The FOCUS model, an unstructured COMPAS implementation to match the high wavenumber dynamics revealed by SWOT in the ACC

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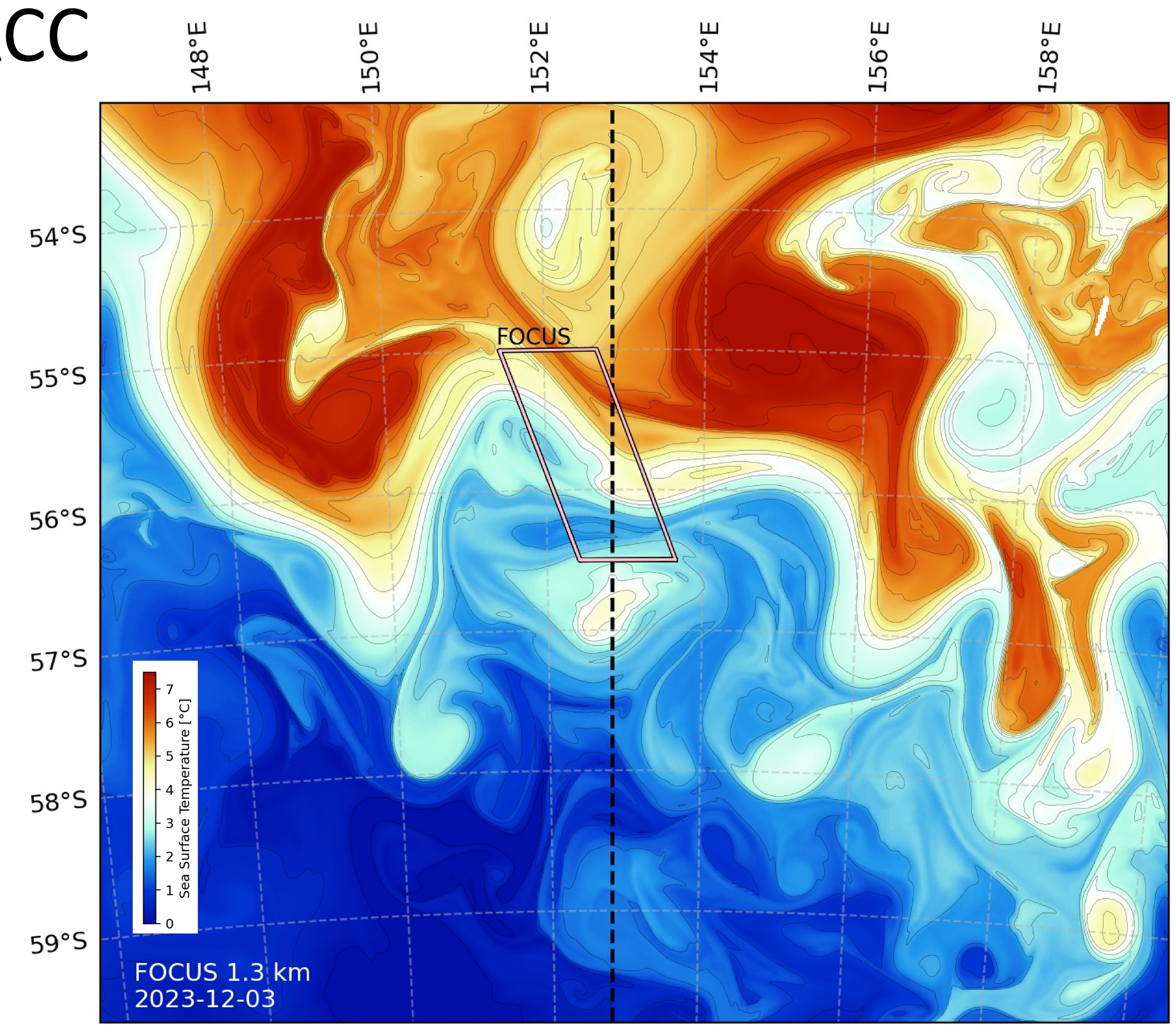
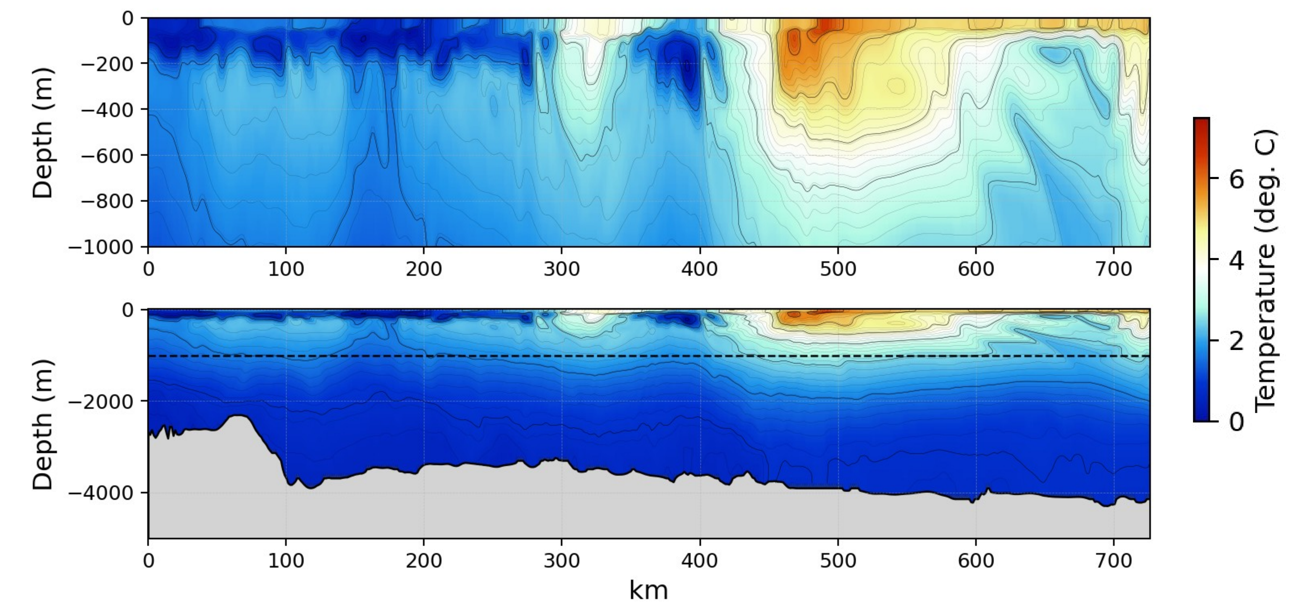
The recently launched **SWOT** (Surface Water and Ocean Topography) satellite provides a new and detailed view of ocean dynamics globally and at scales down to 10 km wavelength [1]. Linking these surface observations to interior processes has the potential to advance our understanding of the Southern Ocean's role in the global climate system. Addressing this includes modelling approaches with kilometre-scale models capable of capturing realistic ocean dynamics across the full wavenumber spectrum revealed by SWOT.

