

CIRCULATION AND WATER MASS MODIFICATION IN THE CHUKCHI- BEAUFORT SEA

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Western Arctic Regional Overview

The physical and biogeochemical properties of the Canada Basin reflect the influence of the Pacific Ocean. Pacific waters, which are modified during transit across the Bering-Chukchi shelf, configure the thermohaline and circulation structure of the Canada Basin. Pacific waters also sustain enormous regional biological production that includes huge marine mammal herds. The distribution and migration routes of these animals influenced prehistoric patterns of human settlement in the western Arctic. Today these organisms provide the cultural core for many of these same settlements. Changes in transport through Bering Strait, the composition of the Pacific inflow, or in shelf/slope water mass modification processes could affect the heat and freshwater budgets of the ocean-atmosphere-ice system of the Arctic. These could lead to changes in global and regional climate and in the patterns and rates of biological production that affect endemic human populations.

Current and proposed research

My current research focuses on a) the Chukchi shelf (including Bering Strait) and b) along the Alaskan Beaufort slope.

Chukchi Sea circulation and water mass modification processes

Shipboard hydrographic and ADCP data in conjunction with time series of velocity, temperature, and salinity time from moorings on the Chukchi shelf are helping to resolve the circulation and water mass modification processes. On annual average 0.8 Sv flows through Bering Strait (Roach et al., 1995) and moves northward across the Chukchi shelf into the Arctic Ocean along three branches (Figure 1): Herald Valley (western Chukchi Sea; ~0.3 Sv), east of Hanna Shoal (central Chukchi Sea; <0.2 Sv), and Barrow Canyon (northeast Chukchi Sea; ~0.3 Sv). The Herald Shoal branch is the richest of the three in terms of nutrients and marine carbon, while the Barrow Canyon branch is the poorest.

Six-years of current time series from Barrow Canyon provide a tentative description (hypothesis) of Chukchi shelf climatology. Transport through the canyon varies seasonally and in-phase with that in Bering Strait: it is a maximum in summer and a minimum in winter. However, the proportion of the Bering Strait transport that exits through Barrow Canyon varies seasonally; 60% of the strait outflow exits through Barrow Canyon in summer, while less than 30% does so in winter. The remainder must exit along the other two paths with the majority probably diverted through Herald Valley (Weingartner et al., 1998). Dense (nutrient-rich) water from the Bering Sea leaves the shelf primarily through Herald Valley in winter, while most of the low-salinity (and nutrient-poor) summer transport exits via Barrow Canyon in summer. The seasonal switching in the location and density of these outflows could affect flow along the continental slope and the distribution of shelf waters in the Canada Basin.

The mean flow on the gently-sloping, outer, central Chukchi shelf is northeastward and opposes the mean winds, indicating that the mean flow dynamics primarily reflects the sea-level difference between the Pacific and Arctic oceans. Central shelf waters are a mixture of the Herald Valley and Herald Shoal outflows. This biologically rich mixture could be important in sustaining the high biomass of upper trophic levels (mammals, benthos, and arctic cod) on the outer shelf. Flow variations over the northeastern shelf are mainly wind-driven and coherent over spatial scales of O(300 km). However, seasonal thermohaline processes also influence the shelf circulation. Horizontal density gradients occur

whose strength and sign vary due to the seasonal advection of different water masses from the Bering shelf and the formation/ablation of ice. These gradients are poorly resolved but they could force seasonally averaged flows of a few cm s^{-1} which are comparable to the annual mean on the outer shelf. In some winters, cold, hypersaline waters form within the extensive coastal polynyas generated along the Alaskan coast. Most of this dense water drains through Barrow Canyon but some propagates across isobaths into the central Chukchi Sea as eddy-like features having speeds of $0.1 - 0.2 \text{ m s}^{-1}$. Such features are suggestive of the energetic dense water eddies formed within polynyi (Gawarkiewicz and Chapman (1995).

