

LABORATORY STUDIES OF DENSITY INCREASE ON SHELVES

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We are conducting four laboratory studies of fluid mechanics processes with applications to Pan Arctic shelf/basin environments. Described below are three projects. A fourth project is described in more detail by Claudia Cenedese.

Density currents down a slope

Laboratory experiments reveal the features of a dense plume of salt water flowing down a slope in a tank of rotating fresh water. Over a wide range of parameters three flow types are found: laminar flow, waves, and eddies. Regime diagrams illustrate the range of variables that produce these three different types, and the parameters indicate some aspects of the dynamics for their formation. Kelvin-Helmholtz instability seems the most likely candidate for wave generation. All three types may be expected in the shelf break at the edge of the Barents and Chukchi Seas. The wave instability may lead to more intense mixing between shelf and Arctic waters. The eddy instability may be associated with eddy formation in the Arctic Ocean.

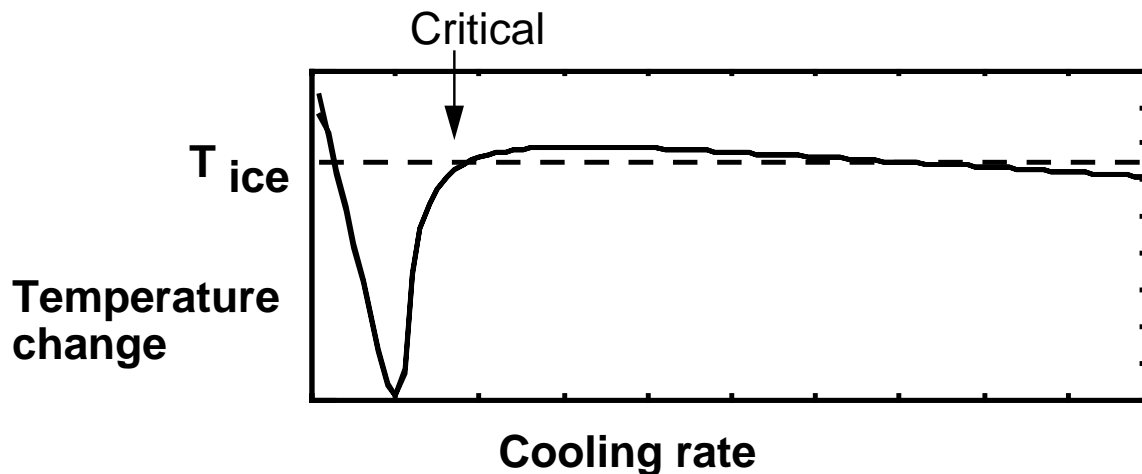
Implications for the SBI

The migration of water across the shelf break is poorly understood virtually anywhere. From this work we hope to determine criteria required for roll waves or eddies in water flowing from the shelf to the Arctic Basin.

Convection with temperature and salinity variations

A simplified box model of the cooling of a salt-stratified ocean is analyzed analytically, numerically, and in the laboratory. We find that cooling a localized region of a body of isothermal salt water that has a layer of fresher water at the surface (the layer is a crude model of the halocline) can result in very nonlinear change in temperature of the water that accumulates within or below the halocline. A calculation for one example is shown in the figure below. The water in the halocline is assumed to have a temperature above the ice melting temperature. In the portion of the curve to the left of the figure, the fresh surface water gets quite cold since it only slowly sinks a short distance down before it spreads away from the region of cooling. If the cooling rate is large enough to reach the temperature change needed for ice formation, ice begins to form. Toward the right, convection is deeper and flow is more rapid. The predicted temperature change of the water curves upward so that it may intersect the ice temperature as shown. At atmospheric cooling rates above the one signified as critical, warmer saltier water from greater depths is brought to the surface at rapid velocities so that water is not as cold as the water formed at lower cooling rates. To the right of the arrow labeled critical, convection could open ice-free regions. This model may also apply to convection by ice formation in polynyas. It also may apply to plumes of freshened river water in early winter. The results show that the formation rate of dense salty water may be quite limited for small cooling rates, but one strong cooling event can trigger intense formation rates that may persist vigorously for the rest of the winter. We have investigated processes like this over a wide range of parameters and also have a

laboratory study. The main implication is that cooling (and also brine rejection) may be quite nonlinear in response to cold air and wind events.



