Ice Keels and Mixed Layers in the Arctic Ocean

Rosalie Cormier[1], Nicolas Grisouard[1], Erica Rosenblum[2], Mikhail Schee[1]

[1]University of Toronto, [2]University of Manitoba

Introduction

Collisions between ice floes result in the development of pressure ridges, mirrored by the formation of underwater keels. As wind forces the lateral movement of these keels, they stir up the surrounding water. The relationship between the decreasing age of Arctic ice and the amount of wind-driven mixing occurring is not well understood.

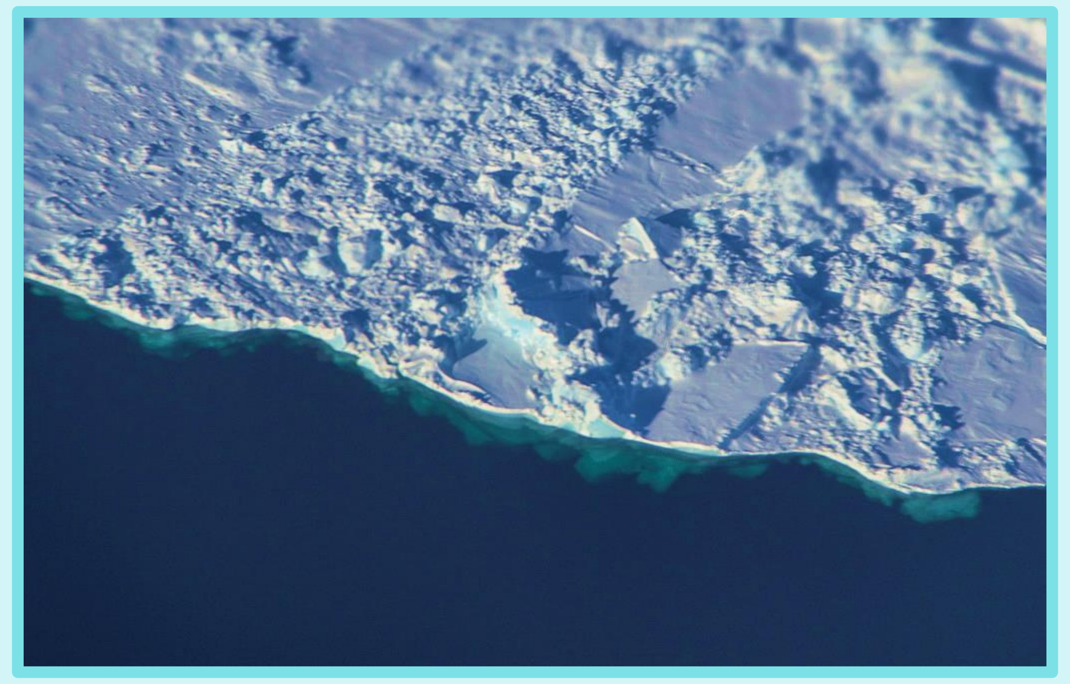


Figure I. Aerial photograph of a pressure ridge and a sea ice keel [1].

In a series of two-dimensional numerical experiments, we simulate turbulence caused by ice keels of various drift speeds and subject to various mixed-layer depths.

Background

Observations from the past several decades confirm a reduction in the average age of Arctic sea ice, which corresponds to increased sea ice mobility and a change in mixed-layer depth [2, 3].

The Arctic Ocean may be modelled as a two-layer stratified system, with a fresher surface mixed layer overlying a thicker, more saline band of water.

