Mesoscale turbulence in the seasonally ice covered Arctic Ocean

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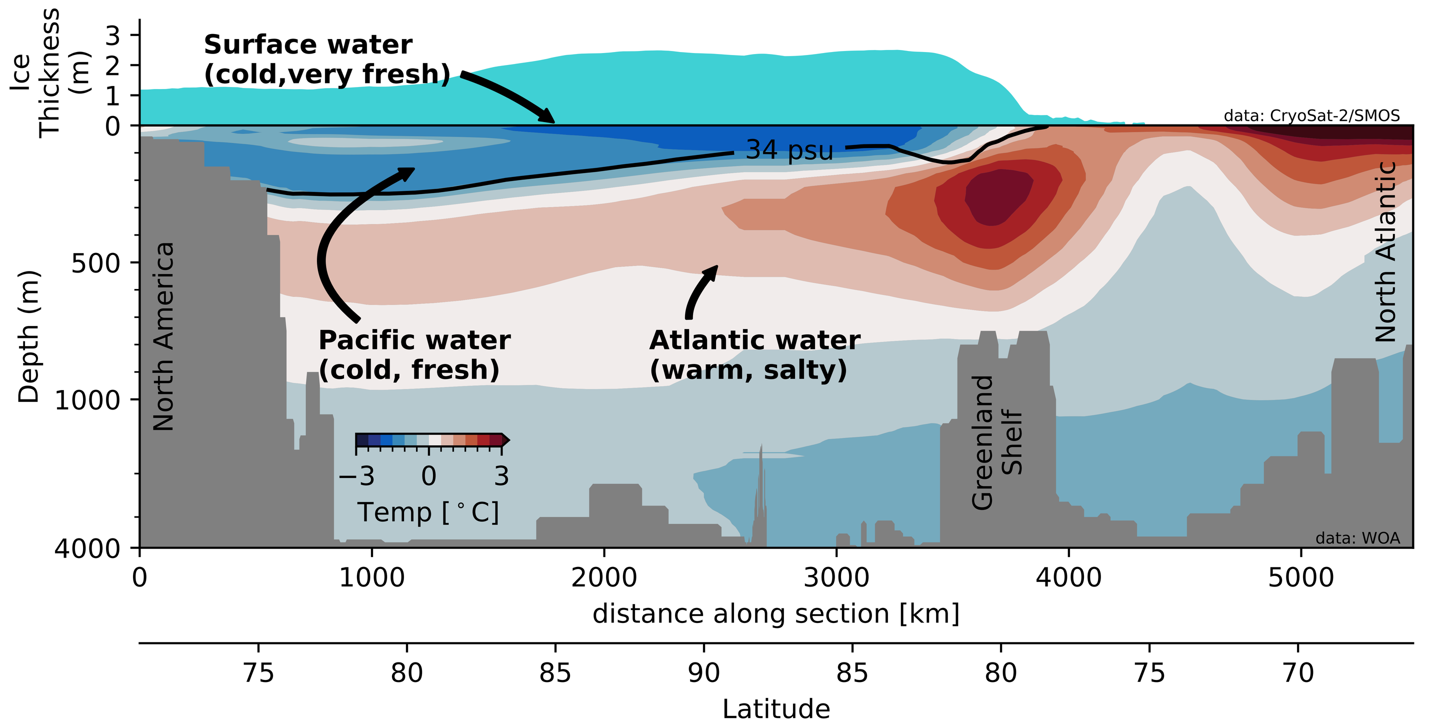
