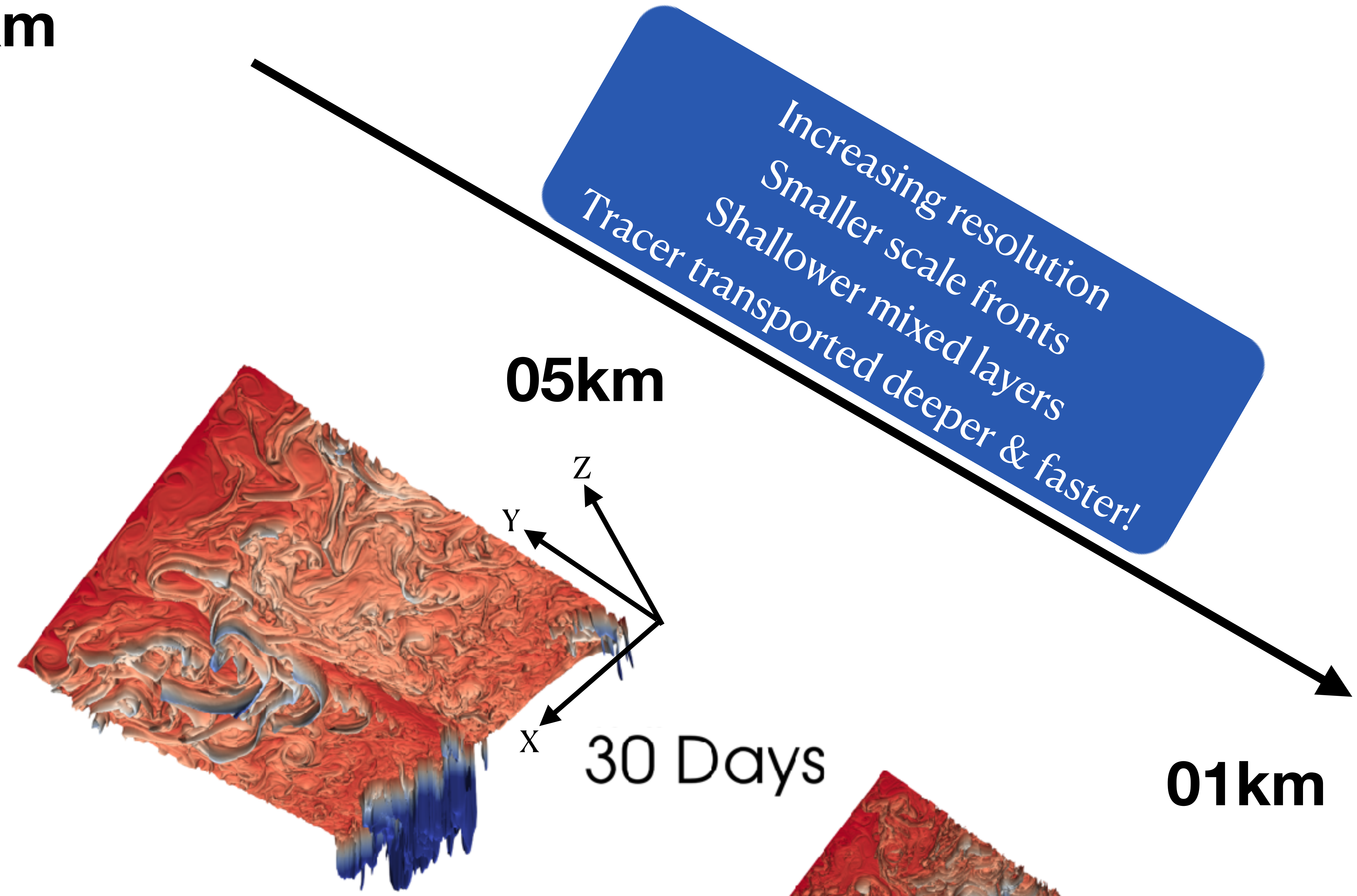
What you are looking at:

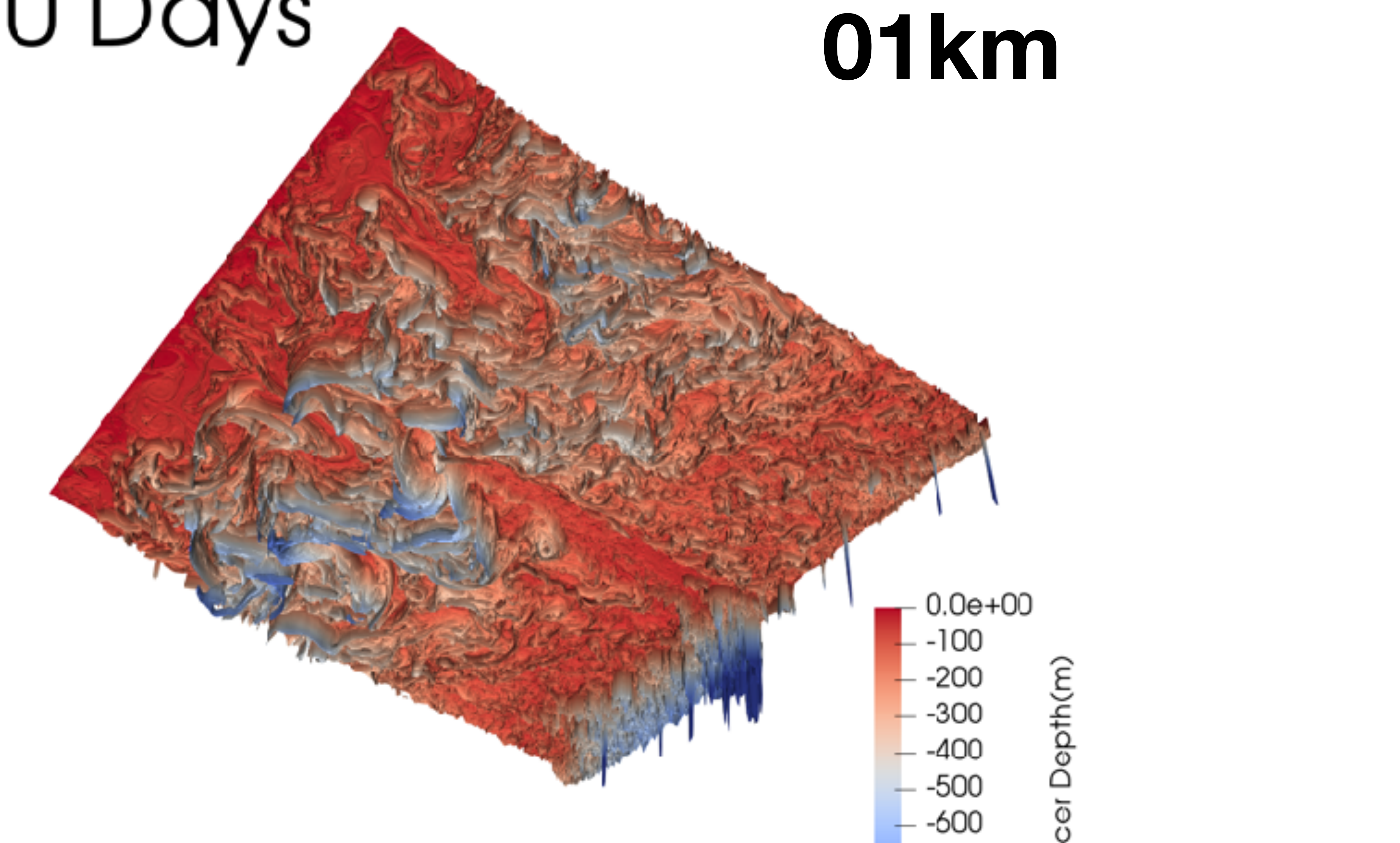
- Looking towards the surface of the ocean from depth.

- A tracer isosurface is visualized, with the colors indicating its depth (red is near surface, and blue is deeper).

- Deep reaching tracer (blue) to the south results from artificially deep mixed layers in the southern part of the domain, which are excluded from rest of the analysis.







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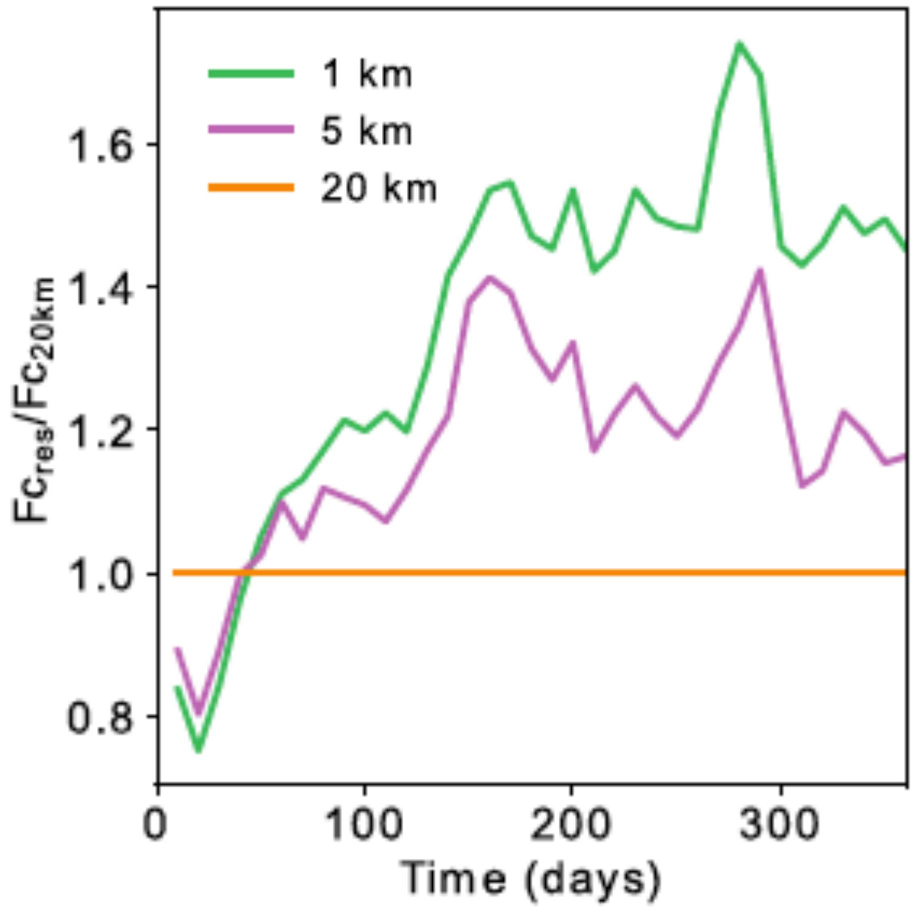
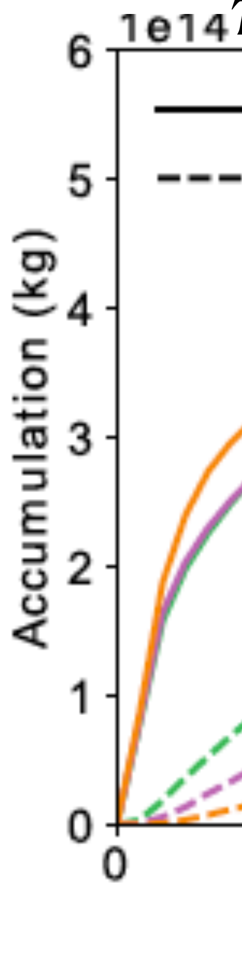
Resolving submesoscales leads to more tracer uptake.

- Surface fluxes at 1km are ~50% higher than at 20km.
- The tracer transported below the mixed layer doubles from 20km to 1km.

