Tracer subduction and energy cycles in an idealized ACC model, and the potential for measuring energy transfers from space

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Abstract

Fronts, at both mesoscale and submesoscales, are generally hypothesized to play a significant role in mediating the transfer of tracers from the surface boundary layer into the interior. With the advent of computational capabilities numerous high resolution modeling studies have shown the enhancement of of vertical velocities with increasing horizontal resolution. In a carefully designed setup of an idealized channel partially blocked by meridional topography and forced by steady forcing, idealization of the Antarctic Circumpolar Current, we vary the horizontal resolution as the control parameter, and analyze the impact of enhanced vertical velocities on tracer subduction. It is found that the submesoscale-permitting simulations flux far more tracer downward than the lower resolution simulations, the 1km simulation takes up 50\% more tracer compared to the 20km simulation, despite the increased restratifying influence of the resolved submesoscale processes. A spectral decomposition of the flow and fluxes illuminated the relative importance of scales, and the inefficiency of inertia-gravity waves in influencing tracer transport. To further understand the physical dynamics in these simulations we diagnosed how energy was being transferred between the mean and eddy kinetic and potential energy reservoirs (Lorenz energy cycles), and if changing the resolution influenced this exchange. In particular we focussed on separating the dynamics of the energy cycles that are active in the interior of the water column and those that are trapped near the surface. We also analyzed the inter-lengthscale exchange of energy to understand the detailed spectral dynamics of the turbulence that is resolved. Lastly, and probably most relevant to SWOT, we looked at the energy budgets in terms of velocity and pressure structure functions, to assess the potential for the future SWOT mission to directly measure the inter-scale energy transfers at the ocean surface.

Role of (Sub)-Mesoscale Generated Vertical Velocities in Tracer Subduction

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Introduction

Ocean eddies at all scales play an important role in uptake of tracers into the ocean. The conceptual framework of understanding tracer uptake into the ocean is as follows :

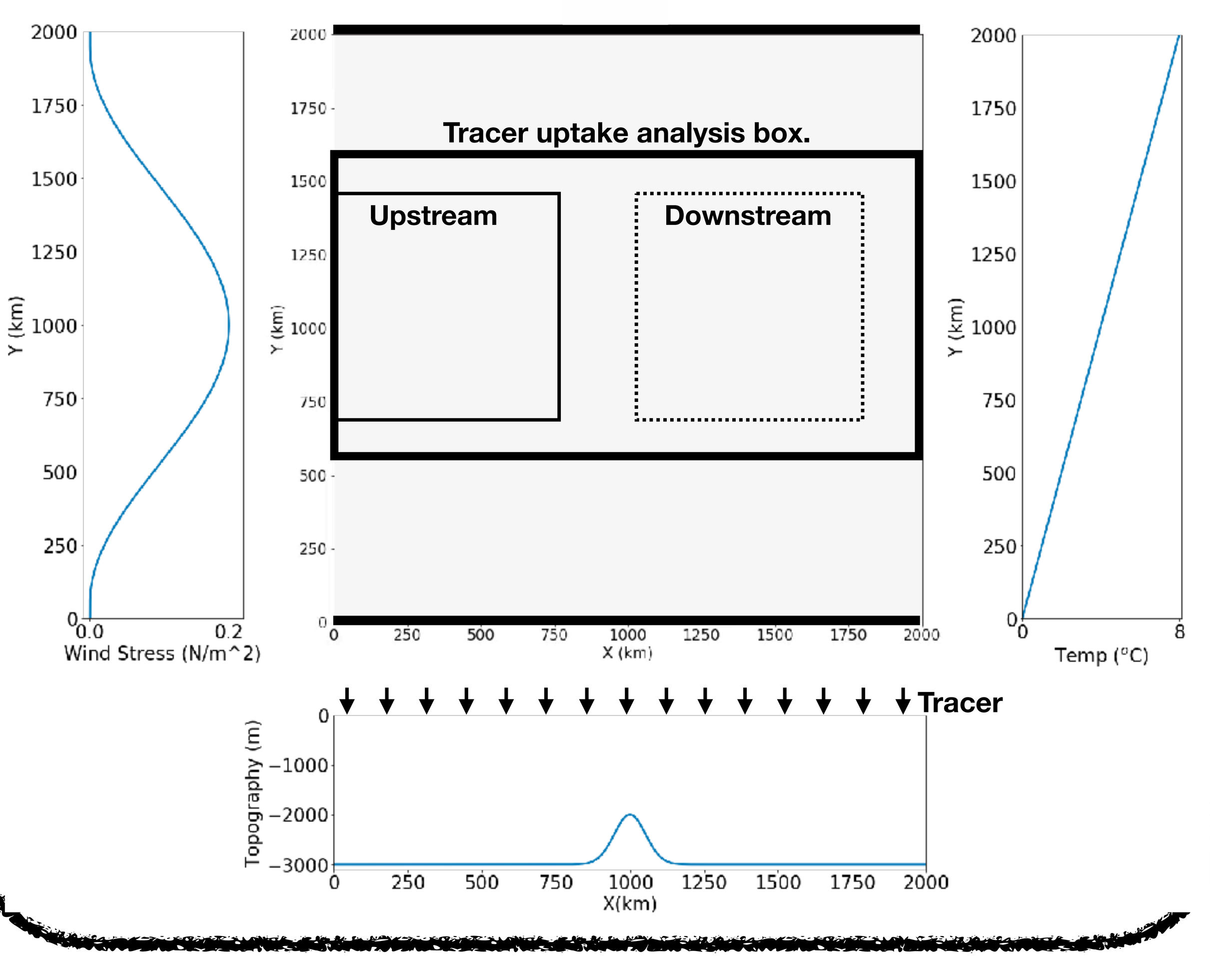
a) Tracer is diffused from the atmosphere into the ocean at the surface by an air-sea concentration gradient.
b) This tracer is rapidly mixed from the near surface throughout the mixed layer.
c) The water from the mixed layer is “somehow” moved across the base of the mixed layer into the interior of the ocean.
d) Once in the interior of the ocean the tracers are stirred along isopycnals.