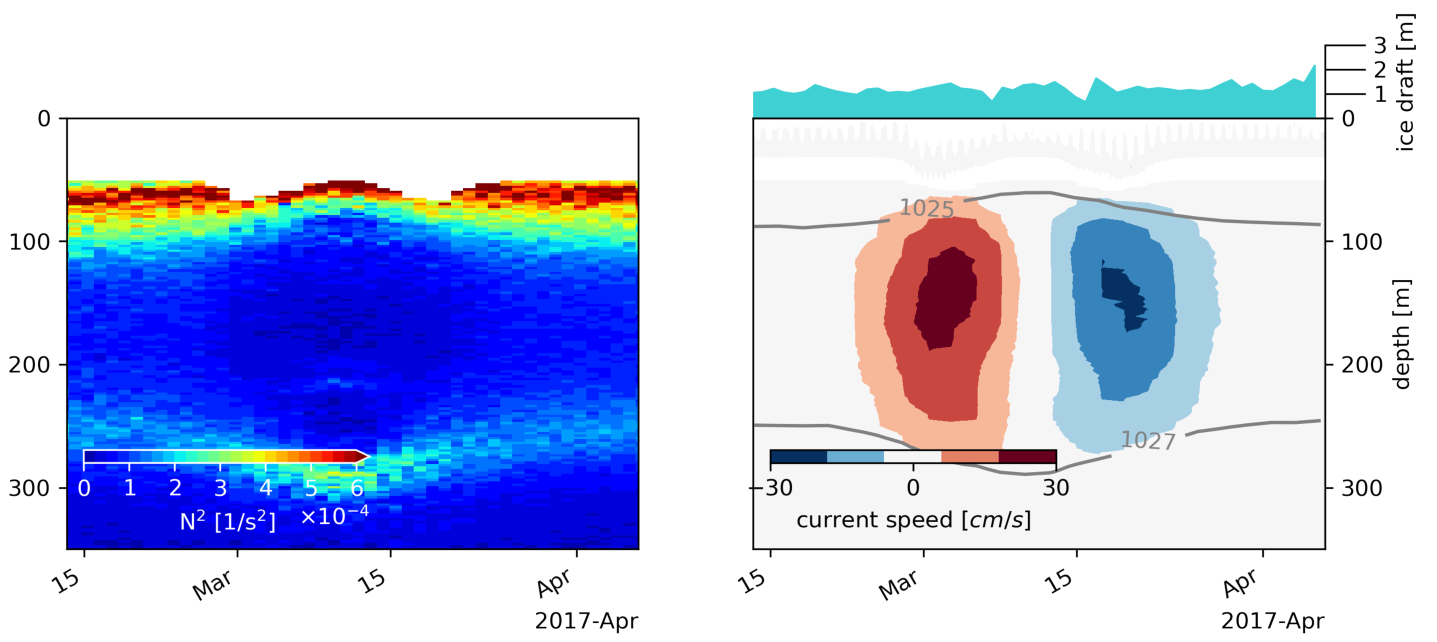
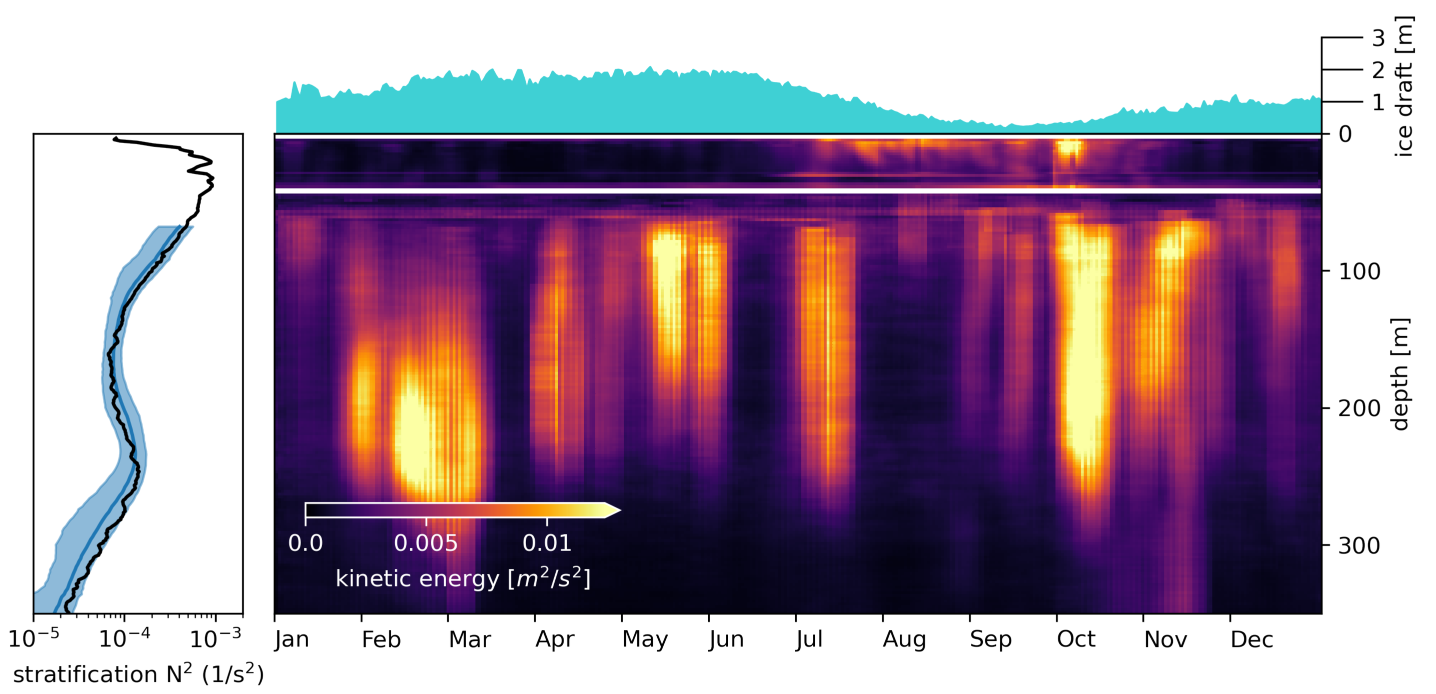
Observations of mesoscale turbulence