This study presents the **FOCUS model**, a high-resolution implementation of **COMPAS** in the Antarctic Circumpolar Current (ACC) meander south of Tasmania. We assess the model sensibility to **horizontal viscosity**, **vertical discretization** and **horizontal resolution**.

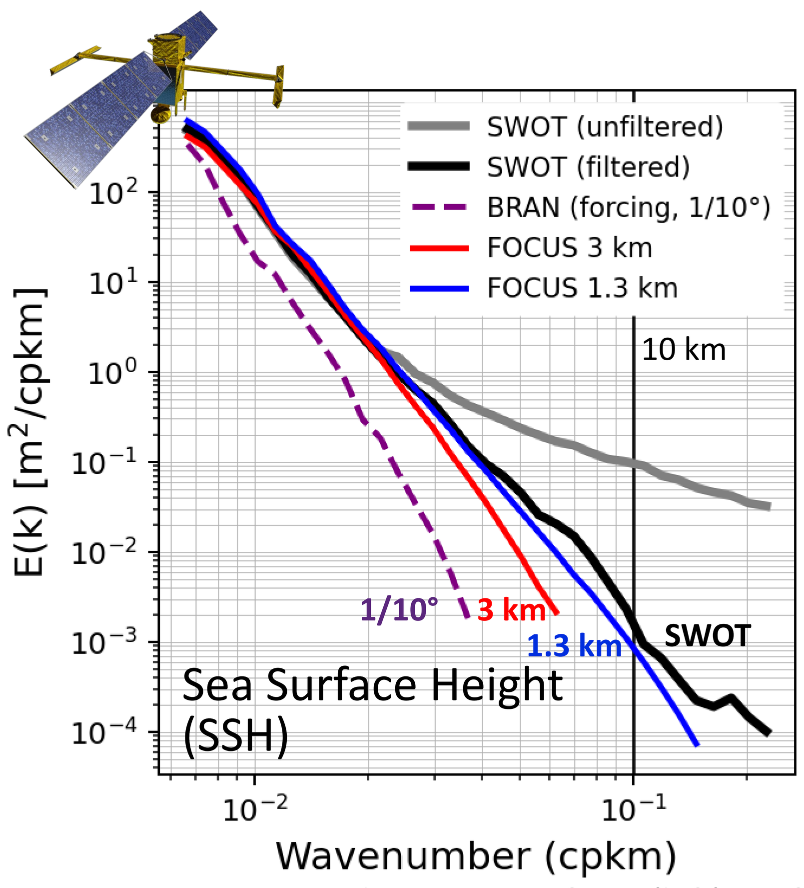


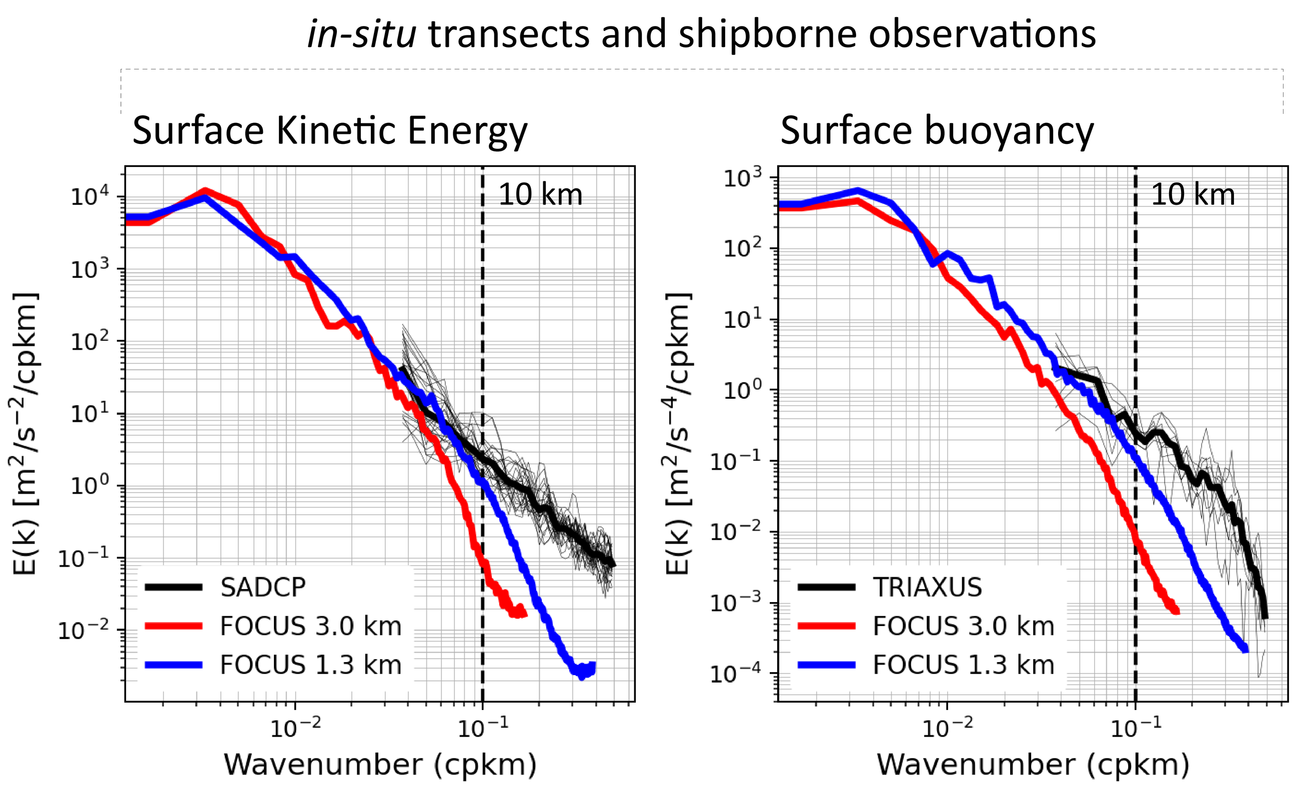
Top: SST snapshot from the FOCUS 1.3 km run. Bottom: Meridional temperature transects showing the the upper 0–1000 m layer and the full depth.