While we have a good understanding of step-(a) (Henry’s law), step-(b) (rapid vertical convection and 3D turbulence), and step-(d) (stirring along isopycnals), it remains unclear what are the rate controlling processes for step-(c). We refer to step-(c) as tracer subduction. It has been argued that the vertical velocities generated by the submesoscale and mesoscale eddies can help transport tracer across the base of the mixed layer, based on evidence from process based model studies. In this study we test if this hypothesis holds, and quantify the relative contribution of different scales to the subduction process.

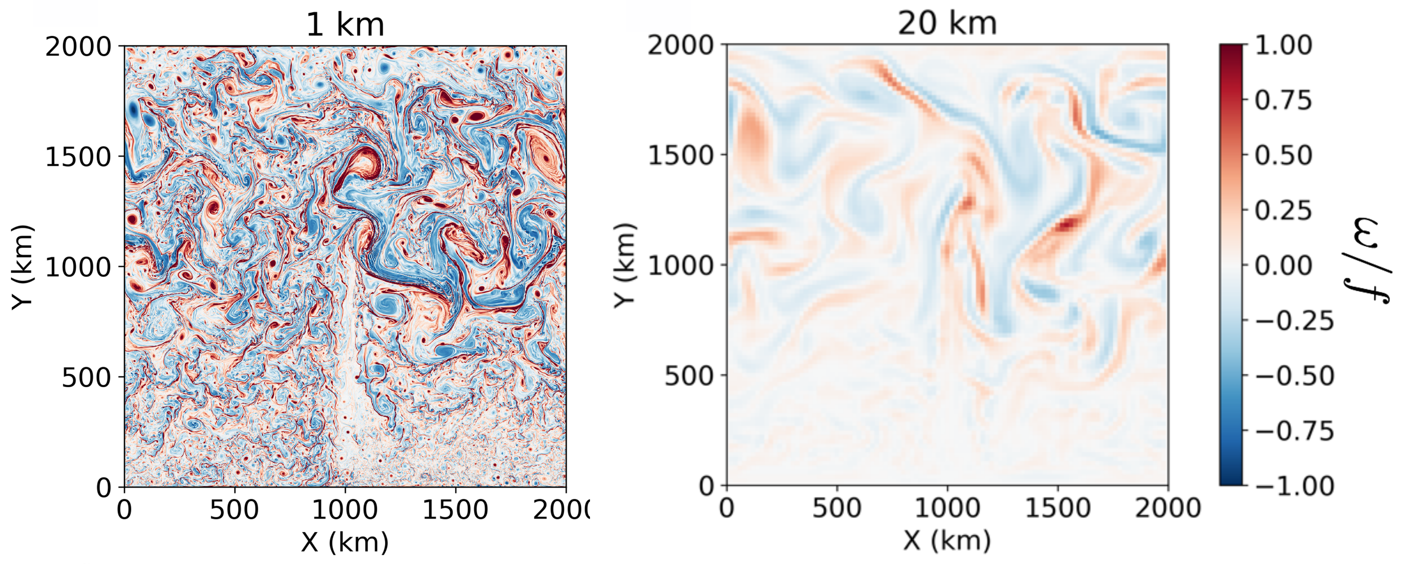
Model Setup

We run a MITgcm channel simulations forced by wind stress and buoyancy restoration at different resolutions (20km, 5km, and 1km). These simulation is run to a steady state and the turbulence is in a forced-dissipated equilibrium.

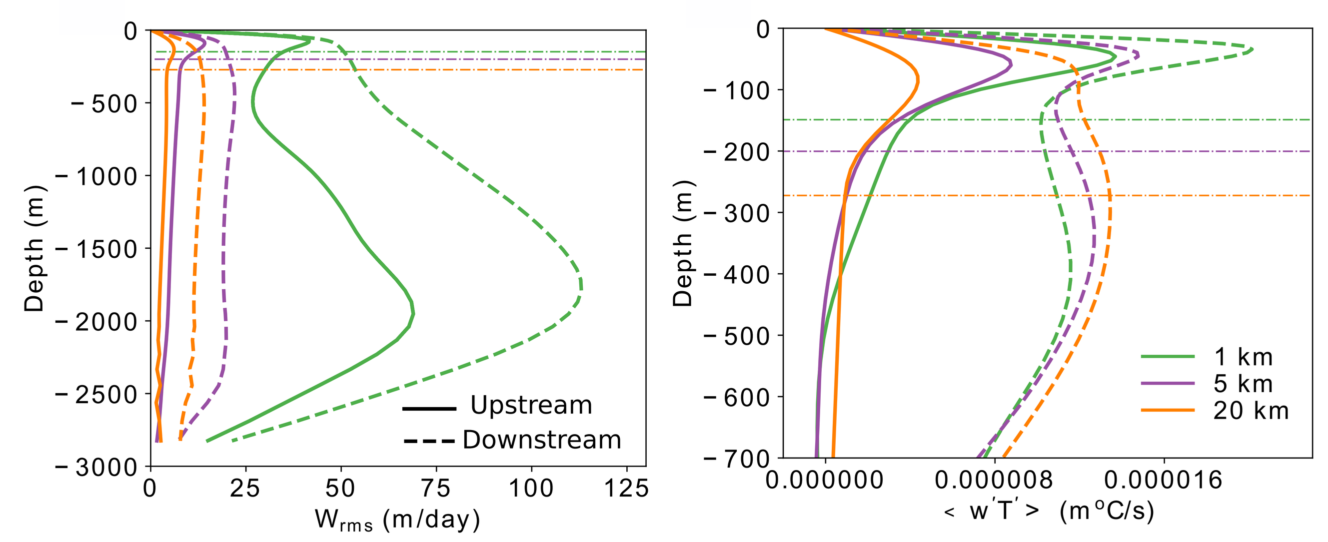
We force a tracer at the surface by restoring the tracer to a fixed value with a piston velocity comparable to that of carbon dioxide in the ocean. The forcing is started after the simulations have equilibrated, and is physically similar to an infinite tracer source at the surface.