Surface flux/Surface flux at 20km



Tracer storage below different depths



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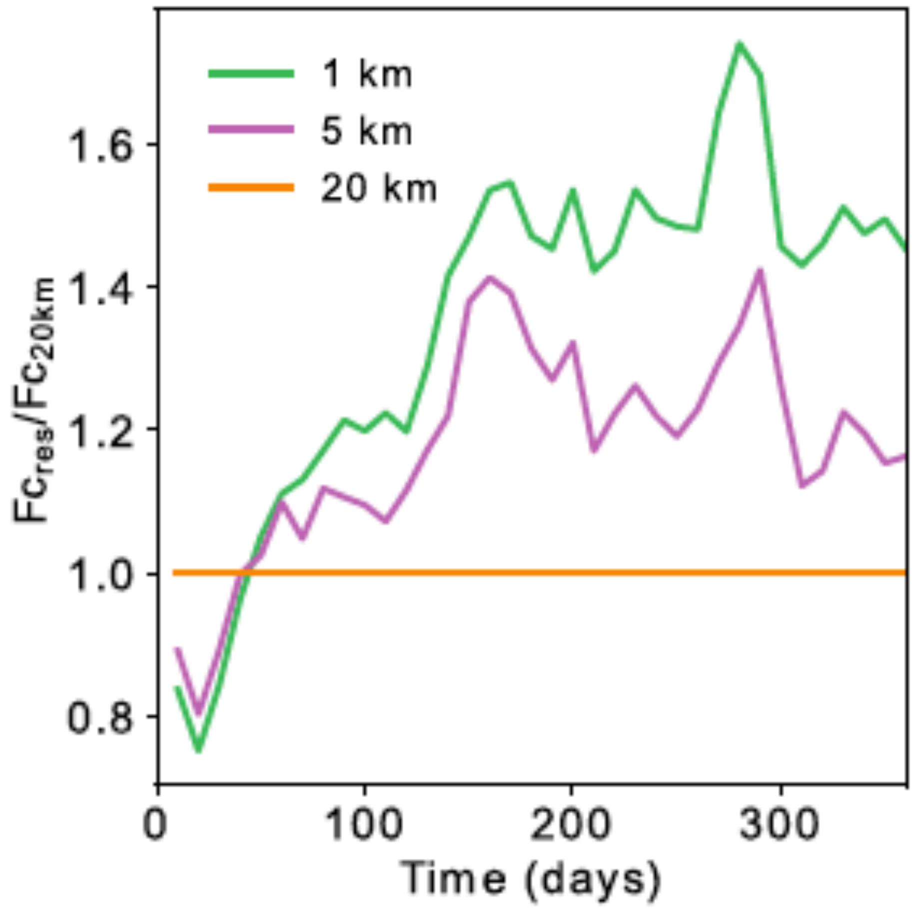
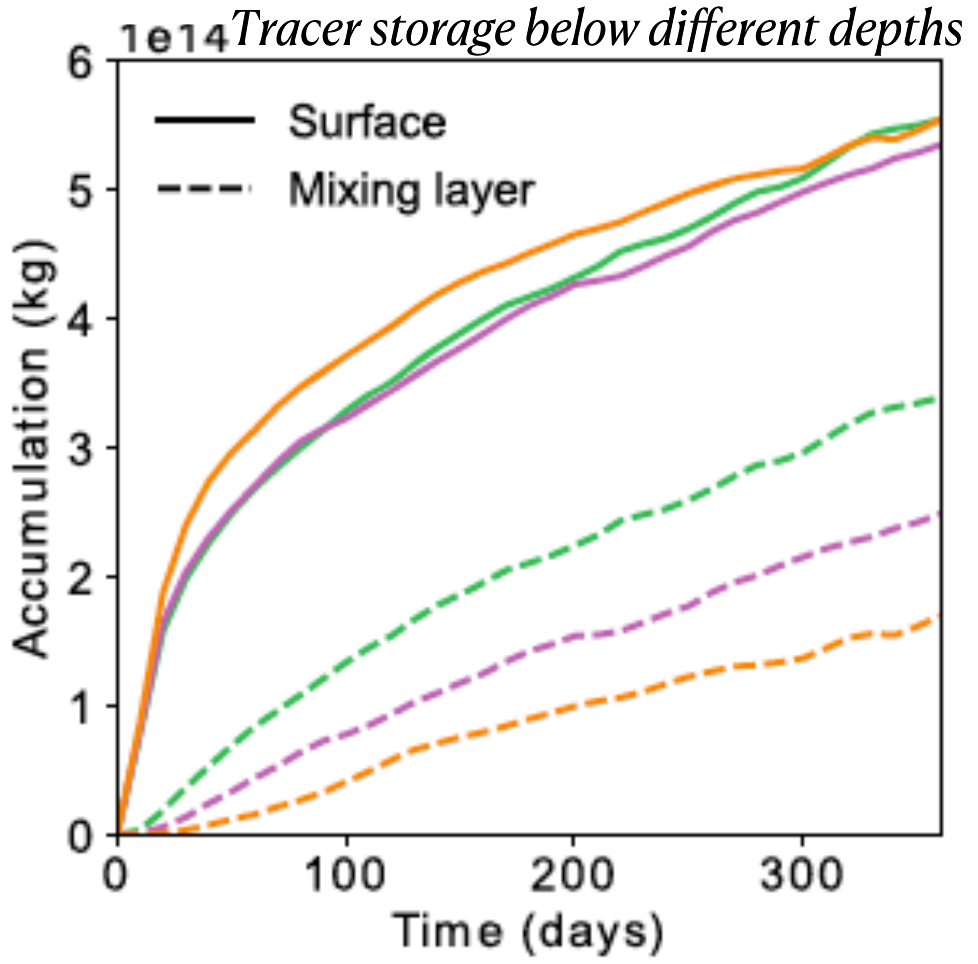
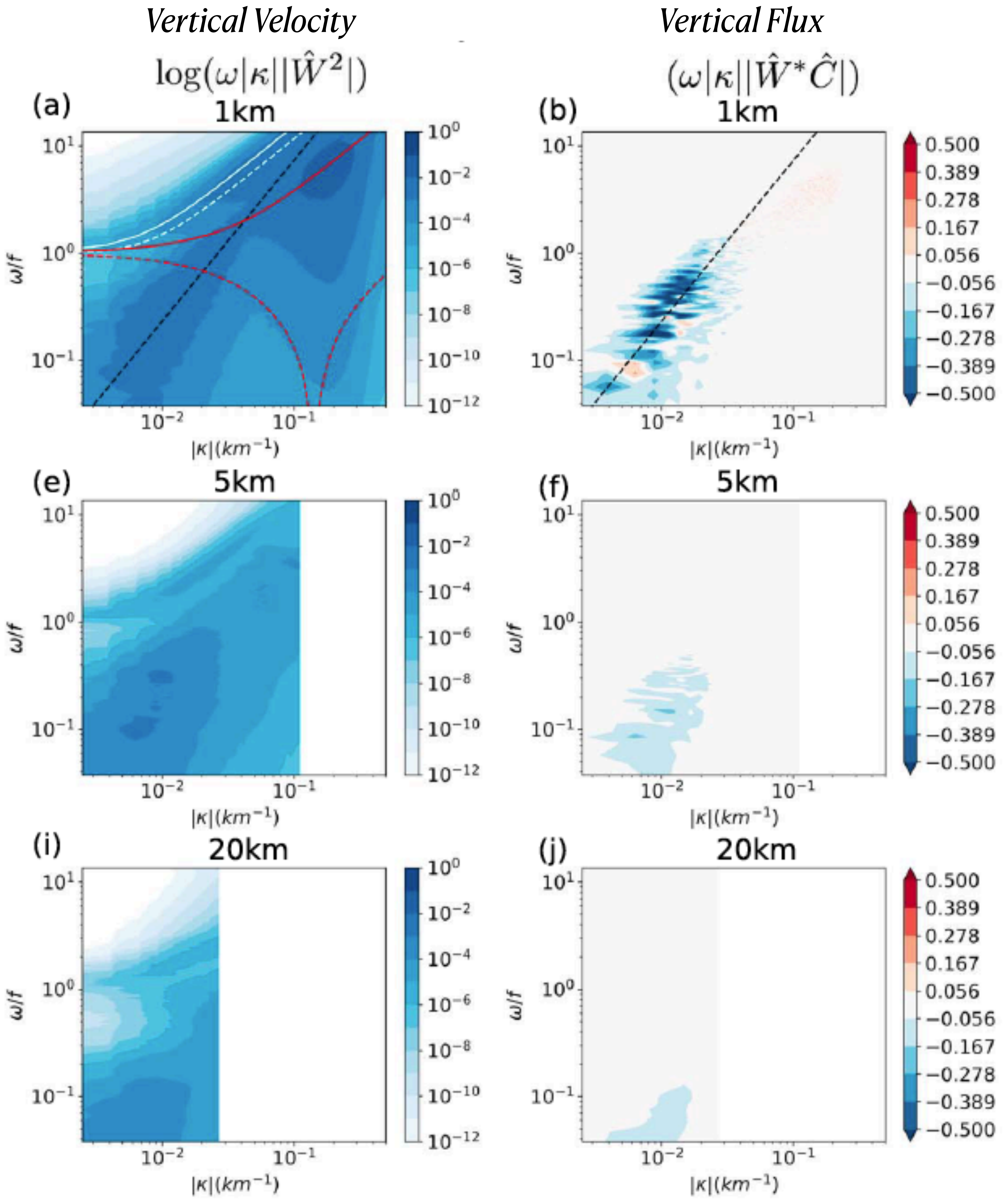




Lessons from spectral analysis

Wavenumber-Frequency



- Internal waves are a dominant part of the vertical velocities, but have no impact on vertical tracer fluxes.

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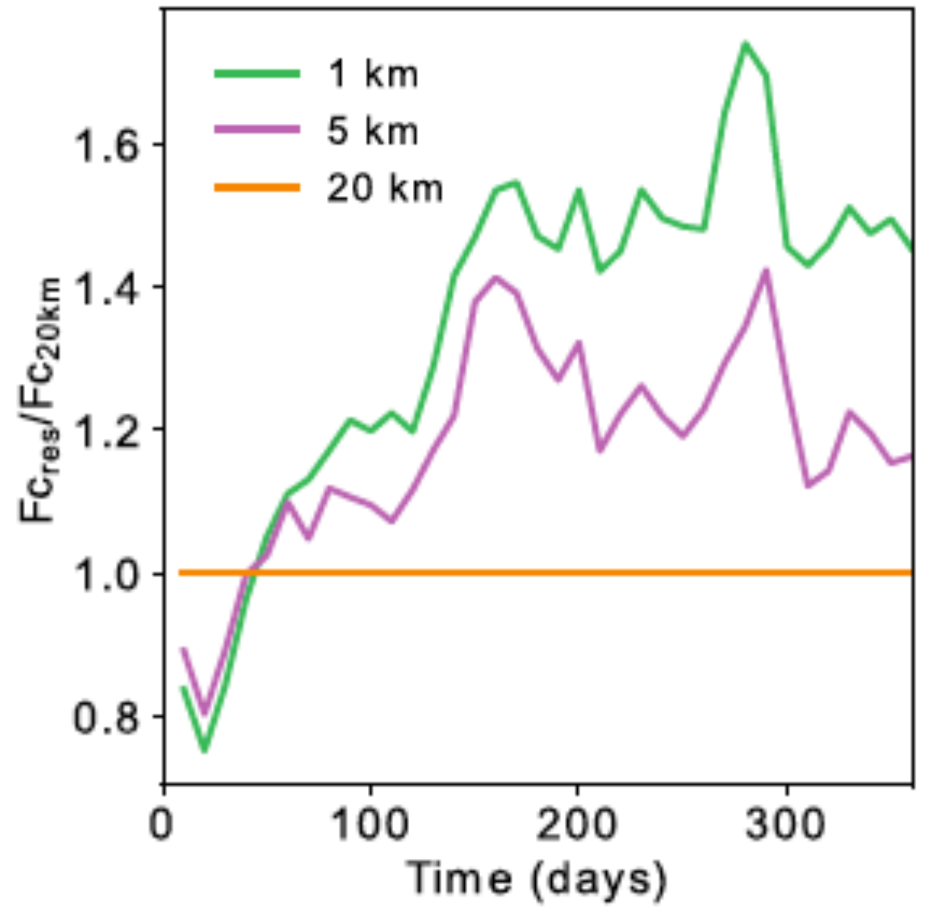