Impact of horizontal resolution

Characterized by a small Rossby radius of around 20 km, truly eddy-resolving models in the ACC require grid spacings ~1–3 km to properly resolve mesoscale variability, with sub-km needed to open the submesoscale. Our FOCUS model downscales the 1/10° BRAN ocean reanalysis [2] through a nested cascade (3 km to 1.3 km), forced at the surface by ERA5 (¼°) atmospheric fields.





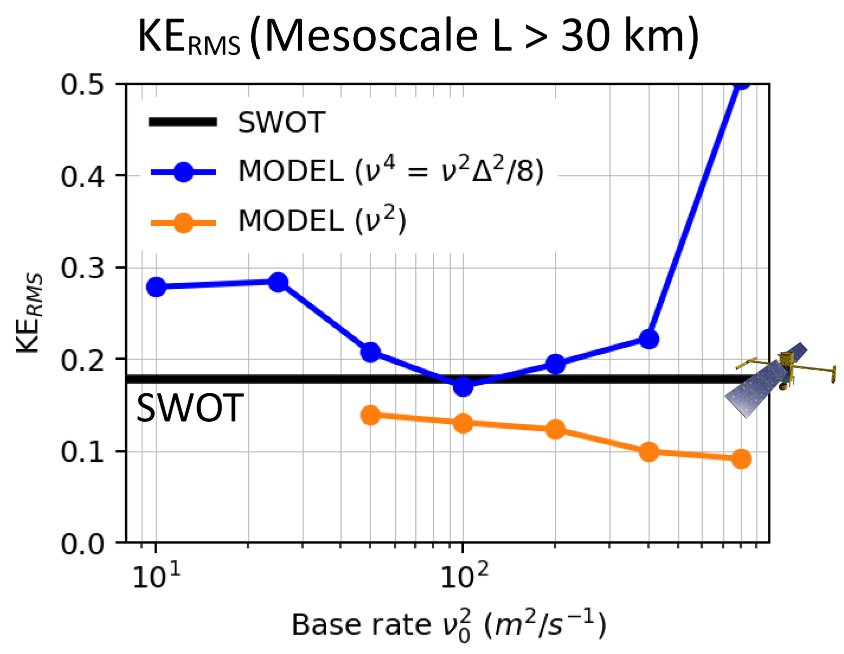
Wavenumber spectra of SSH (left), surface KE (middle) and surface buoyancy (right), compared against SWOT, shipborne ADCP and Triaxus transects, respectively.

Km-scale models resolve the SWOT-revealed energy cascade down to ~10 km wavelengths, the scale at which geostrophic turbulence loses dominance in the region [x]. Ongoing FOCUS experiments refine the grid to 800 m.

Not only grid resolution: km-scale surface forcing will be essential to accurately resolve wind-driven submesoscale instabilities and turbulent heat fluxes.