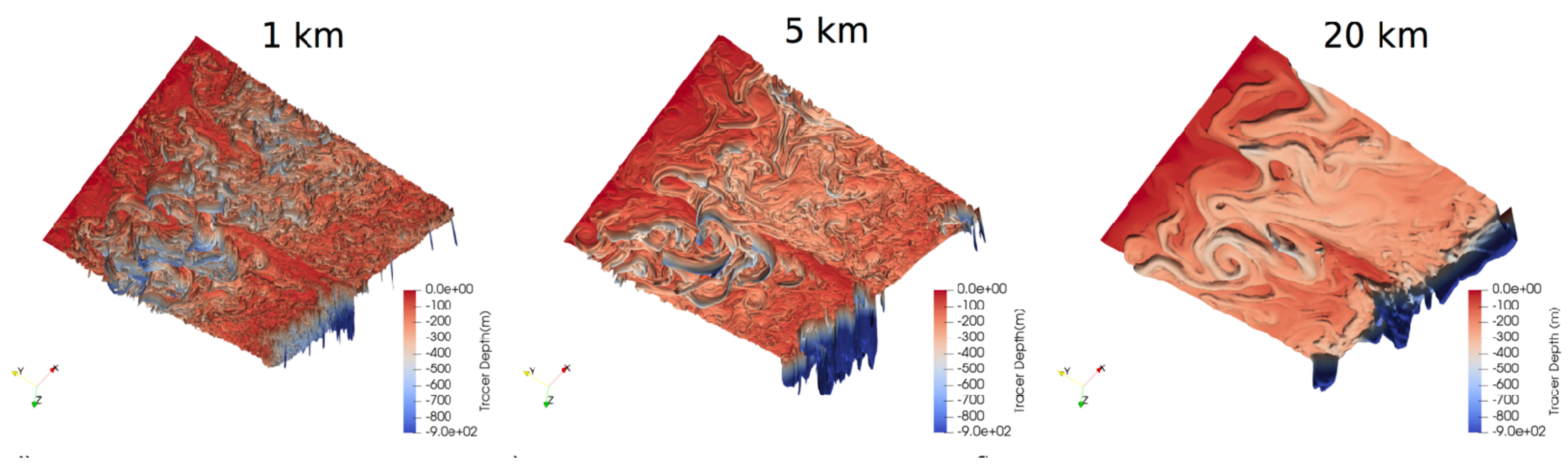
Results



Surface vorticity fields show an active emergent submesoscale field as the resolution in increased.