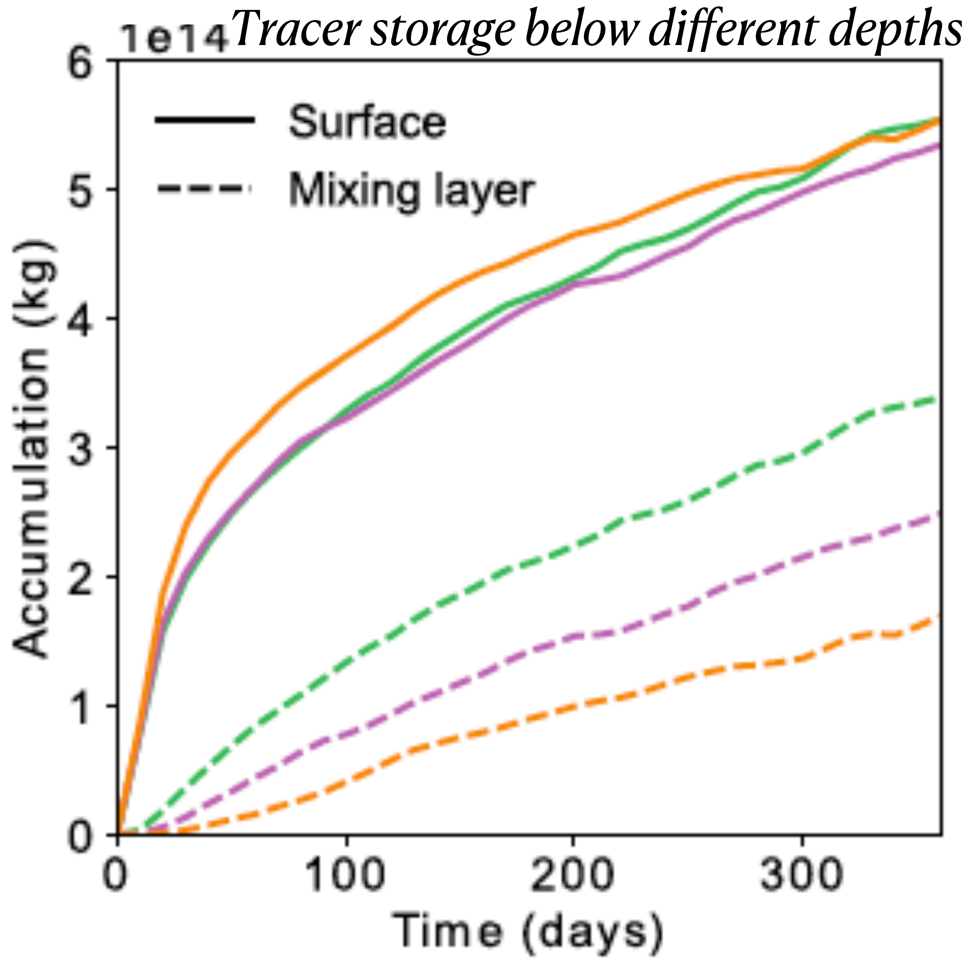

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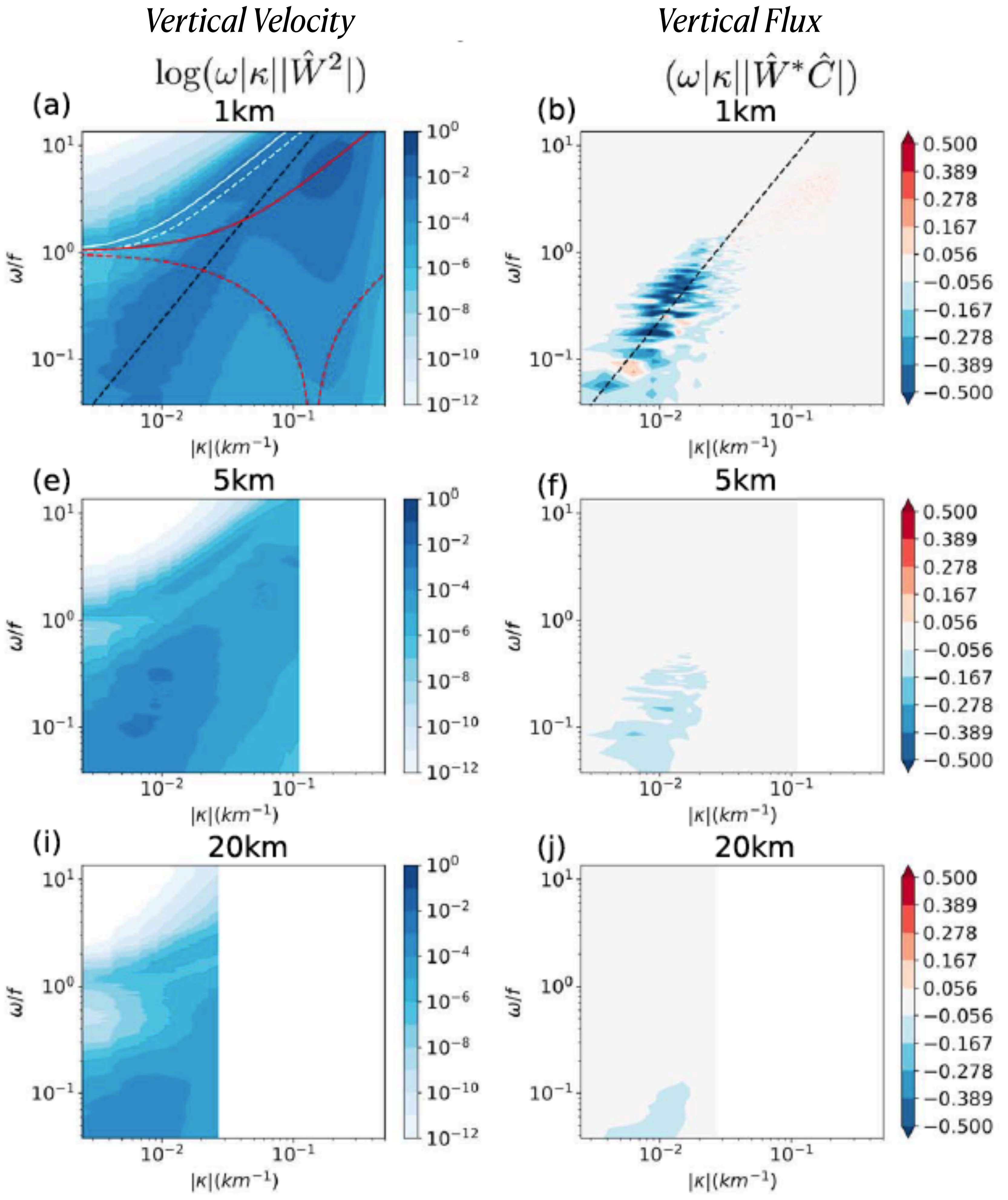

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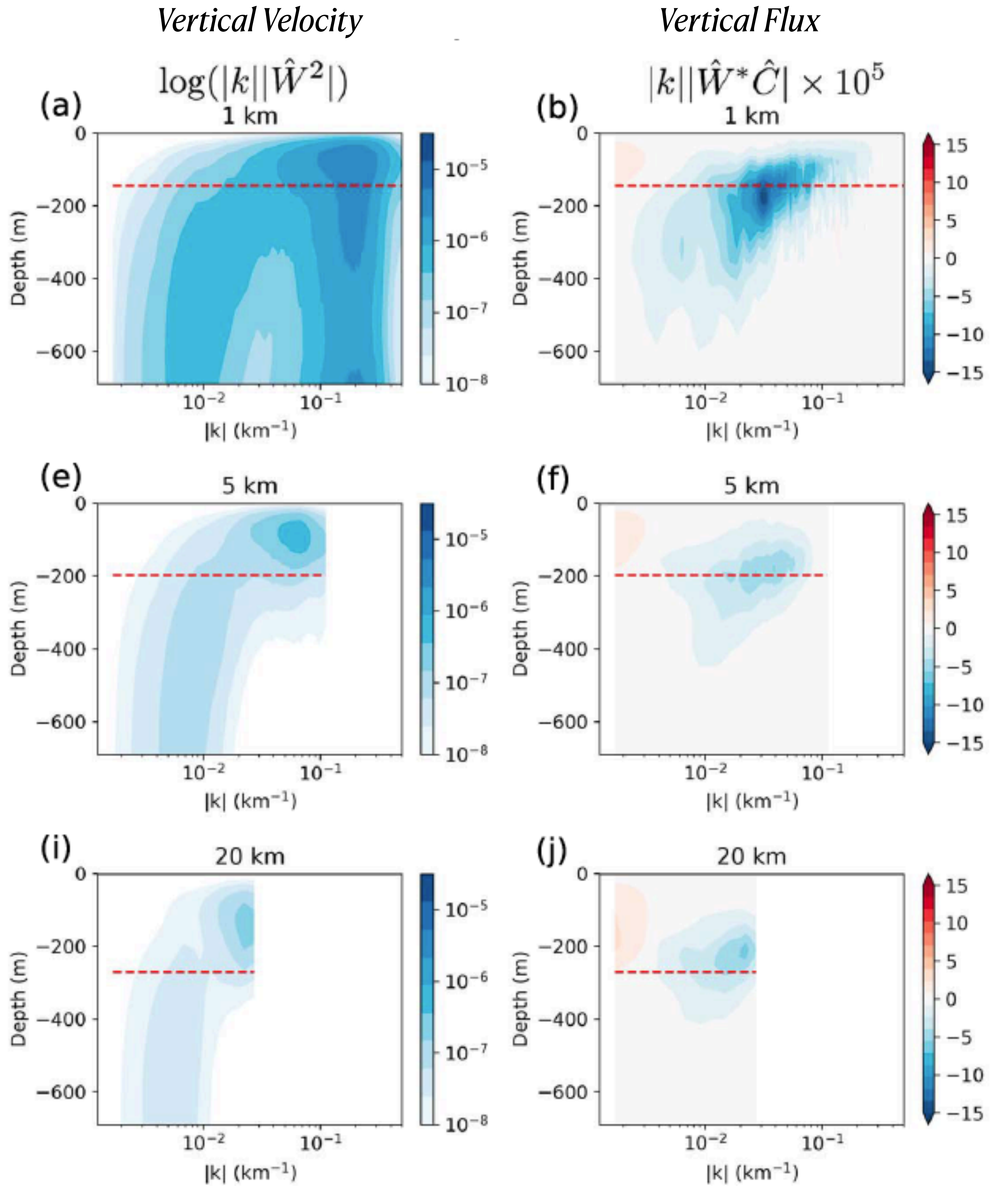
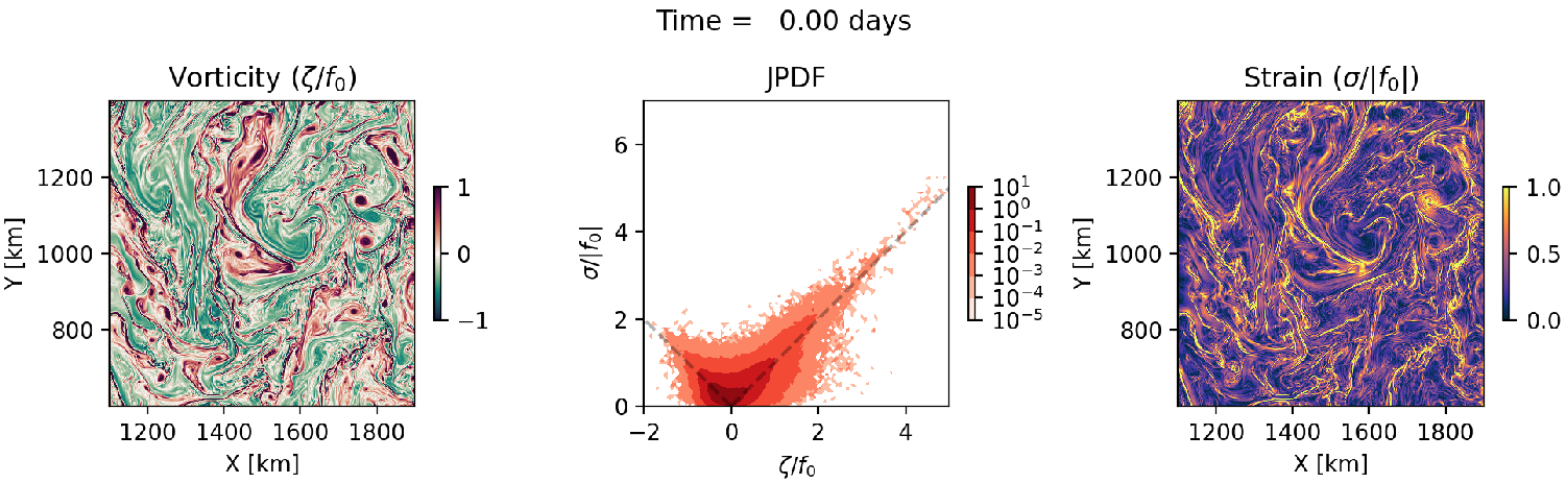
Wavenumber-Depth



- Smaller scales start to play a greater role in vertical fluxes at shallower depths.