This section across the Arctic basin shows the stratification of the Arctic water masses. Cold, fresh waters originating in the Pacific sit above warmer, saltier waters from the Atlantic. Additionally, a 50 m thick layer is maintained by ice melt and river run off close to the surface. This poster describes the mesoscale eddy fields developing in each layer, and discusses the possible implications for the transport of tracers across the basin.



These observations capture an eddy transiting at the center of the Canadian Basin in March 2017. The stratification (left) is characterized by two strong maximaæ at around 50 m and 250 m depth. The shallower peak marks the separation between surface and Pacific waters, while the deeper peak marks the separation between Pacific and Atlantic waters. Currents (right) reach a maximum at a depth of around 150 m, and decay to zero above and below the stratification peaks. Contrary to mesoscale eddies in other ocean, there is no current at the surface, where sea-ice thickness is about 1.5 m (top panel, cyan).



A 15 year climatology obtained from the same mooring shows how both the stratification peaks (left) and the subsurface intensification of mesoscale activity (right) are persistent features. The subsurface intensification of eddy activity is a peculiarity of the Arctic basin, observed by several instruments in multiple locations. This climatology additionally captures the marked seasonal cycle in surface kinetic energy, apparently correlated to the presence of sea ice at the surface (top panel, cyan).

Mooring data were collected and made available by the Beaufort Gyre Exploration Program based at the Woods Hole Oceanographic Institution (http://www.whoi.edu/beaufortgyre) in collaboration with researchers from Fisheries and Oceans Canada at the Institute of Ocean Sciences.