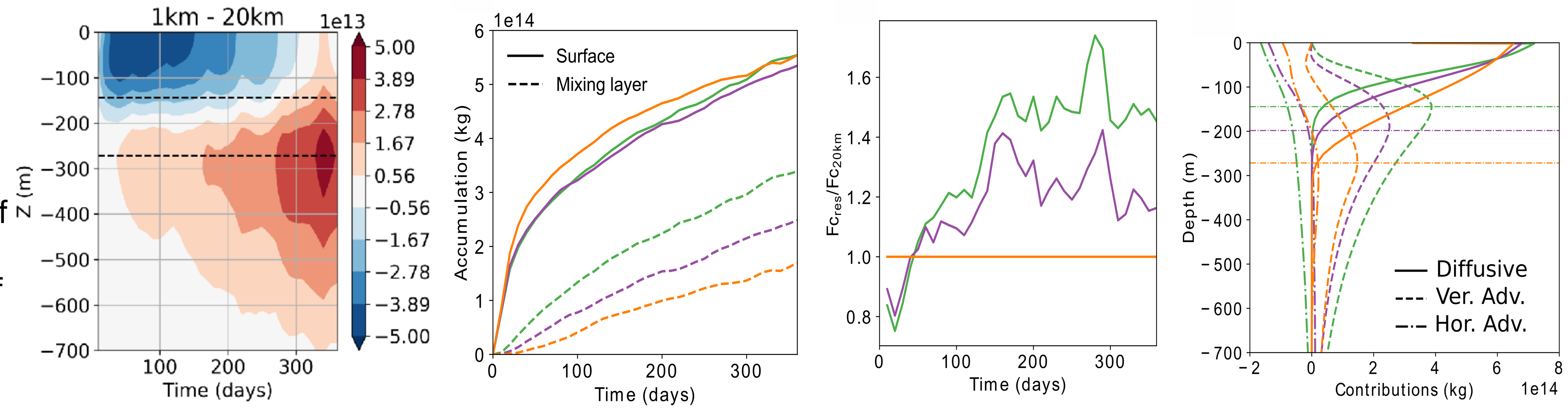


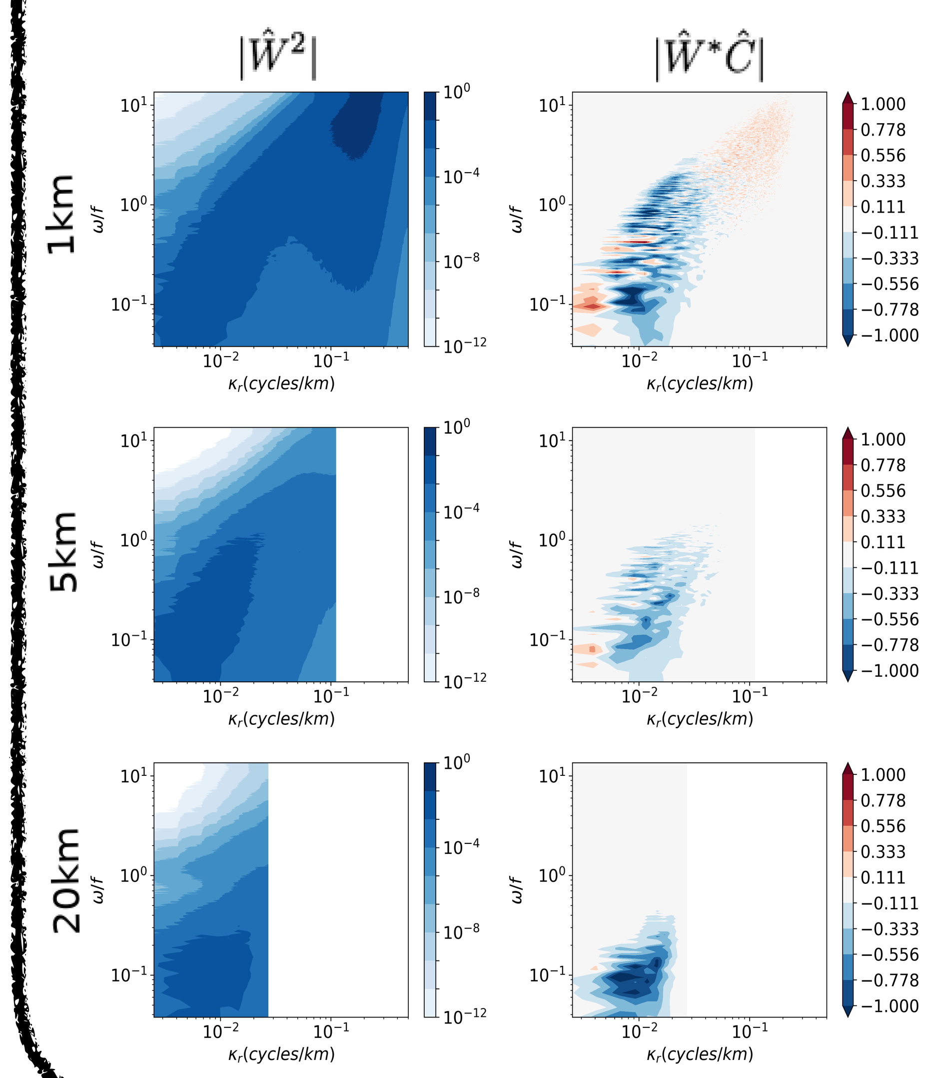
The vertical velocity and restratification in the mixed layer are significantly enhanced at higher resolutions. Thin horizontal dashed lines are representative of the mixing layer depths.



Tracer isosurface (C=0.1) 30 days after the start of the tracer experiment, as seen from the northwest corner at the bottom of the domain, looking towards the southeast surface. Higher resolution simulations show the presence of strong deep reaching fronts.