Balwada et al 2018

Using surface vorticity and strain to distinguish flow features



Based on Scherbina et al 2013

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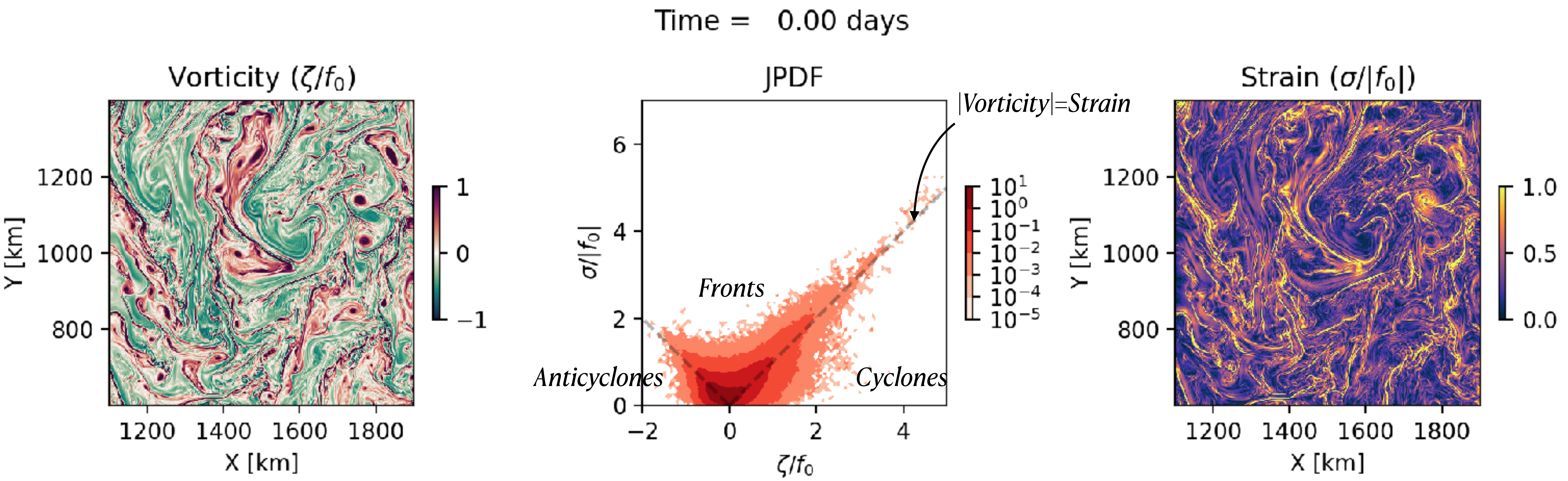

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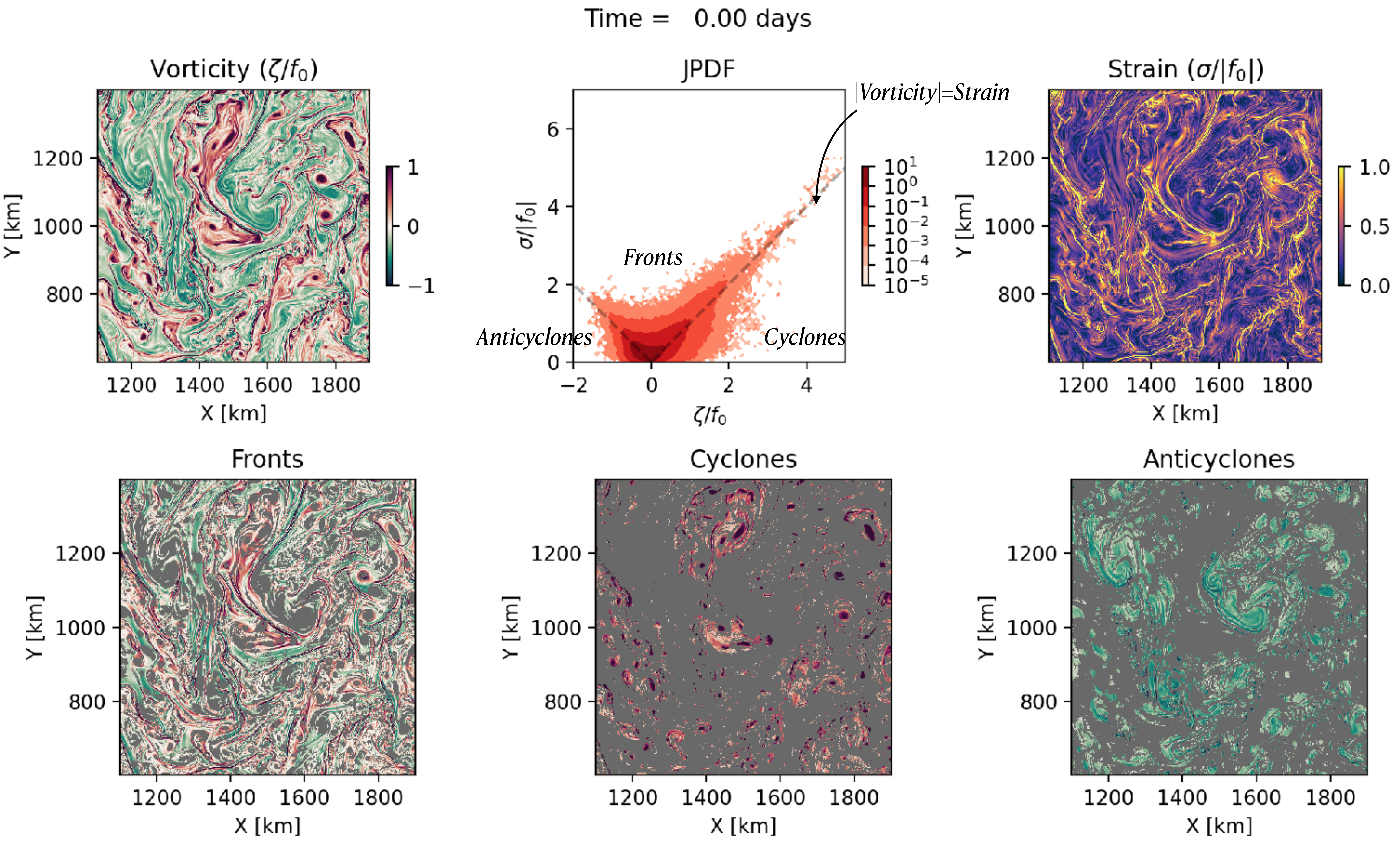

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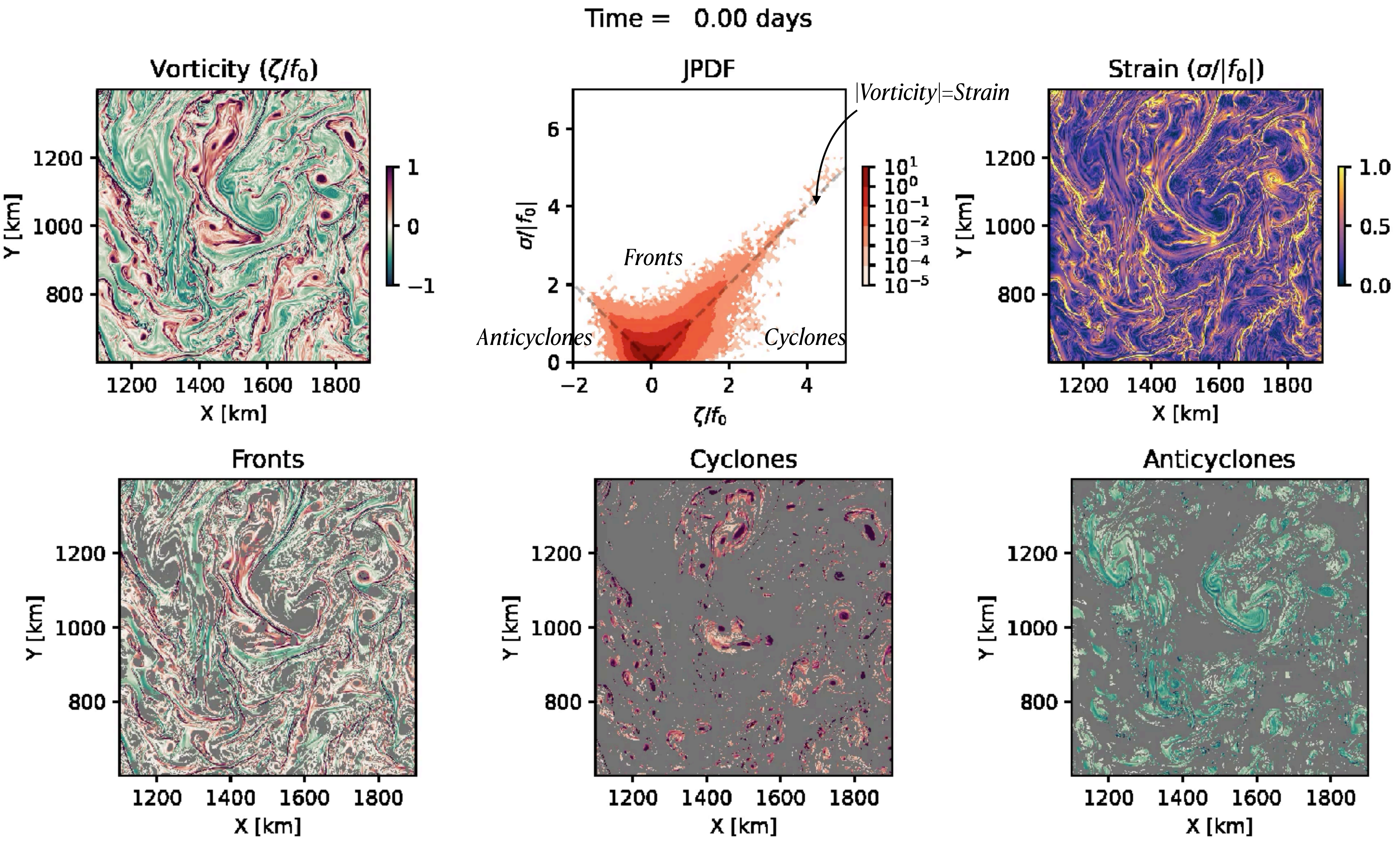