Implications for the SBI

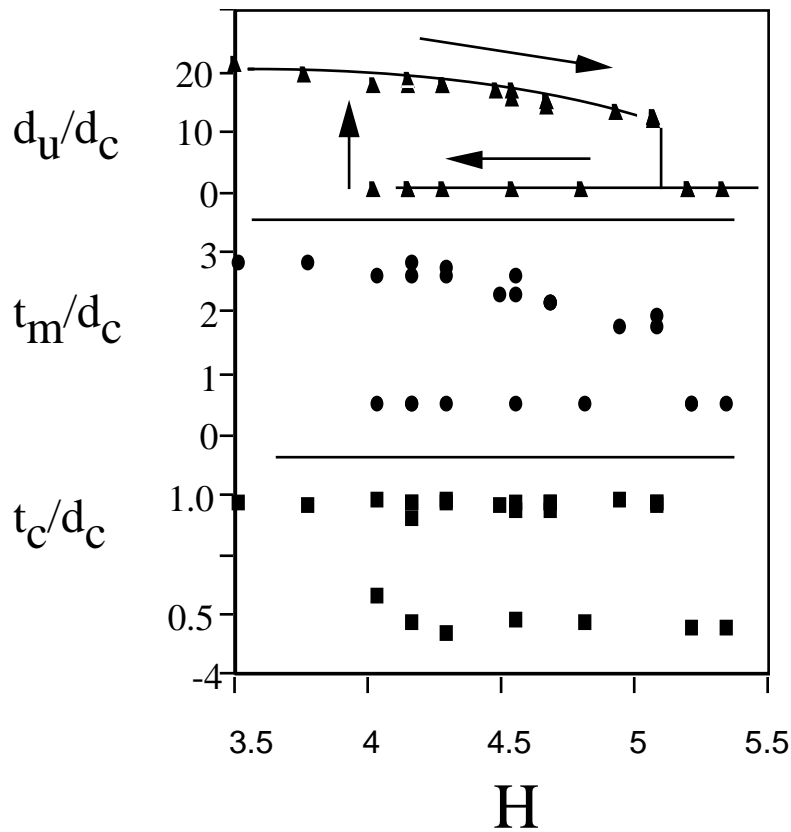
The combined effects of salinity and temperature change coupled with ice formation lead to poorly understood effects that we hope to clarify with laboratory studies and physical considerations. Measurements in water under leads and polynias in the SBI experiment should provide a number of interesting features.

Transitions in location of hydraulic jumps

Hydraulic jumps are found when a fast supercritical current slows to a specific speed and "jumps" to a slower flow, accompanied by intense mixing and turbulence. We have been investigating the behavior of jumps that are produced by a gravity-driven current flowing down a slope. In the absence of friction, the current can accelerate and attain velocities greater than the wave speed. In a certain range of parameters (which we predict using theory developed these last two years) the presence of the jump, and hence the mixing made by the jump, depends on the history of the way the flow was started.

In the laboratory a small flume was used to contain a hydraulic jump upstream of an obstacle. The flume was a uniform channel. A sluice gate produced a rapid flow at the upstream end of the flume. An obstacle in the shape of a weir was constructed of foam and placed in the channel at the downstream end. The current had to flow up and over the obstacle. To vary the flow rate, the channel was tilted to assorted angles with the upstream region higher than the downstream region. Our calculations indicate that more than one possible configuration can exist for exactly the same flows at the upstream end. An example of data confirming this is given in the following figure (apologies for the clipped lettering in the ordinate). It shows: distance of a stationary hydraulic jump in front of the crest of the obstacle (top panel), the maximum thickness of the water in front of the obstacle (middle panel) and the thickness of water over the crest of the obstacle (bottom panel). These lengths are divided by the thickness of water with this volume flux if it is going exactly at the speed of a long surface wave. The variable along the horizontal axis is the scaled height H of the water surface in the upstream reservoir above the crest of the obstacle that feeds the water into the experiment. This variable H is exactly proportional to potential energy that feeds the upstream flow. In the laboratory H is changed by

changing the tilt of the experimental basin. We see that over the range of $3.7 > H > 5.2$, the three variables have two different values.



Such a feature might be found downstream of any current of dense water along the shelf break in the Chukchi Sea region. This is going to make prediction of flows and mixing extremely difficult for some conditions. For example oceanographers might come to a site and find intense turbulence, yet upon reoccupying this site, there may be no such turbulence, even though the same currents and stratification characterize the region

Implications for the SBI

This study may not have any direct counterpart in the SBI region, although dense water formed on the shelf may mix as it descends along the shelf or down a canyon. The link between hydraulic jumps and the roll wave instability described in section 1 is incomplete and should be clarified.

Flows down a canyon

An additional project that investigates flow down a canyon in rotating stratified fluid is conducted by Claudia Cenedese. A range of parameters is found where the current detaches from the coastline to form isolated eddies in the interior of the deep Arctic basin.