Origin of mesoscale turbulence

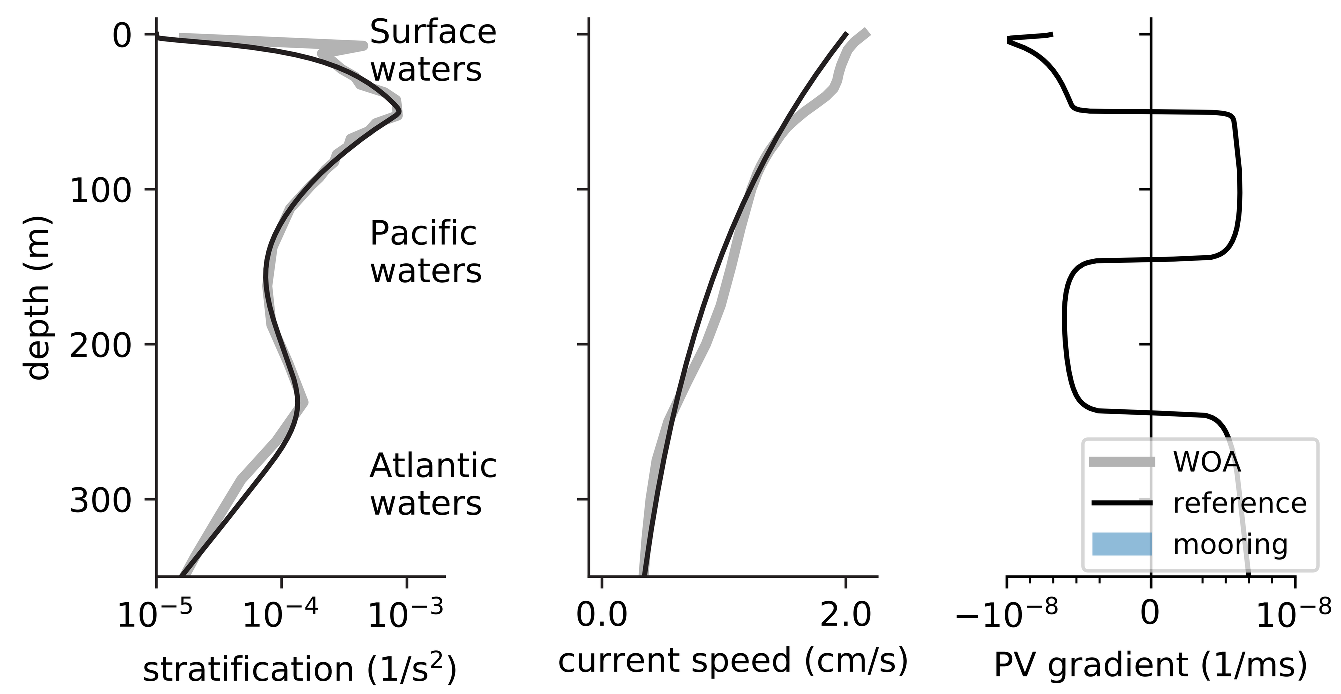
Can the observed vertical distribution of mesoscale activity originate from baroclinic instability? Previous research suggested that friction against sea ice prevents eddies to grow. We revisit these results by taking into account the peculiar Arctic stratification. The relevant dynamical balance is captured by the linearized quasi-geostrophic equations

$$\frac{dq}{dt} = -\mathbf{u} \cdot \nabla Q \qquad \text{PV conservation (interior)}$$