There is large interannual variability in wintertime thermohaline structure and production of dense water on the Chukchi Sea shelf. This variability is due to the fall ice extent and the development of coastal polynyi in winter. Both depend upon the seasonal wind history. Heavy fall ice cover leads to delayed cooling of shelf waters, while light fall ice cover leads to early cooling of the shelf and generally heavy ice (and brine) production. In years when there is extensive development of the coastal polynyas along the coast of Alaska, substantial volumes of hypersaline water ($S > 34$) form in winter and flow through Barrow Canyon (Weingartner et al., 1998). Water with these characteristics is absent from the shelf in years when there is little polynya development.

D'Asaro (1988) hypothesized that strong anticyclonic shear of $O(-f)$ in Barrow Canyon is an important precursor to the formation of Arctic Ocean eddies. However, our canyon measurements suggest that the shears are generally cyclonic of $O(0.1 - 0.4f)$. Moreover, we expect that the outflow from the canyon should turn eastward along the Beaufort slope rather than overshoot the canyon mouth. This outflow joins with an eastward subsurface flow of Atlantic Water moving southward along the Northwind Ridge and thence eastward along the Chukchi-Beaufort slope as part of the subsurface, boundary current (Figure 1).

The Chukchi - Beaufort slope – circulation and thermohaline structure

The flow along the Beaufort Sea slope consists of a shallow ($\sim 50 \text{ m}$) wind-driven westward drift, that comprises the southern limb of the anticyclonic Beaufort Gyre overriding a narrow, eastward flowing current trapped to the continental slope. The latter is part of a greater circumpolar cyclonic circulation (Aagaard, 1989) that transports waters from the Atlantic Ocean and the Eurasian shelf seas to the west into the Canada Basin. The slope flow ultimately transports these waters, plus contributions from the Chukchi shelf, around the Canada Basin and into the Lincoln Sea. Although the boundary flows are an integral part of the Arctic Ocean's circulation, we lack fundamental information on their structure and variability. SCICEX hydrographic data from the winter of 1999 along the Alaskan Beaufort slope suggest a complicated along- and cross-slope density structure and circulation. This includes evidence of a strong, horizontally-sheared, flow along the shelfbreak of the northeast Chukchi Sea, an eastward weakening of the cross-shelf dynamic height, and alongshore convergence of the alongslope flow. The mechanism(s) responsible for these along-slope changes in the density field are uncertain, but they could be important in the exchange of water between the shelf, slope, and interior. Superposed on these broad scale features are shorter-scale ($20 - 50 \text{ km}$) variations. Some of this small-scale variability is likely the small, energetic eddies, found throughout the Arctic Ocean (Manley et al., 1985; Pluedemann, pers. comm.).

Pan-Arctic SBI goals

1. Improve upon the rudimentary shelf climatology hypothesized above but expand to include biogeochemical parameters.
2. Resolve the seasonally varying circulation and thermohaline structure of the Arctic Ocean's continental slope. This will be fundamental in understanding and predicting how shelf waters are transported into the interior.

I want to address these issues in the Chukchi-Beaufort region and compare them with investigators working on other shelves. Shipboard hydrography and time series measurements at select locations are

required. Given the large natural variability, extensive time series are needed in order to: a) establish a meaningful climatology, b) quantify change, and c) place process studies in an appropriate temporal frame. Bio-optical and bio-acoustical instrumentation and moored chemical samplers will augment data collected by standard physical oceanographic instrumentation. There is a clear need for extensive measurements in the Russian EEZ in Bering Strait, Herald Valley, and the Chukchi slope.

References

- Aagaard, K., 1989, A synthesis of the Arctic Ocean circulation., *Rapp P.-V. Reun. Cons. Int. Exploration de la Mer*, **188**, 11-22.
- D'Asaro, E. A., Generation of submesoscale vortices: A new mechanism, *J. Geophys. Res.*, **93**, 6685-6693, 1988.
- Gawarkiewicz, G. and D. C. Chapman, A numerical study of dense water formation and transport on a shallow, sloping continental shelf. *J. Geophys. Res.*, **100**, 4489-4507, 1995.
- Manley, T. O. and K. Hunkins, Mesoscale eddies of the Arctic Ocean, *J. Geophys. Res.*, **90**, 4911-4930, 1985.
- Roach, A.T., K. Aagaard, C. H. Pease, S.A. Salo, T. Weingartner, V. Pavlov, and M. Kulakov, Direct measurements of transport and water properties through Bering Strait, *J. Geophys. Res.*, **100**, 18,443-18,457, 1995.
- Weingartner, T.J., D.J. Cavalieri, K. Aagaard, and Y. Sasaki, Circulation, dense water formation, and outflow on the northeast Chukchi shelf, *J. Geophys. Res.*, **103**, 7647-7661, 1998.

