Modeling the Formation and Offshore Transport of Dense Shelf Water from High-Latitude Coastal Polynyas

David C. Chapman
Department of Physical Oceanography, MS #21
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508) 289-2792 fax: (508) 457-2181 email: dchapman@whoi.edu

Glen Gawarkiewicz
Department of Physical Oceanography, MS #21
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508) 289-2913 fax: (508) 457-2181 email: ggawarkiewicz@whoi.edu

Award Number: N00014-99-1-0333

LONG-TERM GOALS

Our long-term goal is to understand the role that dense water, formed on high-latitude continental shelves, plays in the thermohaline circulation of the Arctic Ocean and the maintenance of the mean hydrographic structure of the deep Arctic basins, e.g. the upper halocline.

OBJECTIVES

Our immediate objective is to improve our basic understanding and ability to predict (1) the formation and offshore transport of dense shelf waters formed beneath high-latitude coastal polynyas and (2) the pathways by which dense shelf waters enter the deep basins.

APPROACH

Our hypothesis is that dense water, formed beneath coastal polynyas, is transported across the shelf via small-scale (15-25 km) eddies (e.g. Gawarkiewicz and Chapman, 1995; Chapman and Gawarkiewicz, 1997; Chapman, 1999; Gawarkiewicz, 2000). These dense water eddies are capable of moving offshore across the shelf break and into the deep basins where they contribute to the maintenance of the observed thermohaline structure. We have been testing this hypothesis with a combination of (1) process-oriented numerical modeling, (2) analyses of historical observations, and (3) numerical modeling of realistic coastal polynyas.

WORK COMPLETED

We are ending our no-cost extension year, so the project is winding down. During this year, the following projects have been completed or are nearing completion:

(1) A study of the effects of bottom friction on dense water production in idealized coastal polynyas,

(2) A study of the joint roles of ice cover and shelfbreak topography on wind-driven upwelling and downwelling on broad Arctic shelves,

(3) A study of the fate of dense shelf water formed in coastal polynyas on the Chukchi Shelf, including a comparison with observations.

RESULTS

(1) Contrary to a recent publication, bottom friction is shown to have minimal effect on dense water production from a narrow (~10 km wide) coastal polynya. The primary effect is to slow the polynya rim current at the bottom, thus reducing the vertical shear and delaying the onset of instabilities. The net result is to delay the approach to equilibrium and, thereby, produce a slightly higher equilibrium density than previously predicted. The offshore flux of dense water is not appreciably affected. Bottom friction effects are more important for wider polynyas because eddies, once generated, cannot propagate far before decaying away. In this case, an equilibrium density anomaly may not be achieved.

(2) Summer melt-back of the ice cover away from Arctic coastlines leaves the shelf waters exposed to upwelling and downwelling favorable winds for a brief period. There is great interannual variability in the location of the summer ice edge. We are using a primitive-equation numerical model to study the effectiveness of upwelling/downwelling winds on Arctic shelves for different locations of the ice edge. We find that the ice edge acts as a kind of switch for wind-driven exchange between the shelf and basin. That is, when the summer ice edge remains over the shelf (shoreward of the shelfbreak), little or no wind-driven exchange can occur. In contrast, when the ice edge melts back beyond (seaward of) the shelfbreak, wind-driven upwelling can easily draw water from deep within the halocline layer of the deep basin. This potentially provides an important source of heat, salt and nutrients to the shelves, which will vary tremendously on interannual and longer time scales. The results also have important implications for possible changes in ice cover under scenarios of altered climate.

(3) We have used a primitive-equation numerical model to simulate the fate of dense water formed in coastal polynyas on the Chukchi Shelf. Without ambient currents, eddies carry dense water far offshore, producing near-bottom signals that are consistent with some observations. In contrast, the coastal current that is known to flow along the northern coast of Alaska forms a very narrow, swift boundary jet that squeezes between the coast and Barrow Canyon, following the isobaths around Pt. Barrow and flowing onto the Beaufort Shelf. The current is capable of directing the dense-water eddies along the coast and into Barrow Canyon, where they move rapidly down the canyon into the deep basin. Thus, the presence of the current along the northern Alaska coast has profound effects on the pathways of dense water transport across the shelf.

IMPACT/APPLICATIONS

Coastal polynyas represent important regions of dense water production on Arctic shelves. The amount of dense water produced each year depends strongly on the meteorological conditions for that year, producing high interannual variability. This can also lead to large changes in the ice cover during summer, which in turn impacts the effectiveness of surface winds at generating shelf-basin exchange. Our results support the hypothesis that small-scale dense-water eddies carry dense water away from polynyas and can produce significant shelf-basin exchange.

TRANSITIONS

There are no transitions at this point.

RELATED PROJECTS

We have collaborated with Tom Weingartner (U. of Alaska, Fairbanks) and Thorsten Markus (U. of Maryland) in the examination of historical observations from the Chukchi Shelf and the realistic modeling of this region.

REFERENCES

Chapman, D.C., 1999. Dense water formation beneath a time-dependent coastal polynya. *J. Phys. Oceanogr*., **29**, 807-820.

Chapman, D.C. and G. Gawarkiewicz, 1997. Shallow convection and buoyancy equilibration in an idealized coastal polynya. *J Phys. Oceanogr*., **27**, 555-566.

Gawarkiewicz, G., 2000. Effects of ambient stratification and shelfbreak topography on offshore transport of dense water on continental shelves. *J. Geophys. Res*., **105**, 3307-3324.

Gawarkiewicz, G. and D.C. Chapman, 1995. A numerical study of dense water formation and transport on a shallow, sloping continental shelf. *J. Geophys. Res*., **100**, 4489-4507.

PUBLICATIONS

Chapman, D.C., 2002. Comment on ‘‘Cross-shelf eddy heat transport in a wind-free coastal ocean undergoing winter time cooling’’ by J.M. Pringle, *J. Geophys. Res*., accepted.

Winsor, P. and D.C. Chapman, 2002. Distribution and interannual variability of dense water production from coastal polynyas on the Chukchi Shelf, *J. Geophys. Res*., in press.