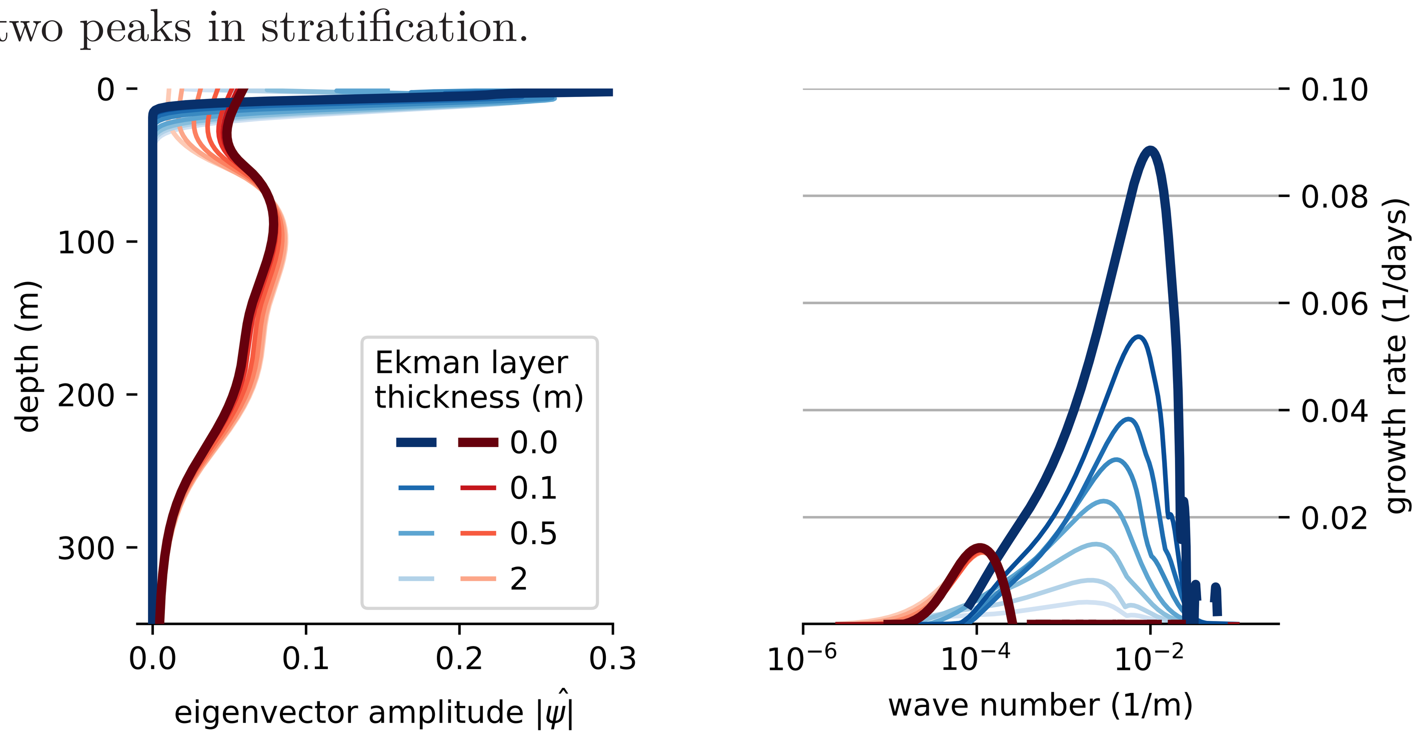
$$\frac{d\rho}{dt} = -\mathbf{u} \cdot \nabla \bar{\rho} \pm w_{Ek} \frac{\partial \bar{\rho}}{\partial z} \qquad \text{Density conservation (boundary)}$$

whose three main ingredients are i) the interior potential vorticity (PV) gradient ∇Q, ii) the surface density gradient $\nabla \bar{\rho}$, and iii) friction against sea-ice, here modeled as an Ekman-driven density flux into the boundary $w_{Ek} \frac{\partial \bar{\rho}}{\partial z}$. PV and density gradients can feed the instability, while friction against sea ice damps it.

To study the problem, we chose stratification and velocity profiles (black curves below) that closely match the observations (gray and cyan curves) and compute the resulting PV gradient:



Our results show that, in contrast to previous analysis, the interior Arctic is baroclinically unstable. The vertical structure of the growing perturbations (left below) closely resembles the vertical structure of the observed kinetic energy. A surface intensified instability (blue) develops in the shallower 20 m or so of the water column, while a subsurface intensified one (red) develops between 50 m and 250 m, bounded by the two peaks in stratification.