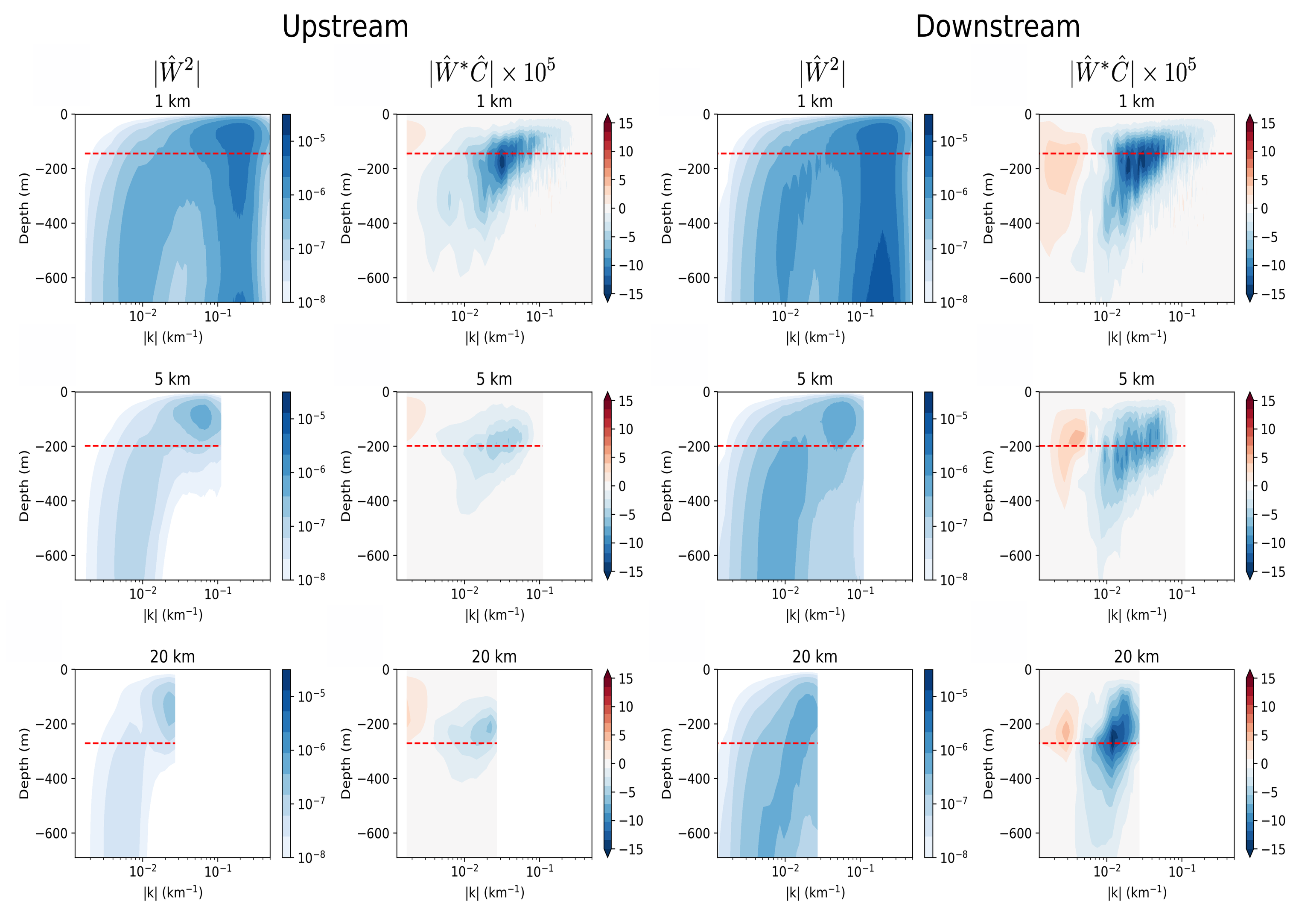
a) Relative difference in tracer accumulation between the 1km and 20km simulation. b) Accumulation below the surface and below the mixed layer as a function of time. c) Tracer flux through the surface as a function of time relative to the 20km simulation. d) Contribution from different components to the total accumulation at the end of 1 year.





(Left) Wavenumber frequency power spectrum of vertical velocity and cross-spectrum of vertical tracer flux at a depth of 400m for different resolutions in the downstream region.

(Right) Wavenumber power spectrum of vertical velocity and cross-spectrum of vertical tracer flux as a function of depth for different resolutions in the upstream and downstream regions.



Summary

- Higher model resolution produces more overall uptake of tracer, despite the shallower mixed layer.
- Vertical eddy fluxes and diffusive fluxes compensate in interesting ways as the resolution changes.
- The dominant scales of the vertical flux are not the same as the scales of the most energetic vertical motions (internal waves).