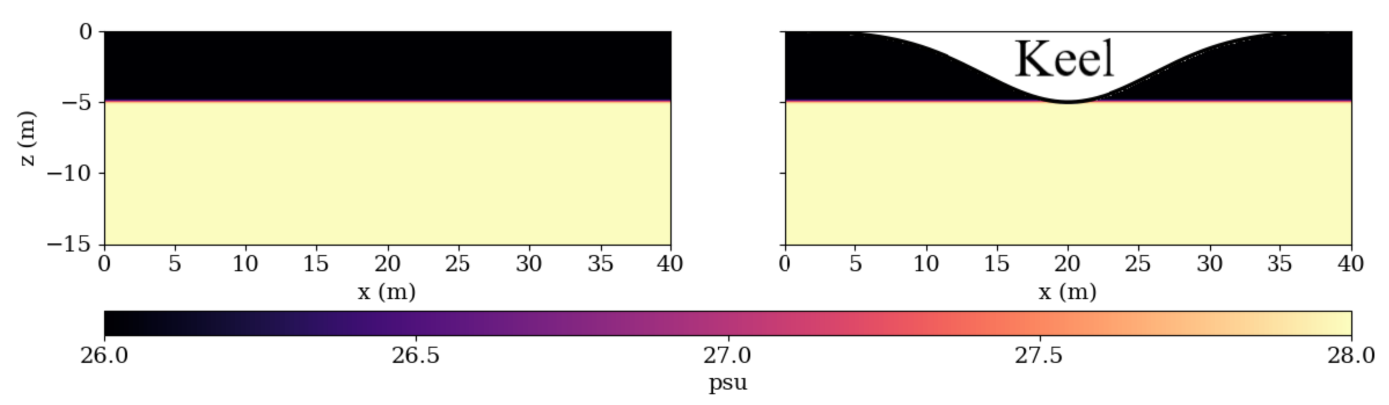


Figure II. Sample salinity plots for a two-layer-stratified ocean, in open water (L) and in the presence of an ice keel (R).

Flow with speed U and characteristic length scale Δh (here, the difference between the keel depth and mixed-layer depth) is classified by its Froude number Fr, defined by

$$\mathrm{Fr} = U/\sqrt{(g_{red}\Delta h)}; \quad g_{red} = (g\Delta\rho)/\rho_0 \quad [4].$$

We examine two pairs of systems: in the first, we vary Fr_i (the initial Froude number) via the initial drift speed U_i, and in the second, we vary it via the parameter Δh_i (the initial value of Δh).

Effect of Variable Drift Speed

First, we consider a pair of systems in which Δh_i = 1m. To attain the desired initial Froude numbers 0.8 and 1.2, we set U_i equal to 0.10m/s and 0.15m/s, respectively. We allow the systems to evolve for approximately 350 seconds.

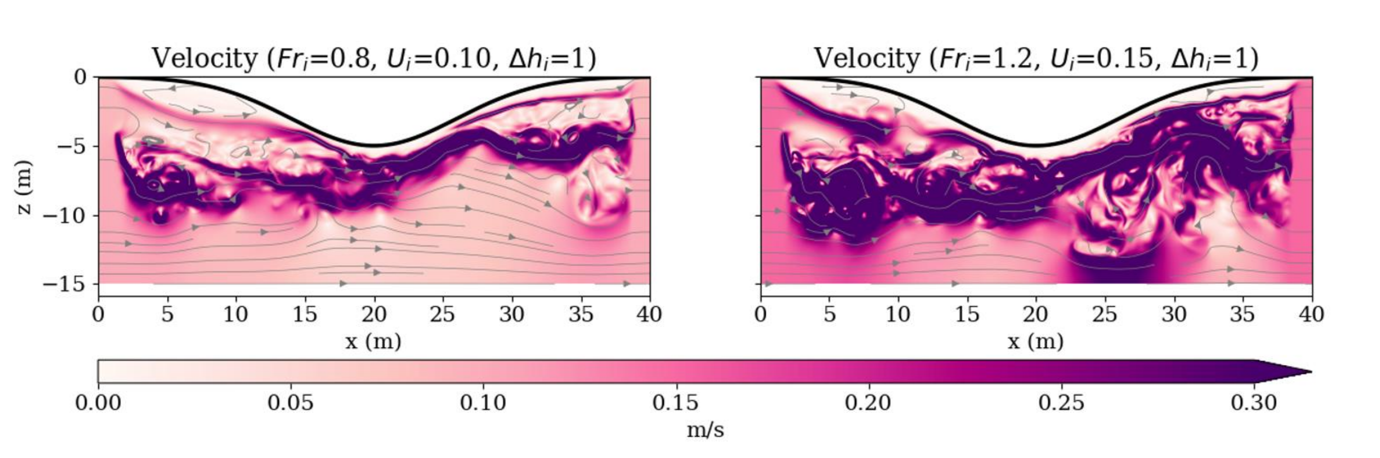


Figure III. Evolved velocity fields for systems with variable drift speed (Experiments A and B, respectively).