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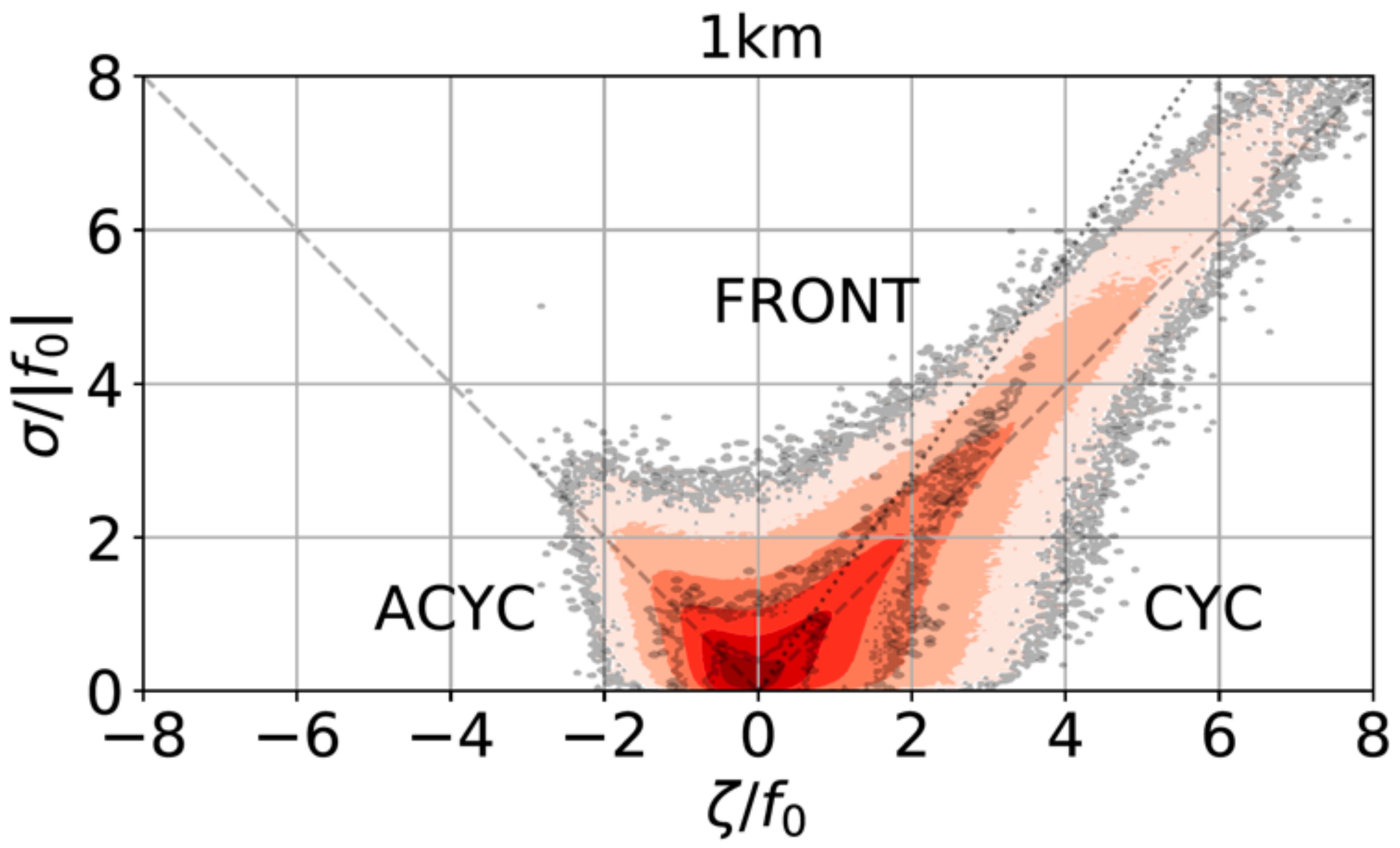
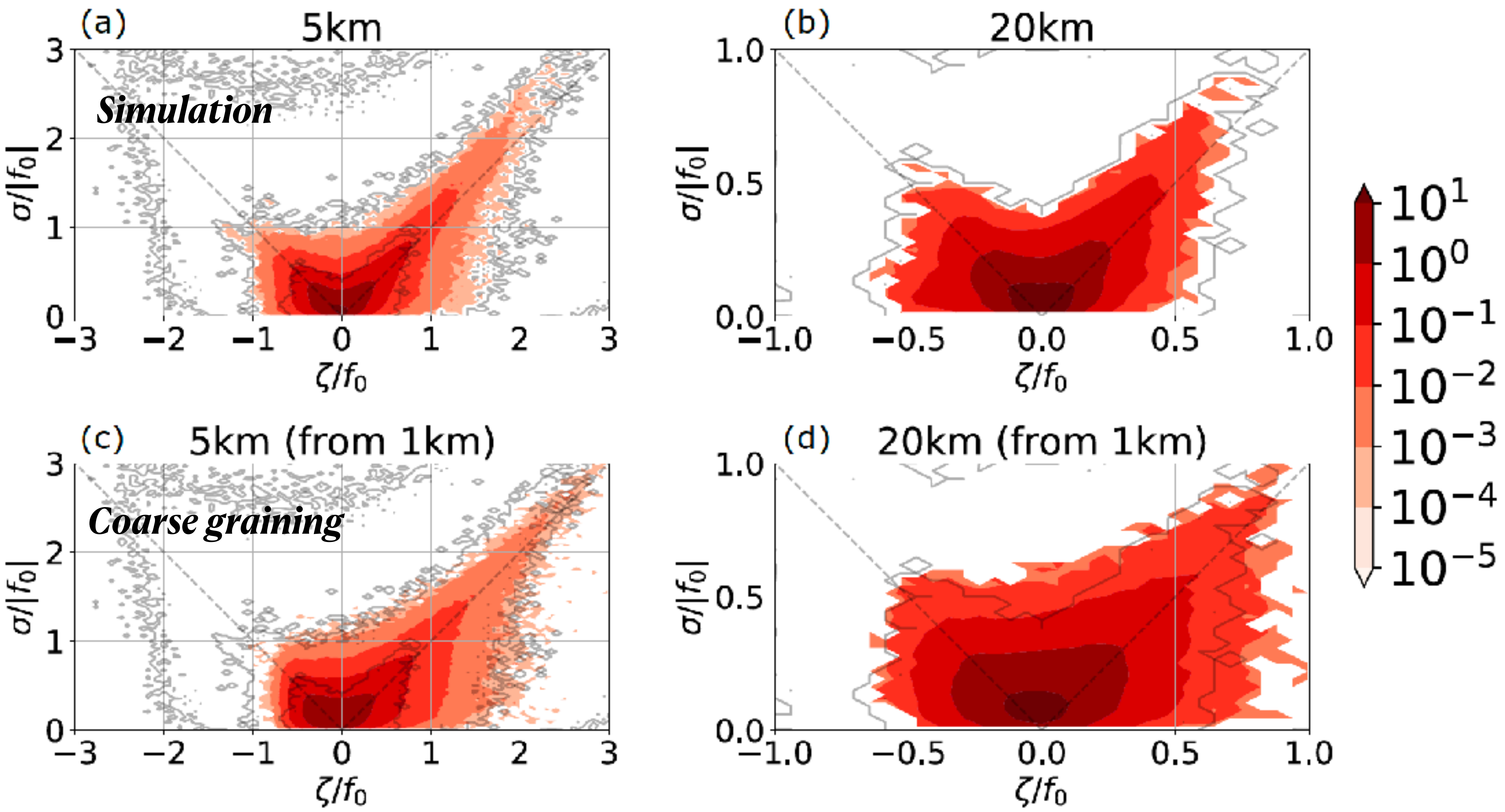
Increasing resolution
Vorticity-Strain JPDF expands
Outer extent of the JPDF is associated with smaller scales





-We will use conditional means to estimate the properties associated with different parts of the vorticity-strain space.