Model viscosity controls KE and heat fluxes across the ACC

The ACC is characterised by sharp fronts and high strain, so the choice of horizontal viscosity strongly impact eddy kinetic energy and the associated heat fluxes. We tested both scale-selective Biharmonic (ν^4) and Laplacian (ν^2) closures along with a Smagorinsky (strain-dependent) scheme, on the 3 km model.

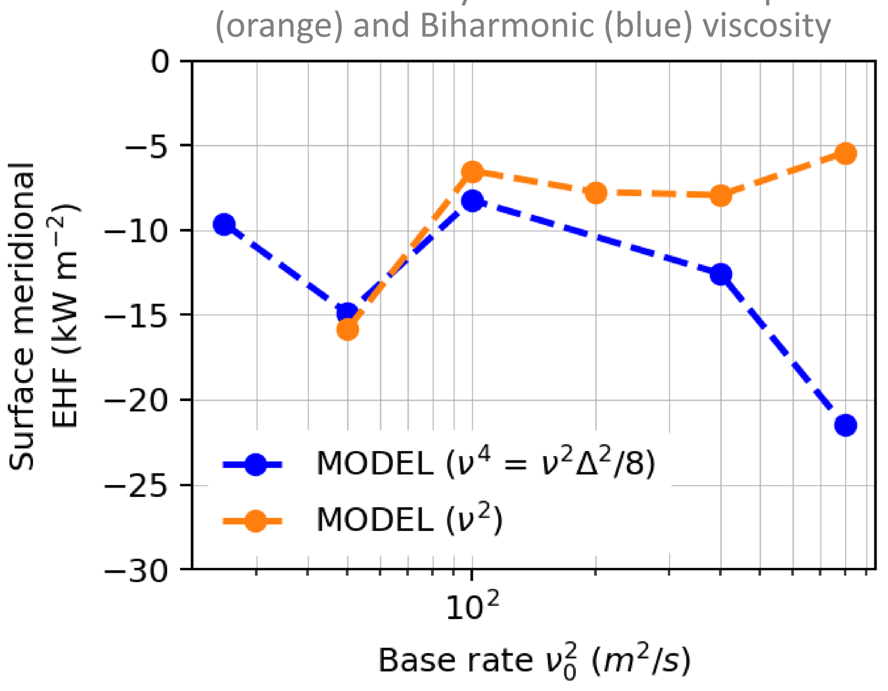


Spatial RMS of mesoscale KE for different values of horizontal viscosity associated with Laplacian (orange) and Biharmonic (blue) viscosity

Laplacian viscosity (ν^2) damps energy at all scales, so increasing it drives mesoscale KE below SWOT observations. In contrast, we find an optimal scale-selective biharmonic viscosity (ν^4) that matches SWOT at mesoscale; but if set too high, it over-damps the dissipation range, inducing excessive inverse cascade and accumulation of mesoscale KE (on-going investigation on the COMPAS numerical closure).

Surface meridional Eddy Heat Flux (EHF) (negative = poleward heat transport). We compute EHF in each run that differ only in viscosity closure, to <u>illustrate</u> how this choice impacts surface heat transport.