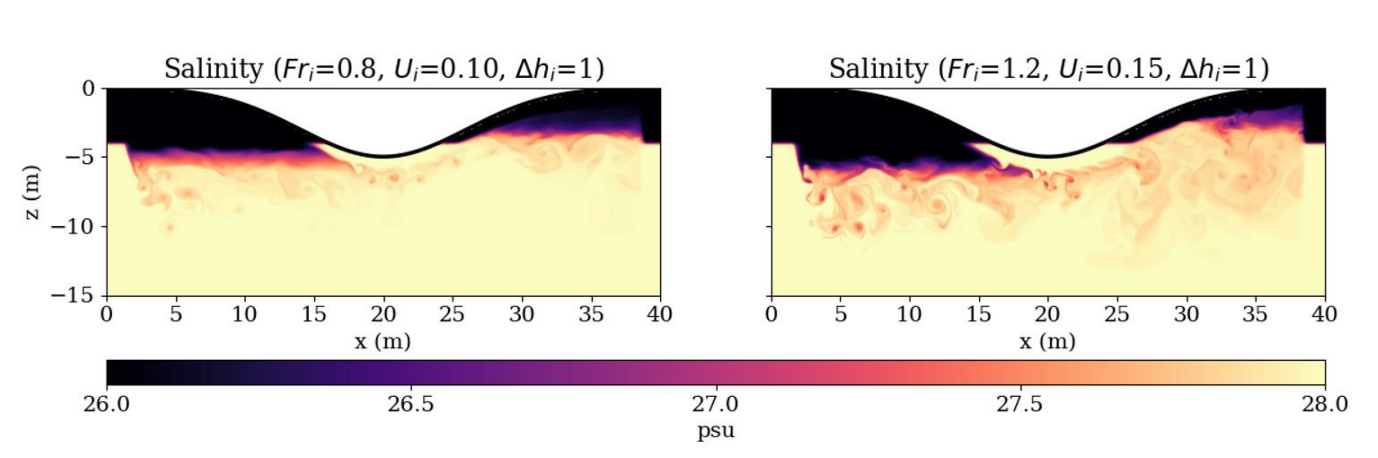


Figure IV. Evolved salinity fields for systems with variable drift speed (Experiments A and B, respectively).

At this instant, we observe substantially greater turbulence in the Experiment B system. We also observe a greater degree of salt redistribution within the water in this system.

Effect of Variable Mixed-Layer Depth

Next, we consider a pair of systems in which U_i = 0.10m/s. To attain the desired initial Froude numbers 0.8 and 1.2, we set Δh_i equal to 1m and 0.44m, respectively. We allow the systems to evolve for approximately 350 seconds.