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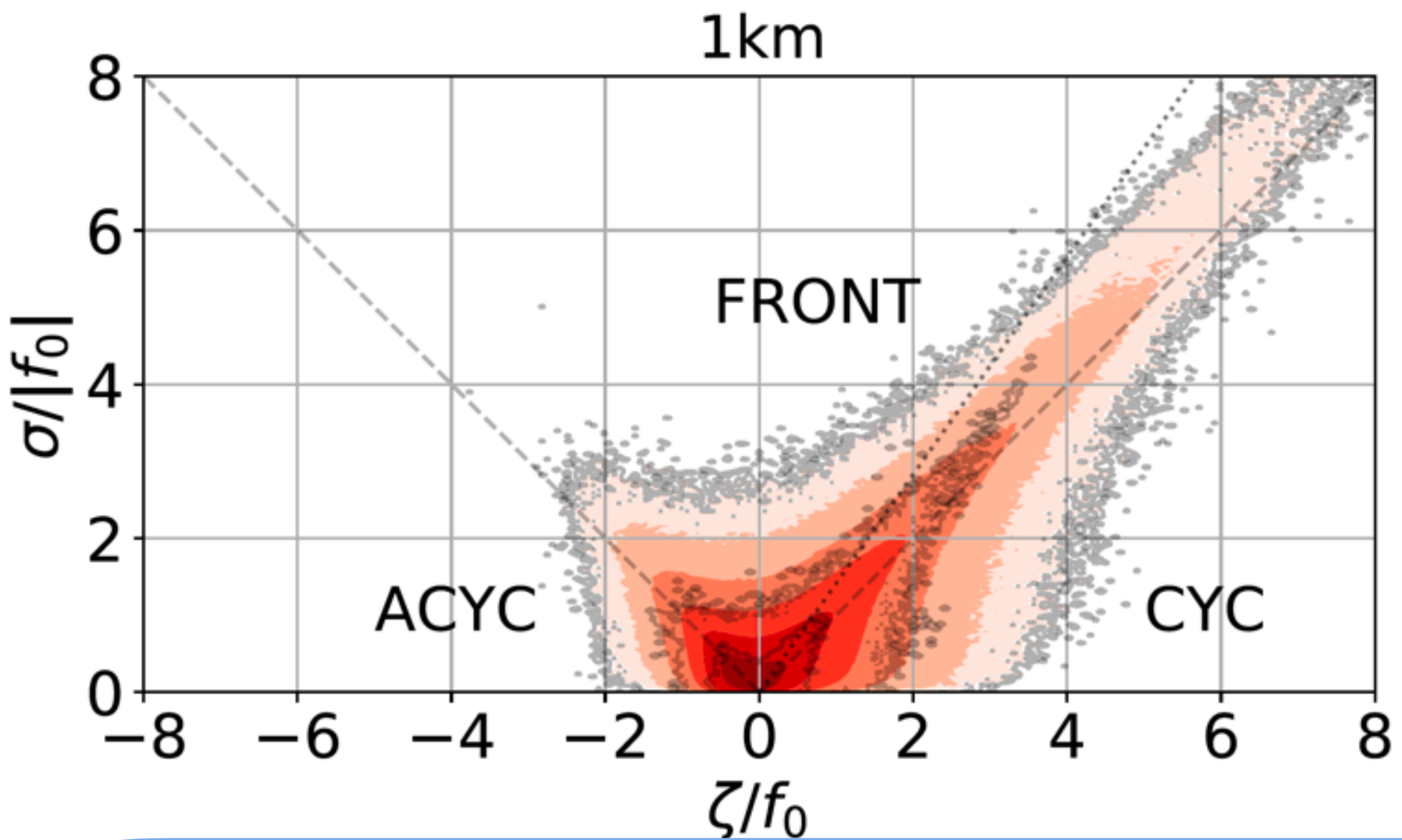
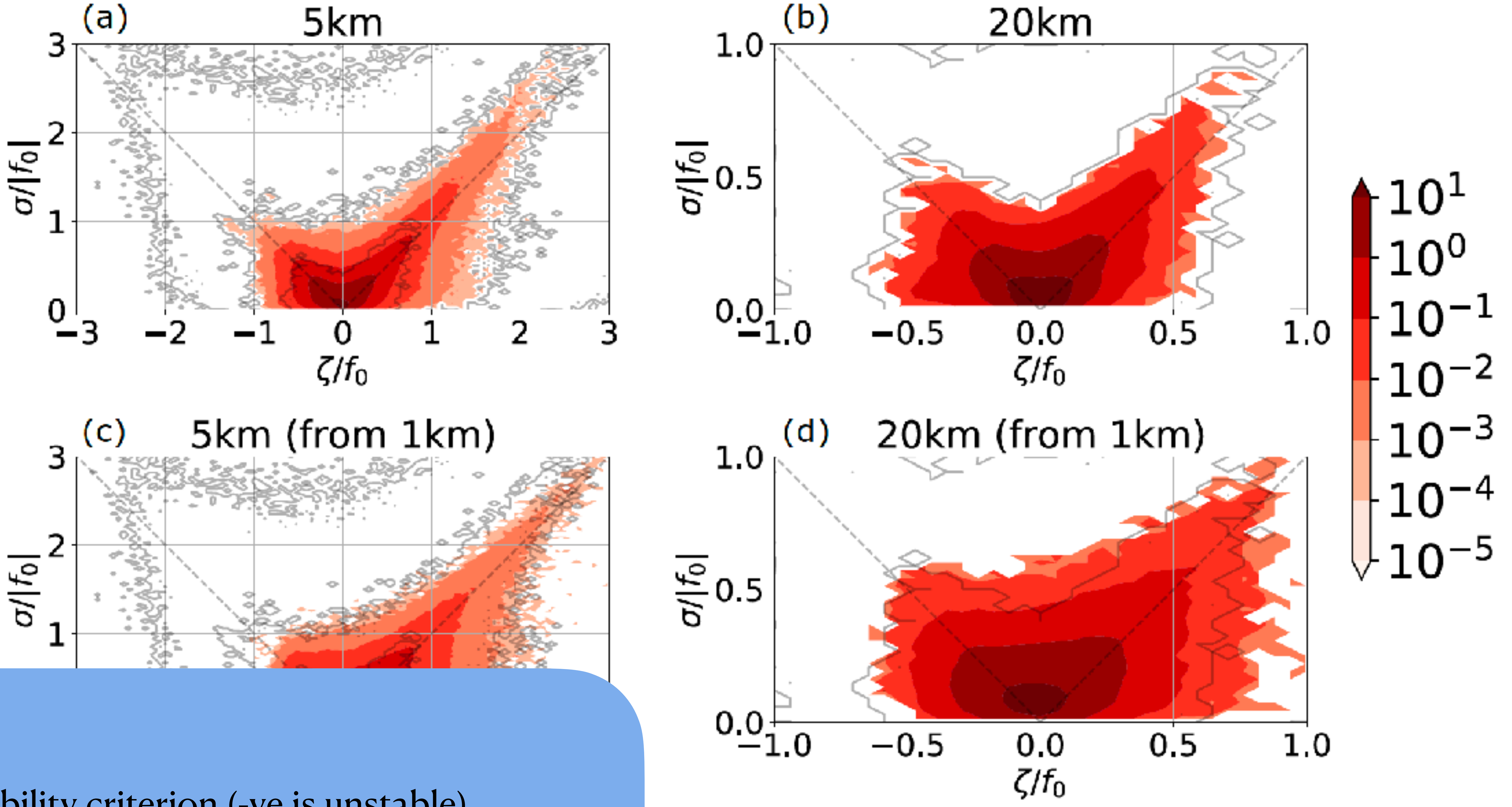
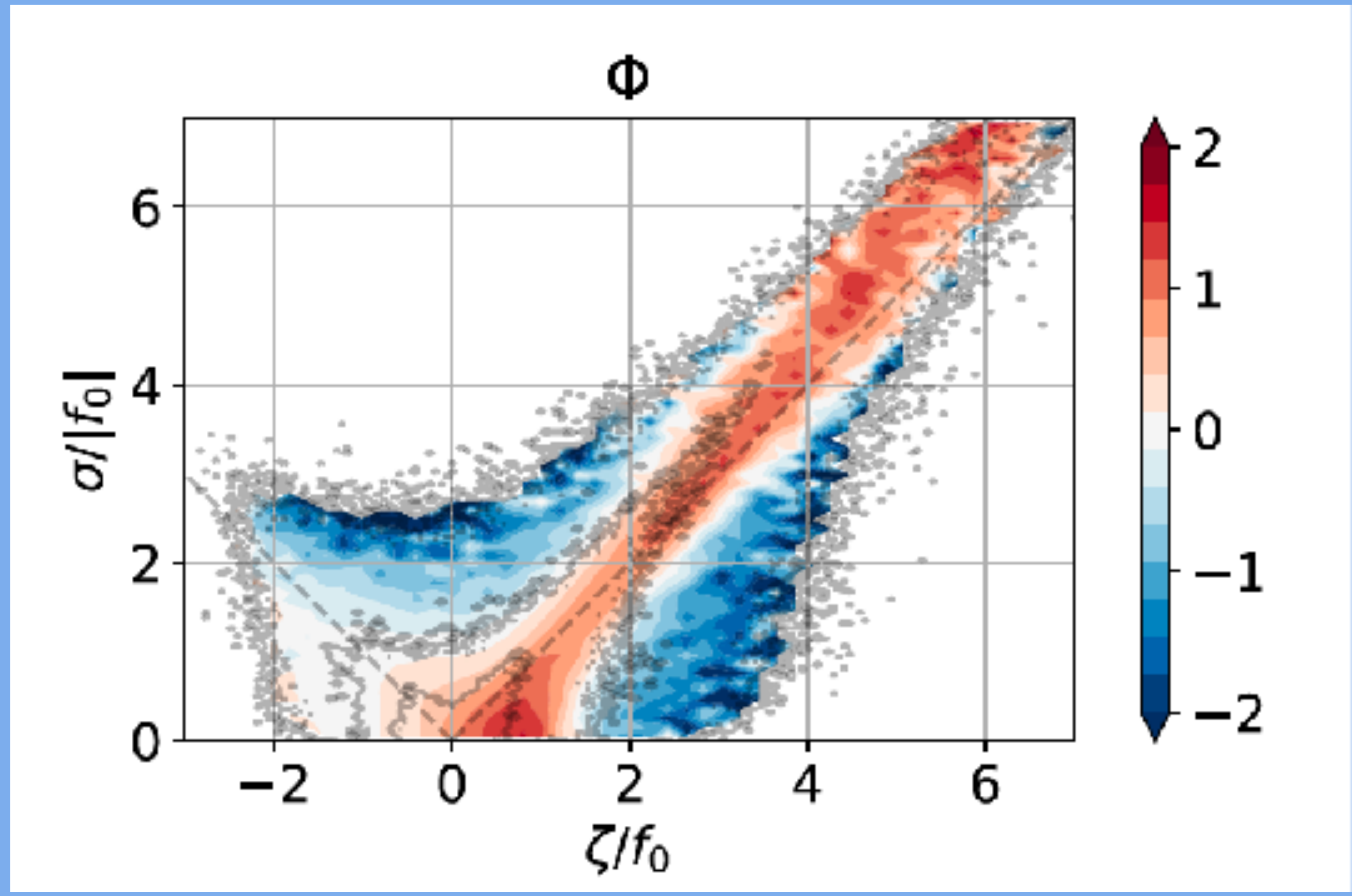


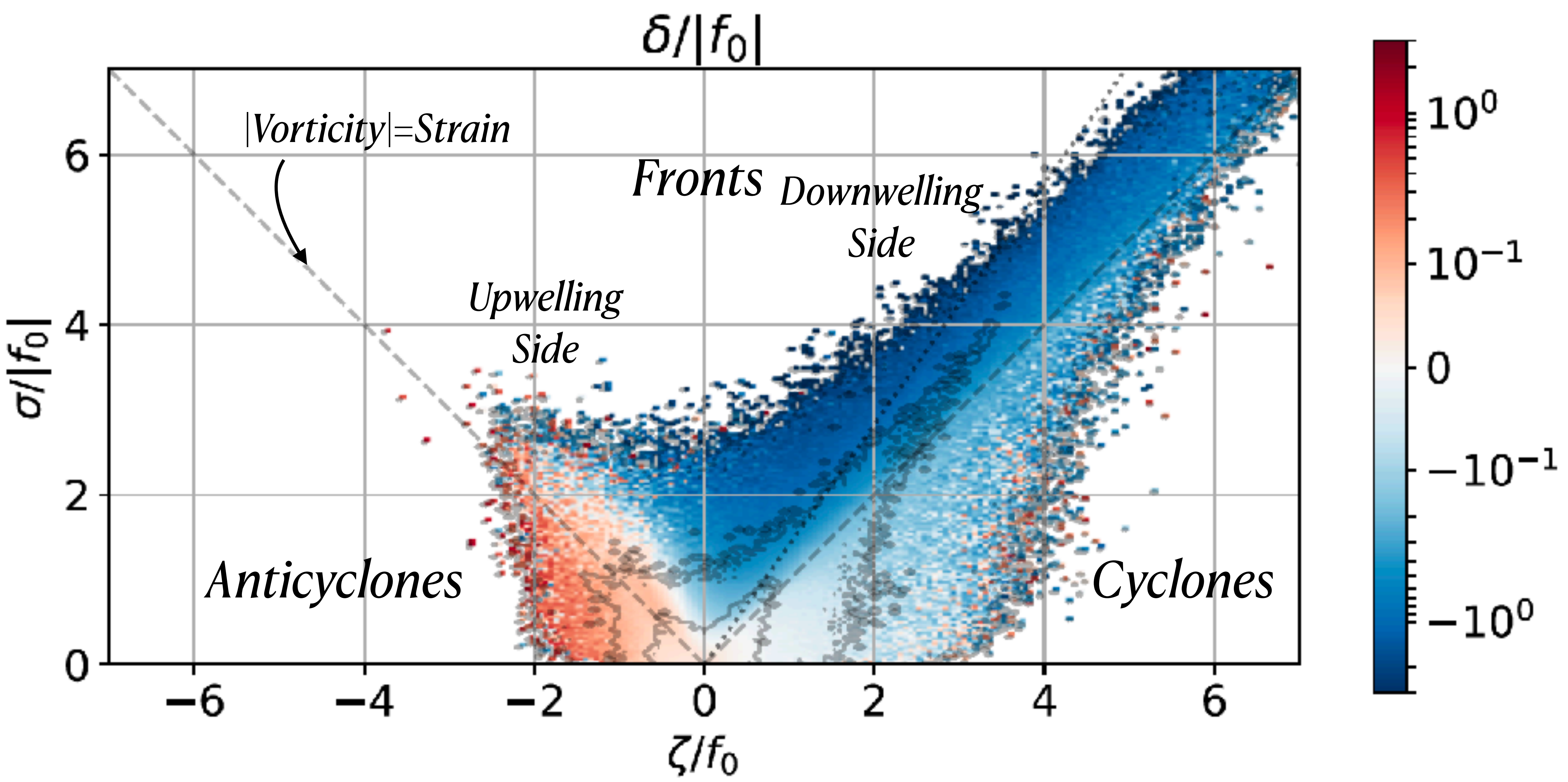




ϕ - Instability criterion (-ve is unstable)

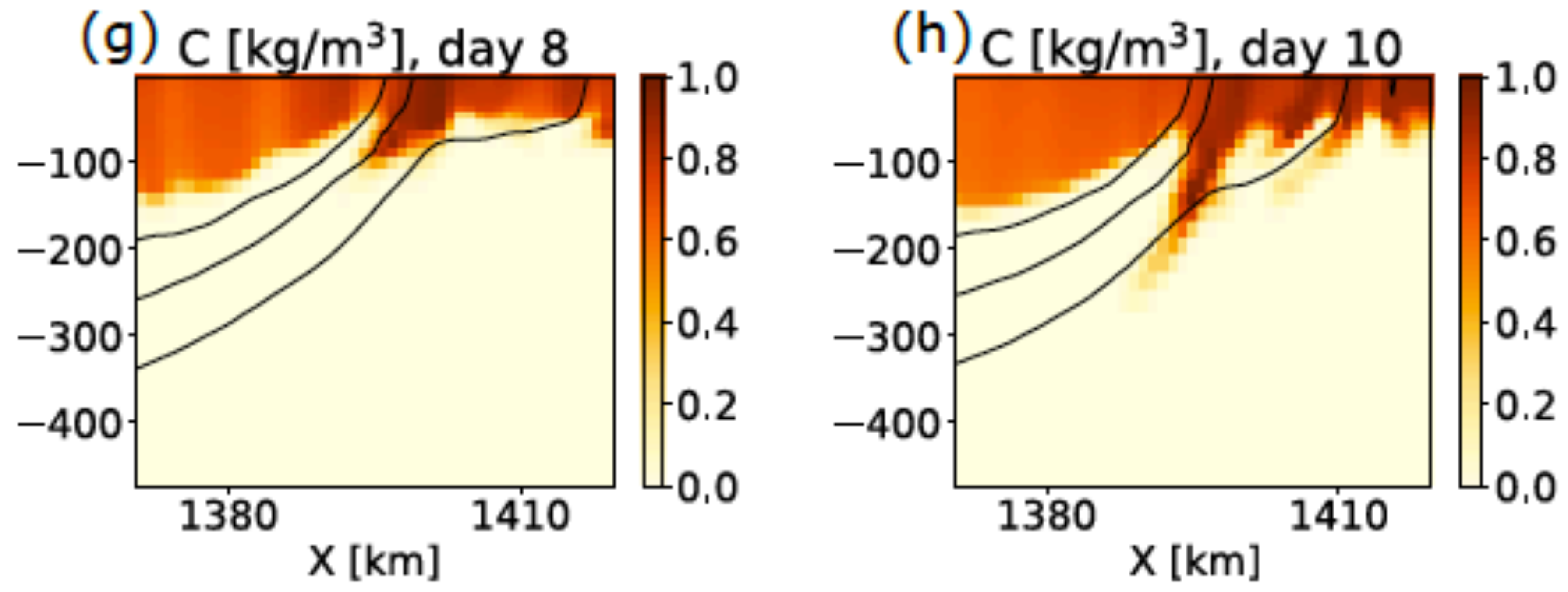
Distinct shape can be explained by larger potential for instabilities on the extremities; negative PV based with the consideration for effects of curvature.
(Buckingham et al 2020)