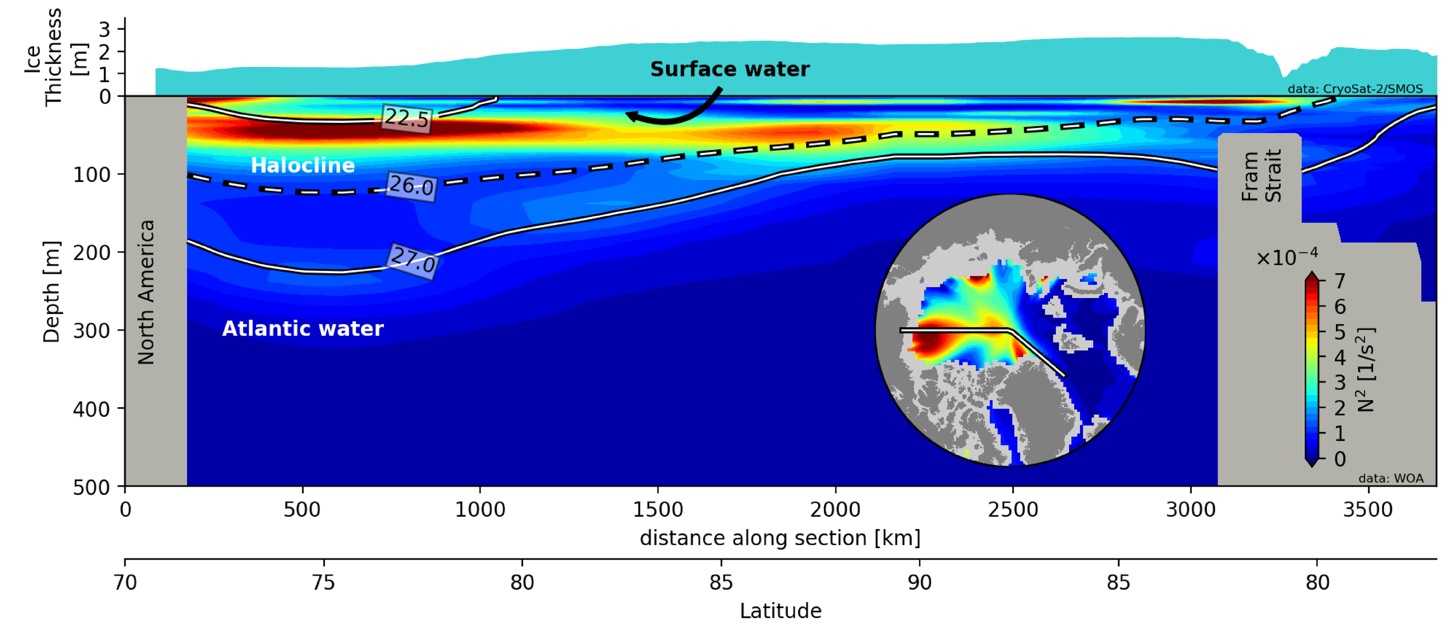


Each perturbation is characterized by very different growth rates and length scales (right), implying a very different eddy activity in the various layers: ten days and 100 meters for the surface one, two months and 10 km for the subsurface one.

