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Circulation of winter water on the Chukchi shelf in early Summer

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ABSTRACT

Using a variety of data sources we investigate the properties and pathways of Pacific-origin winter water as it spreads across the eastern Chukchi shelf in early summer. The focus is on the time period June–July 2011 during which an extensive shipboard hydrographic/velocity survey was undertaken as part of the Impacts of Climate on Ecosystem and Chemistry of the Arctic Pacific Environment (ICESCAPE) program. A revised circulation scheme is constructed revealing that the transport pathways on the Chukchi shelf are more complex than previously thought. Notably, the well known branch progressing northward from the Central Channel bifurcates as it reaches Hanna Shoal, flowing around both sides of the shoal and dividing into smaller filaments that continue towards Barrow Canyon. Mass is conserved in the circulation scheme, with approximately 1 Sverdrup flowing poleward across the Chukchi shelf within these pathways, then exiting Barrow Canyon. The salinity of the winter water varied on the shelf in 2011, with saltier water found in the upstream portion of what is defined as the central pathway. Using sea ice concentration data and atmospheric reanalysis fields, we argue that salinization of the winter water in the central pathway occurred via brine rejection as the parcels progressed north and passed through the Cape Lisburne polynya. This demonstrates that winter water pervading the interior shelf can be transformed by convective overturning north of Bering Strait, presumably stirring up nutrients from the sediments and thereby influencing primary productivity in the region of Hanna Shoal.

1. Introduction

Pacific water enters the Arctic Ocean through Bering Strait and flows northward across the wide and shallow Chukchi Sea. The characteristics of the water vary strongly with season, from warm and fresh water in summer to relatively salty and very cold water in winter and early-spring (Woodgate et al., 2005). The winter water is formed because of ice growth, which densifies the surface layer and leads to convective overturning that reaches the bottom. As such, the water is near the freezing point, weakly stratified, and high in nutrients that were stirred into the water column from the sediments. These properties together exert a strong influence on the physical state and ecosystem of the western Arctic Ocean. The dense winter water ventilates the upper halocline of the Canada Basin (Aagaard et al., 1981), its vorticity structure influences the manner in which the water is fluxed off the Chukchi and Beaufort shelves (Pickart et al., 2005; Spall et al., 2008), and the high nitrate concentration fuels primary productivity throughout the region (e.g. Hill et al., 2005). Hence, it is of high importance to determine the precise pathways, mixing, and residence time of the winter water as it traverses the Chukchi shelf, none of which are presently well known.

Based on mooring data obtained through the years, and various numerical modeling studies, the basic circulation pattern of the Chukchi Sea has become more clearly defined. To first order the flow is dictated by the bottom topography of the Chukchi shelf (Fig. 1). North of Bering Strait the Pacific water is steered into three main branches: the western branch flows through Hope Valley into Herald Canyon (Winsor and Chapman, 2004), the middle branch flows through the topographic depression between Herald Shoal and Hanna Shoal known as Central Channel (Weingartner et al., 2005), and the eastern branch follows the coastline of Alaska towards Barrow Canyon. In summer and early-fall the eastern branch is referred to as the Alaskan Coastal Current (Paquette and Bork, 1974), advecting the warm and fresh coastal water originating from the eastern Bering Sea and Gulf of Alaska. Recent evidence suggests that, at this time of year, most of the inflowing transport through Bering Strait is carried by this current together with the Central Channel

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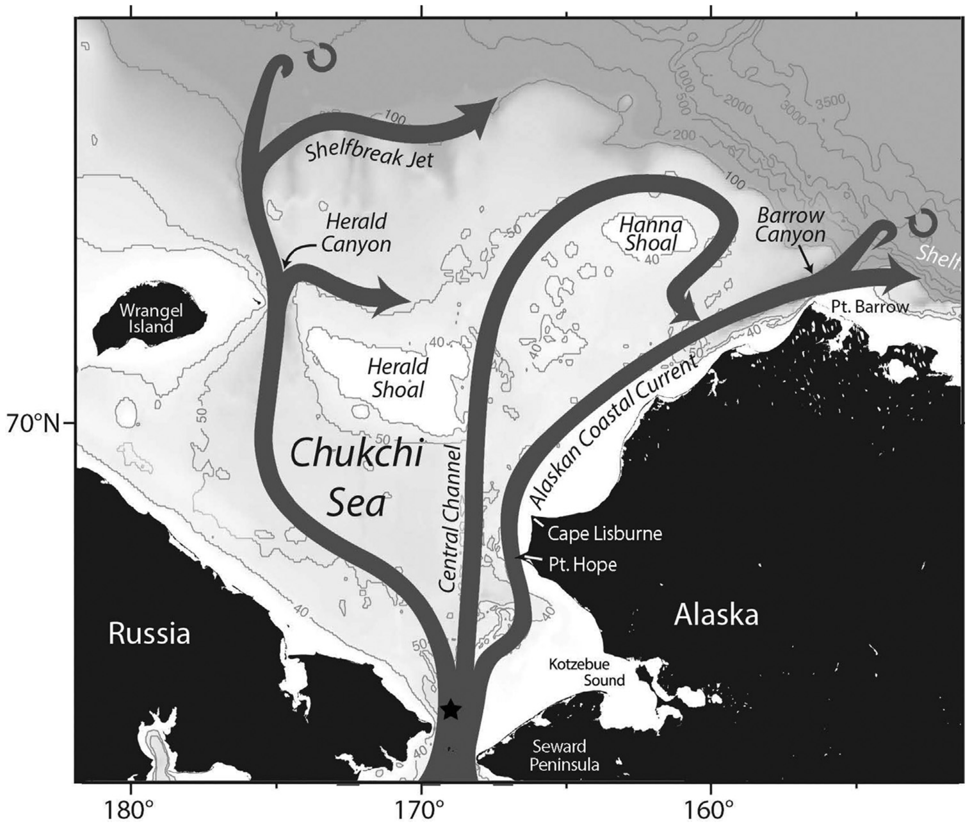