Impact of different flow features on surface divergence



Mean impact of different flow features on tracer fluxes

$$\partial_t \langle C \rangle^z = -\overline{wC} + \overline{K\partial_z C} + \overline{F}\,\delta(z)$$



Net impact of different flow features on tracer fluxes

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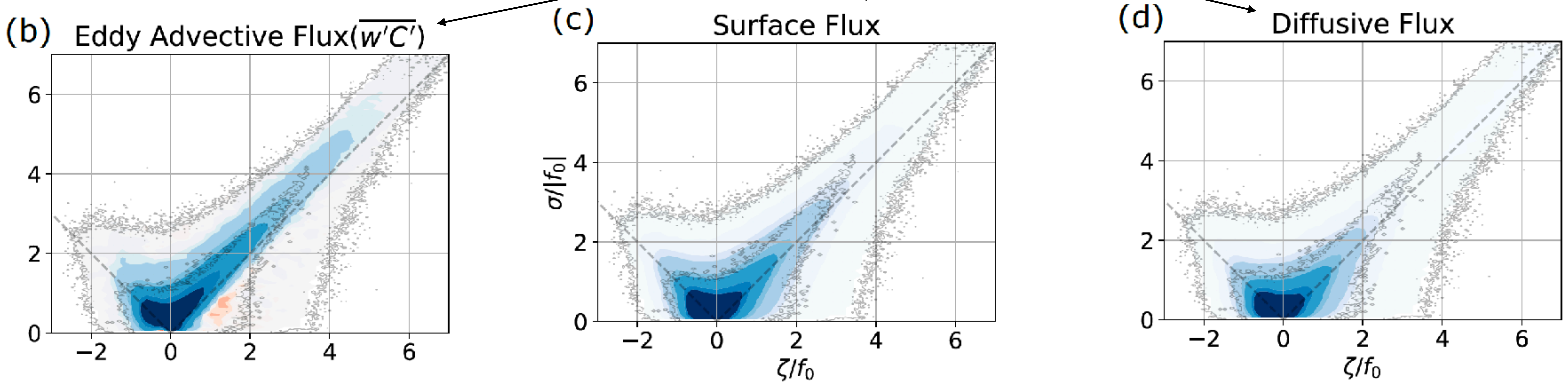

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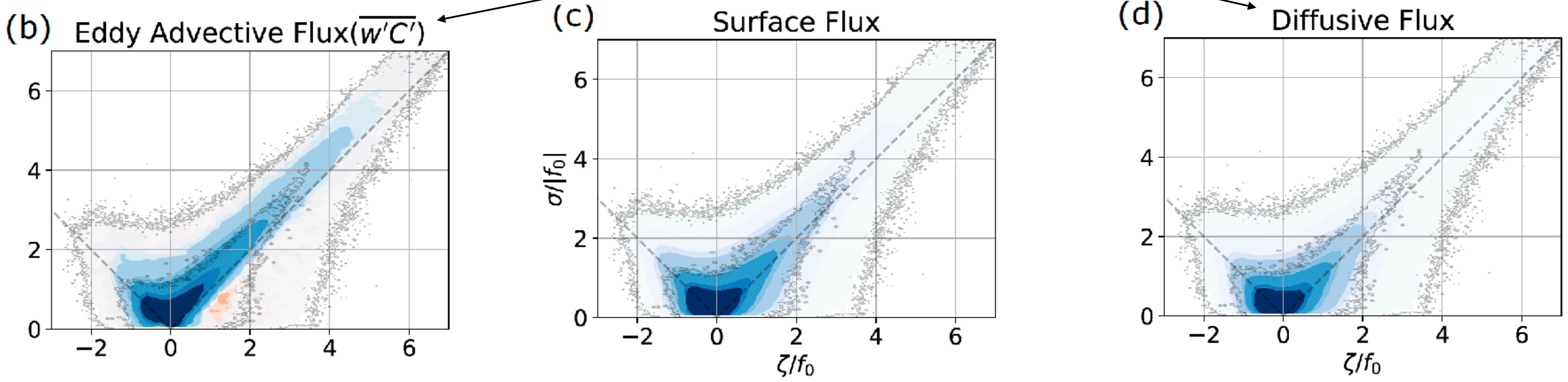
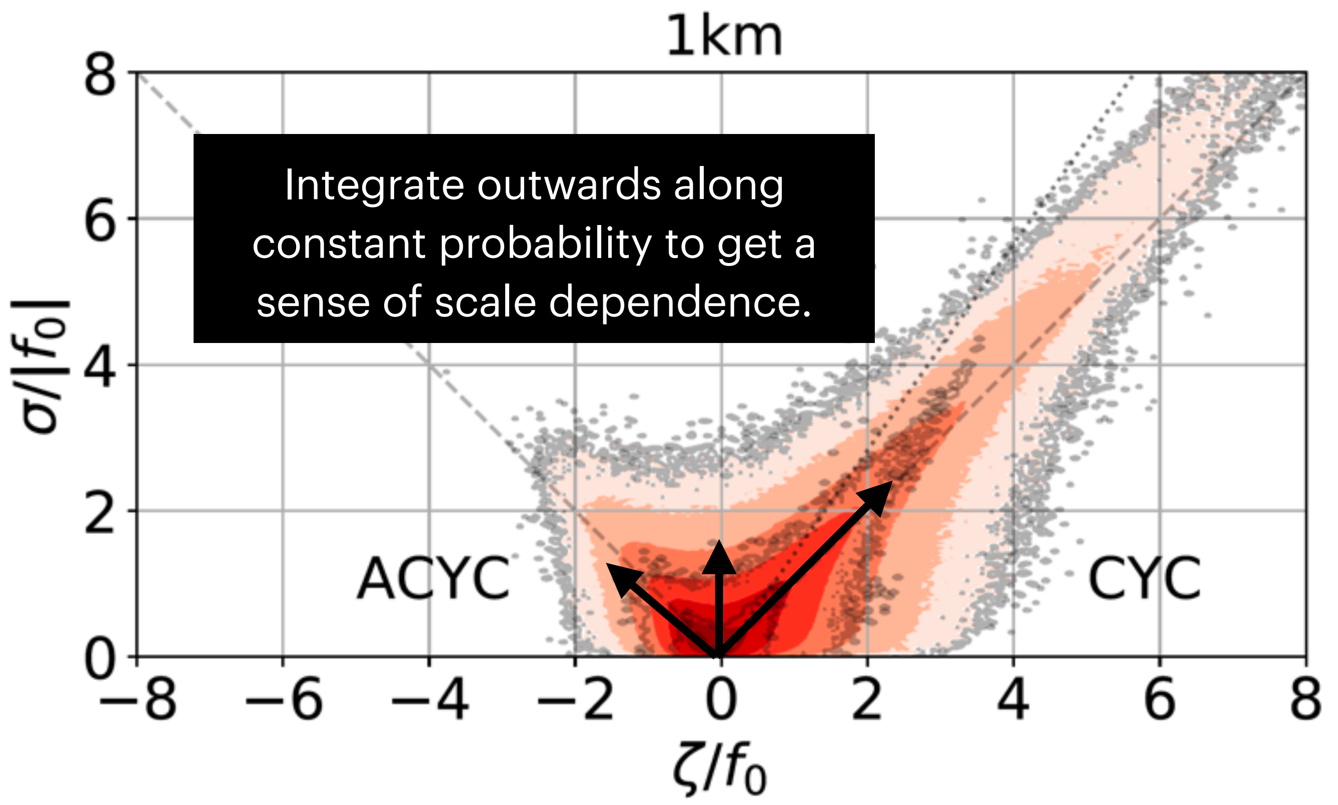
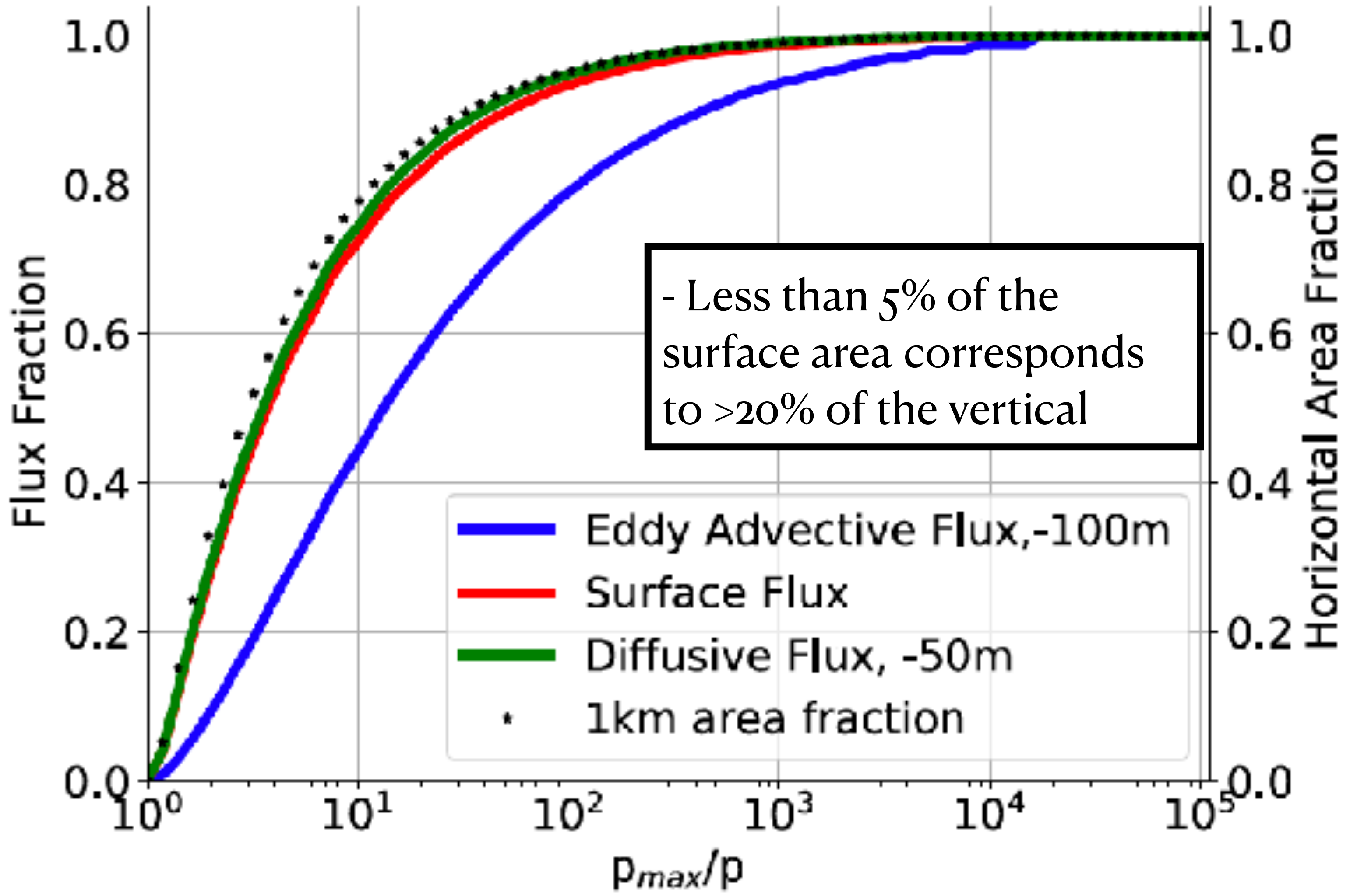






Fronts have an outsized impact on vertical tracer fluxes.