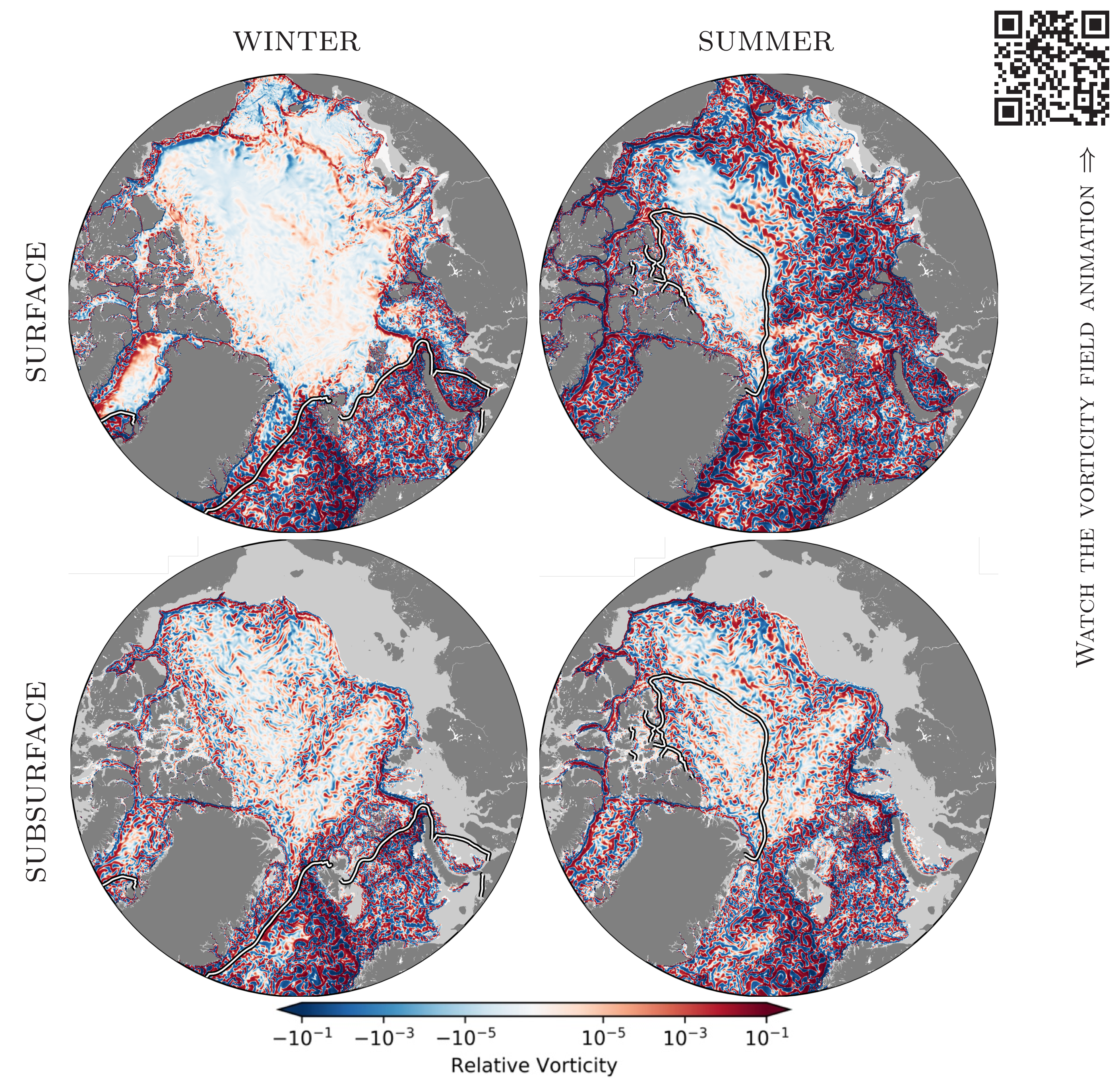
The effect of friction between the eddy currents and sea ice is also very different. Subsurface-intensified perturbations are unaffected. In contrast, the development of surface-intensified instability is halted by very little friction, thus explaining their marked seasonal cycle.

Conclusions and implications

Independent mesoscale eddy fields develop within each water mass layer in the Arctic. Each eddy field is characterized by very different time and length scales, implying very different levels of eddy activity, mixing and transport. The surface eddy field is additionally strongly affected by the presence of sea ice.



Each eddy field is bounded by peaks in stratification, shown in the above figure. The shallower peak, located at around 50 m depth, extend across most of the basin. Above, a strong eddy field develops every summer and subsides every winter, suggesting a strong seasonality in the horizontal turbulent mixing and transport. A less intense but persistent eddy field is predicted and observed at depth. The insensitivity of deeper layers to the presence of sea ice allows mixing and transport to continue across the seasons.



High resolution simulations confirm that this seasonal variability — or lack thereof — extends to the entire Arctic basin. Maps of relative vorticity close to the surface (top) show how the intensity of mesoscale activity varies by several orders of magnitudes when crossing the ice edge (white and black line, marking 80% concentration). The same map at a depth of 150 m shows little seasonal variation between ice free summers (left) and ice covered winters (right).

As the Arctic stratification changes, so will its mesoscale eddy field, with implications for the transport of heat as well as chemical and biogeochemical tracers across the basin. The dynamical framework presented here will hopefully contribute to a better prediction and understanding of these changes.

Simulation from IFREMER. The configuration has a high vertical (75 levels) and horizontal (3-4km) resolution in the Arctic Ocean.