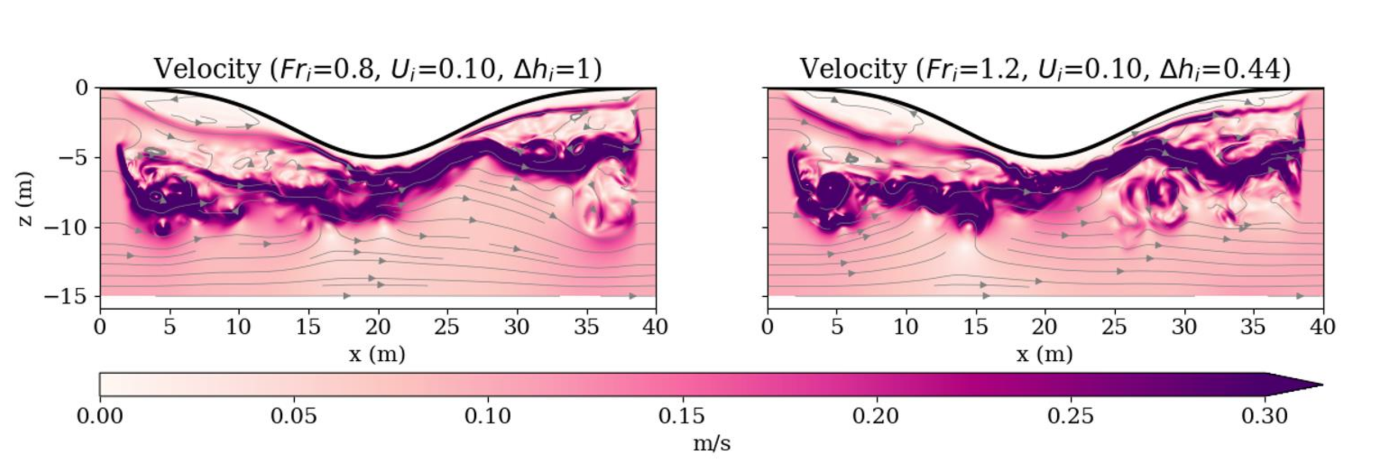


Figure V. Evolved velocity fields for systems with variable mixed-layer depth (Experiments A and C, respectively).