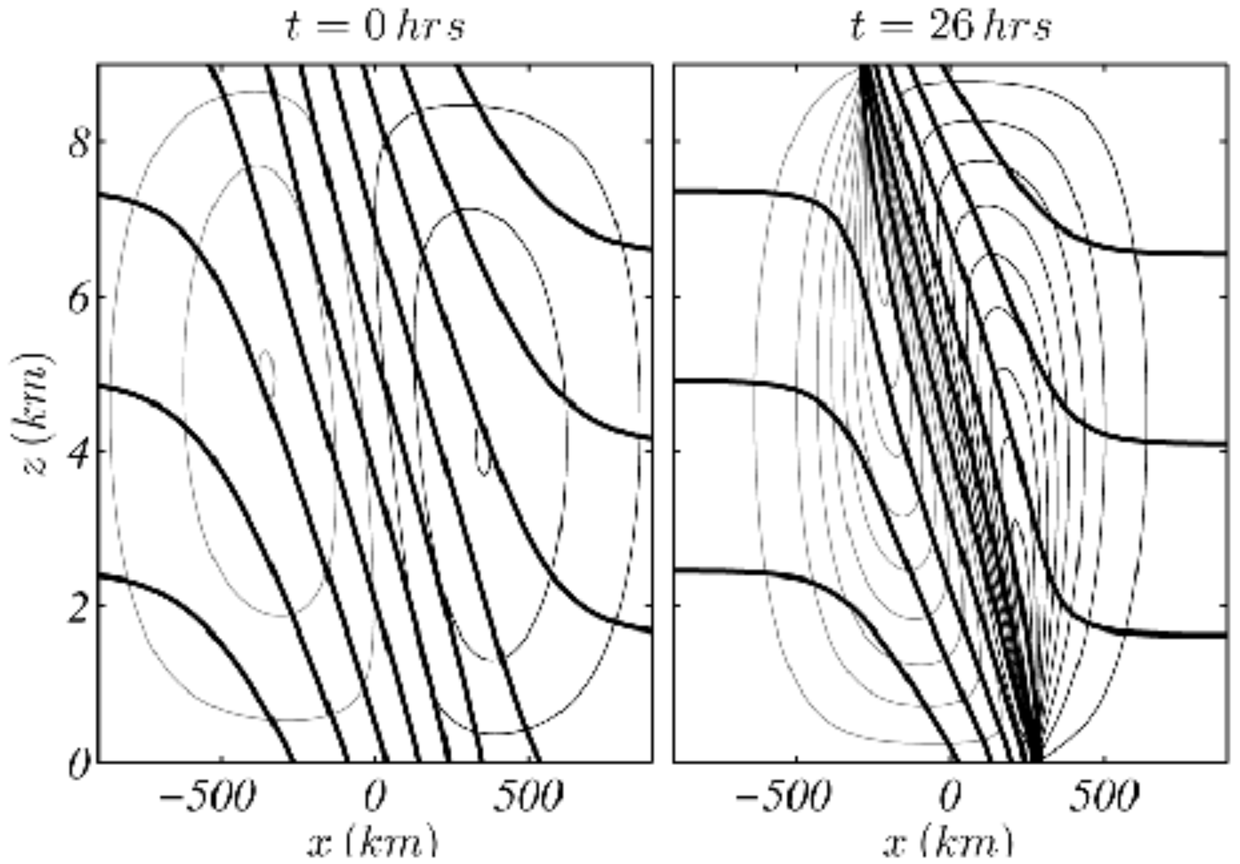
Balwada, Xiao et al 2021 (in review at JPO)

Conclusions

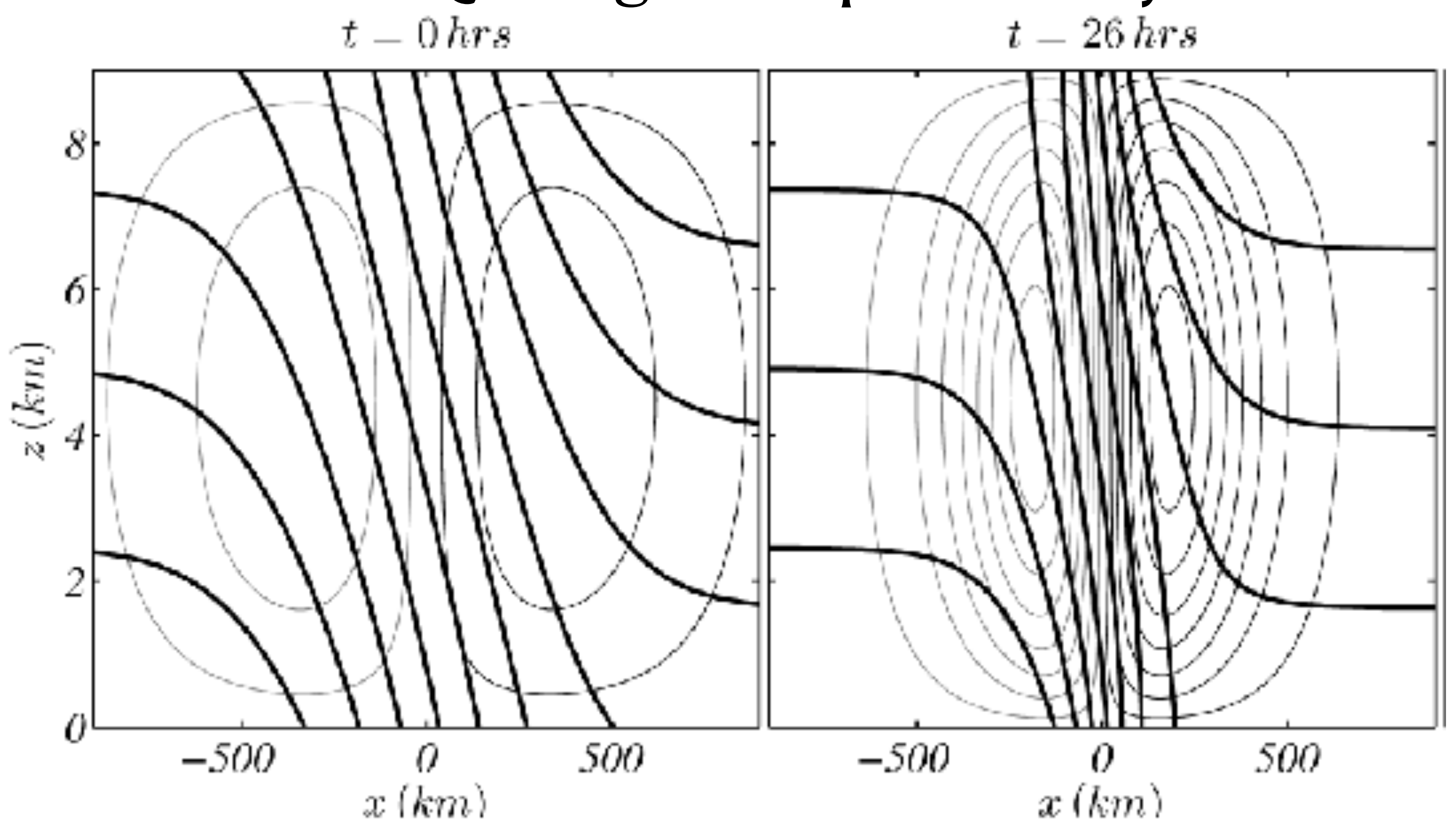
- Increasing model resolution increases tracer ventilation - 50% increase from 20 to 1km.
- Spectral methods reveal that internal waves play dominant role in increased vertical velocities but negligible role in increased tracer fluxes.
- Wide range of scales responsible for vertical fluxes near the surface, and this range shrinks to larger scales with depth.
- Surface vorticity and strain can be used together to decompose the flow into fronts, cyclones and anticyclones.
- Fronts have an outsized impact on tracer ventilation - 20% of the flux through 5% of the surface area (this ratio likely increase even further with resolution).

Vertical asymmetry of submesoscale fronts

Semi-geostrophic theory



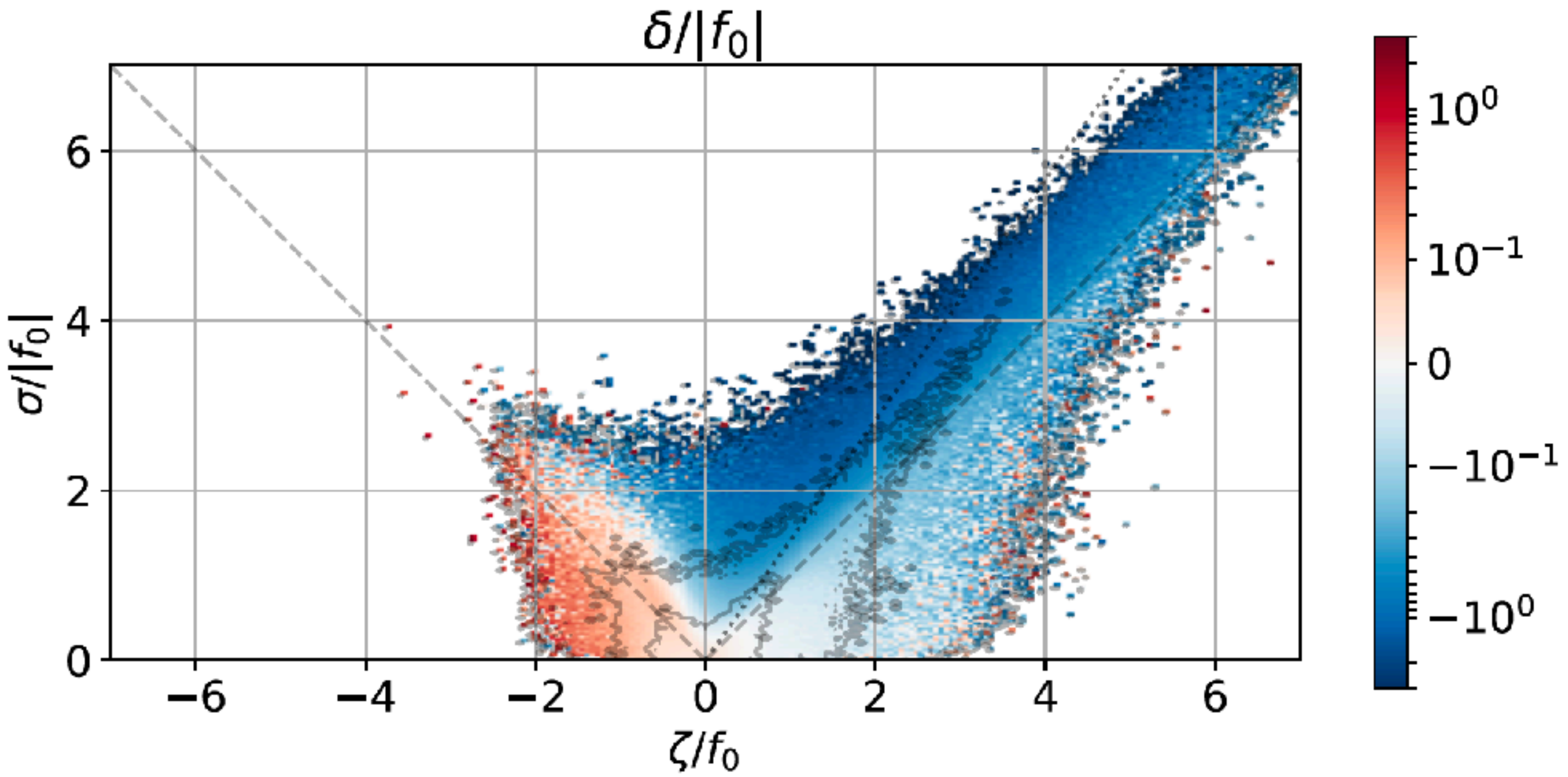
Quasi-geostrophic theory



Asymmetric front, with downwelling sliding under the front core.

Shakespeare 2015

Surface divergence (1km)



Vertical velocities