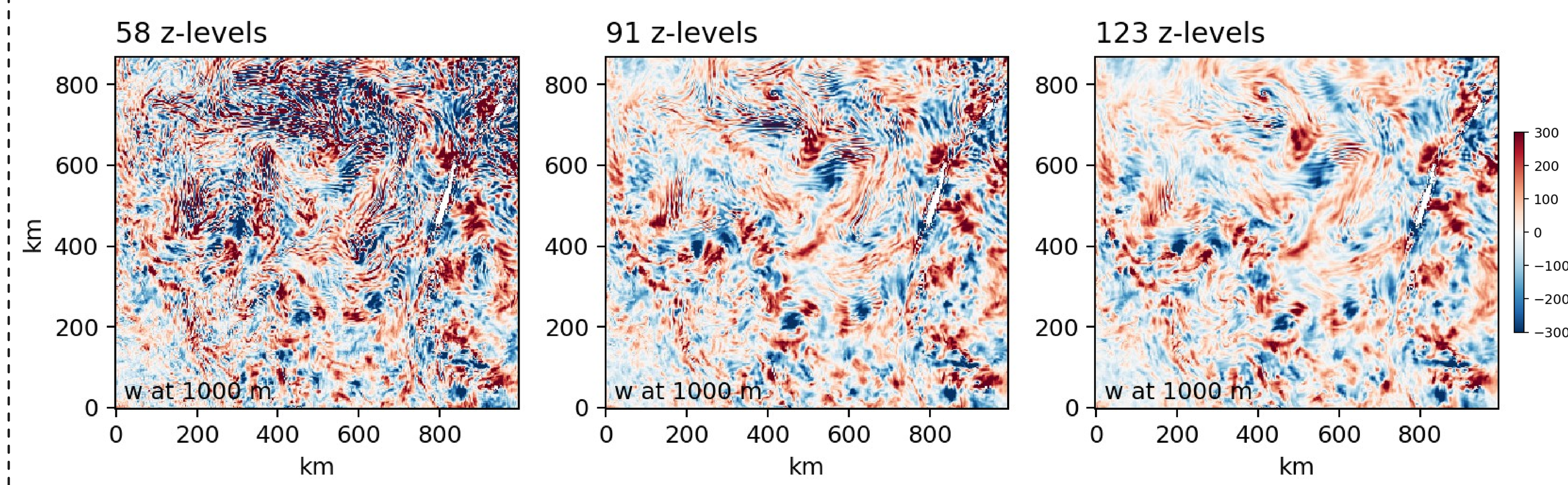
Surface meriodional EHF for different values of horizontal viscosity associated with Laplacian (orange) and Biharmonic (blue) viscosity



- By providing accurate, high-resolution surface observations across broad scales, SWOT represents an unique opportunity to improve model tuning and physics, and refine heat-flux estimates
- Next steps include conducting assimilation experiments and Observing System Simulation Experiments (OSSEs) to validate proxies to infer vertical dynamics from SWOT SSH observations (see Carli et al. And Thompson et al. presentations)

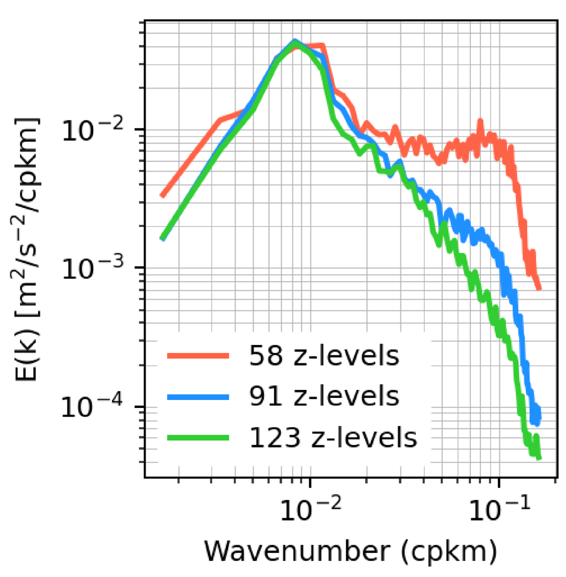
Vertical discretization and vertical velocities

Across the ACC, vertical structure changes sharply: a shallow pycnocline south of the Polar Front and a deeper pycnocline to the north, with ubiquitous deep-reaching features. Here we assess how vertical resolution affects spurious noise in vertical velocities by comparing the 3-km model with 59, 92, and 123 z-levels.



As vertical resolution increases, the grid-scale noise is reduced and the horizontal wavenumber spectrum of w steepens, evidence of a more physical cascade with less grid-scale accumulation. This is most pronounced north of the Polar Front, where a deeper pycnocline requires enhanced interior resolution.

In the 3-km setup, we found that vertical grid spacing requirements are stricter than baroclinic-mode criteria alone [3], reflecting a numerically motivated need to suppress stratification-driven instabilities [4]. As horizontal resolution increases, vertical resolution must scale at least linearly with horizontal grid spacing.



Horizontal wavenumber spectrum of vertical velocities

References

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