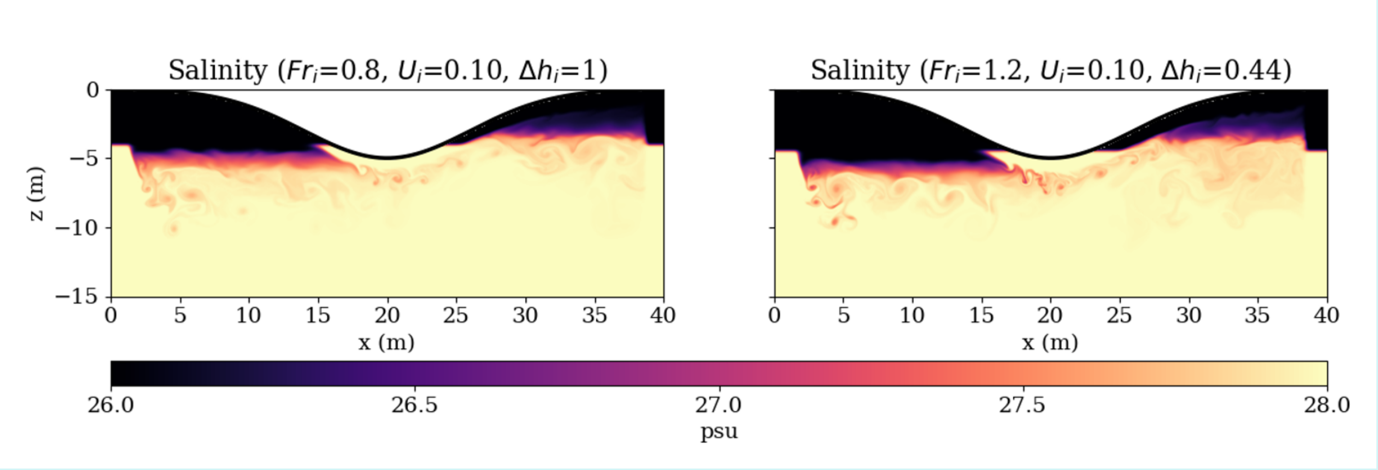
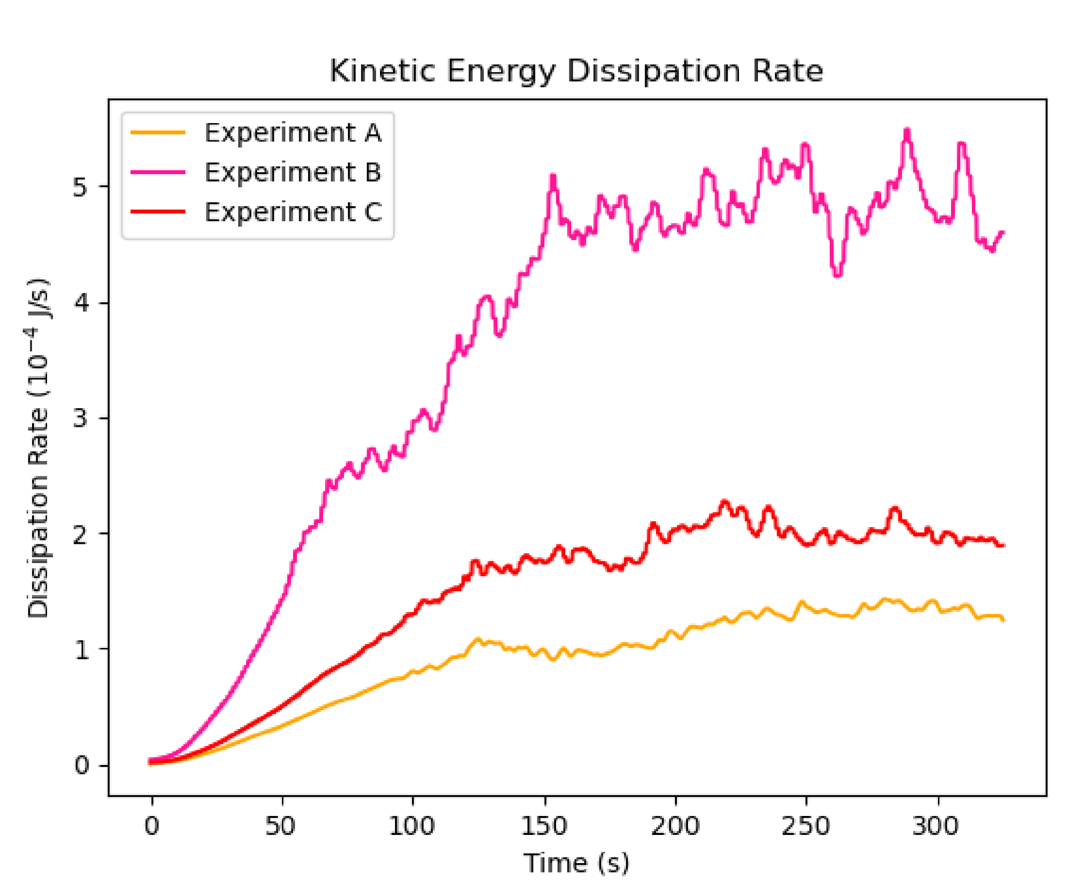


Figure VI. Evolved salinity fields for systems with variable mixed-layer depth (Experiments A and C, respectively).

We observe less turbulence in these simulations than in the Experiment B system due to their lower drift speeds. Despite their dynamical differences, the velocity and salinity fields for the systems with variable mixed-layer depth look quite similar, suggesting that changes to mixed-layer depth do not affect Arctic stirring by keels as significantly as changes to drift speed.

Kinetic Energy Dissipation

Figure VII. Plot of kinetic energy dissipation rates for the three experiments.



Experiment [Initial Froude Number]	Exp. A [0.8]	Exp. B [1.2]	Exp. C [1.2]
Dissipated Energy (10^{-3} J)	1.97	7.82	3.20

Table I. Total dissipated kinetic energies in the three experiments.

Future Study

- Account for the influence of Earth's rotation
- Track the Froude number across the domain, throughout each simulation
- Determine the impact of variable density difference $\Delta\rho$ (*i.e.*, variable g_{red})
- Use observations to quantitatively investigate changes to the Arctic sea ice cover, and use simulated data to predict future behaviour

References

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Correspondence: rosalie.cormier@mail.utoronto.ca