Fig. 1. Schematic of the circulation of Pacific water in the Chukchi Sea, prior to this study. Place names are listed along with the location of the Bering Strait mooring A3 (black star).

branch (Gong and Pickart, 2015; Itoh et al., 2015). Averaged over the entire year, however, it is argued that the western branch transports roughly 50% of the Pacific water (some of which gets diverted through Long Strait into the East Siberian Sea), while the other two branches transport roughly 25% each (Woodgate et al., 2005). Modeling studies indicate a similar annually averaged partitioning of the flow (Winsor and Chapman, 2004; Spall, 2007).

Winds influence the circulation on the Chukchi shelf significantly on a variety of timescales. Woodgate et al. (2005) demonstrated that the dominant observed variability in velocity over most of the shelf is due to changes in the large-scale wind field (with the exception of Herald Canyon). Assimilating Woodgate et al.'s (2005) mooring data and other available in-situ data into a diagnostic model, Panteleev et al. (2010) showed how the shelf circulation is sensitive to the seasonal wind patterns. During mid- to late-autumn, when the winds tend to be strongly out of the northeast, more of the inflowing Pacific water is diverted towards Herald Canyon. This is consistent with the numerical model results of Winsor and Chapman (2004) and also with the inferences of Weingartner et al. (1998) based on data from the eastern shelf. In contrast, during spring when the winds weaken, the flow is more evenly distributed among the three branches. On shorter timescales the currents in the two canyons that cut into the shelf – Barrow Canyon in the east and Herald Canyon in the west – are strongly influenced by synoptic weather systems. Upwelling and reversed flow to the south readily occur in both canyons (Aagaard and Roach 1990; Pickart et al., 2010).

The detailed circulation and ultimate fate of the Pacific water in the northern part of the Chukchi shelf remain uncertain at this point. Numerical models imply that when the wind forcing is weak much of the water ultimately ends up in Barrow Canyon (Winsor and Chapman, 2004; Spall 2007). This is because the flow generally follows bottom depth contours (Fig. 1). The water in the eastern branch roughly parallels the coast of Alaska and flows directly into the canyon. After the water in the middle branch passes through Central Channel the topography steers it anti-cyclonically around Hanna Shoal towards the head of Barrow Canyon. For the western pathway, north of Herald Shoal the bathymetric contours bend to the east (Fig. 1) which also brings some of the water in this branch around Hanna Shoal into Barrow Canyon. The remainder of the western branch continues northward through Herald Canyon and reaches the canyon mouth where it encounters the edge of the Chukchi shelf. Previous results suggest that this outflow forms an eastward-flowing shelfbreak current (Pickart et al., 2005; Mathis et al., 2007; Pickart et al., 2010) that eventually reaches the mouth of Barrow Canyon.

The timing of the northward progression of Pacific water through the Chukchi Sea is also uncertain. Both observations and models indicate that it takes roughly 3–4 months for water to traverse from Bering Strait to the central portion of the shelf (Woodgate et al., 2005; Winsor and Chapman, 2004; Spall, 2007). Not surprisingly, it takes significantly longer for the water in the middle and western branches to reach Barrow Canyon than it does for the water in the eastern branch. Spall's (2007) model indicates an advective time of 6–8 months for the flow through Central Channel and Herald Canyon that bends to the east on the northern part of the Chukchi shelf and drains through Barrow Canyon. The simulation of Winsor and Chapman (2004) suggests that the portion of the western branch that forms the Chukchi shelfbreak jet takes more than two years to reach the mouth of Barrow canyon. In contrast, Weingartner et al. (1998) estimate that in the summer months the swift Alaskan Coastal Current transports water from Bering Strait to the head of Barrow Canyon in just 2–3 months. It should be remembered, however, that the travel times of all of the branches are significantly longer when under the influence of northerly winds (Winsor and Chapman, 2004).

In addition to the model studies quoted above, observational evidence also suggests a "long route" of Pacific water on the northern