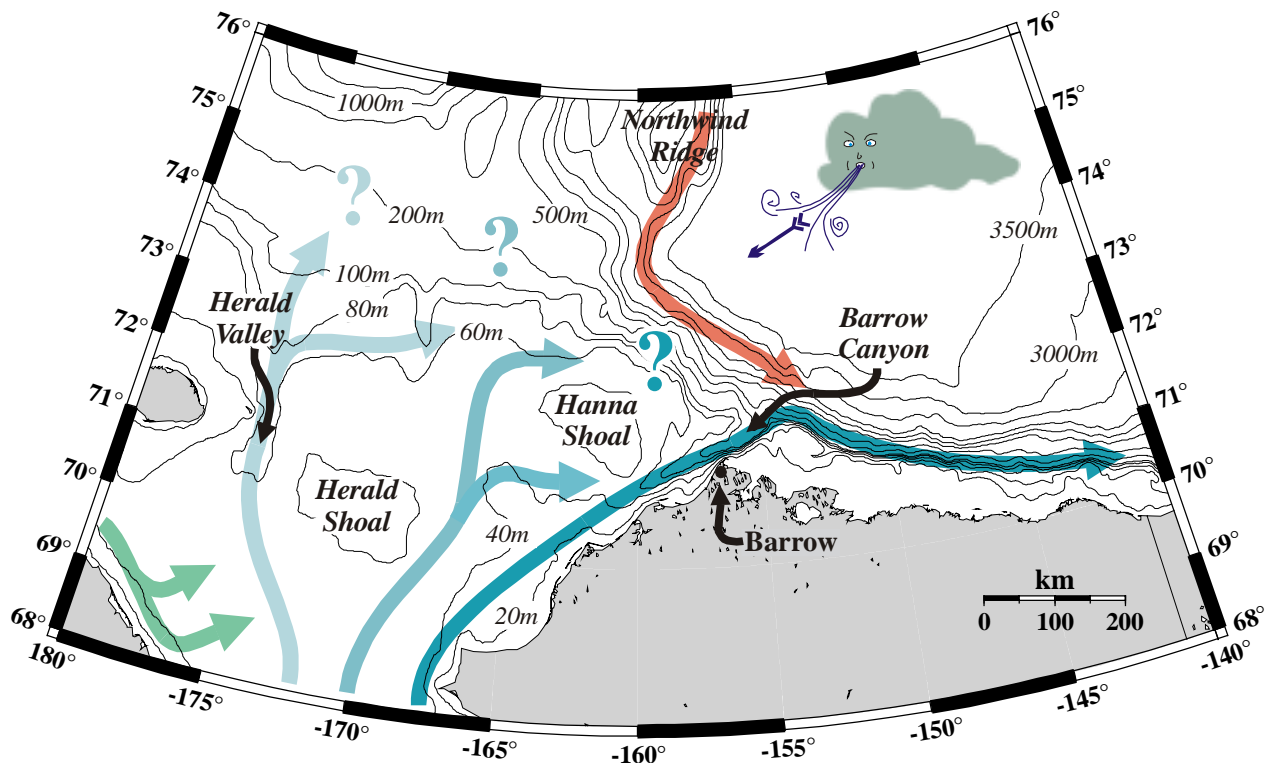


Figure 1. Circulation schematic of the northern Chukchi shelf and Beaufort Sea slope. The blue arrows depict the three transport paths of Bering Strait water (deep blue being lowest salinity and nutrients and light blue being highest salinity and nutrients). The Barrow Canyon outflow connects with the deeper flow of Atlantic Water (red) from along the Northwind Ridge. The shelfbreak circulation west of Barrow Canyon is uncertain. The green arrows depict the Siberian Coastal Current which occurs seasonally (summer and fall only).