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Seasonal to interannual variability of the Pacific water boundary current in the Beaufort Sea

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A B S T R A C T

Between 2002 and 2011 a single mooring was maintained at the core of the Pacific water boundary current in the Beaufort Sea, approximately 150 km east of Pt. Barrow, Alaska. Using velocity and hydrographic data from six year-long deployments, we examine the variability of the current on seasonal to interannual timescales. The seasonal signal is characterized by enhanced values of volume, heat, and freshwater transport during the summer months associated with the presence of two summertime Pacific water masses, Alaskan Coastal Water and Chukchi Summer Water. Strikingly, over the decade the volume transport of the current has decreased by more than 80%, with comparable reductions in the heat and freshwater transports, despite the fact that the flow through Bering Strait has increased over this time period. The largest changes in the boundary current have occurred in the summer months. Using atmospheric reanalysis fields and weather station data, we demonstrate that an increase in summer easterly winds along the Beaufort slope is the primary cause for the reduction in transport. The stronger winds are due to an intensification of the summer Beaufort High and deepening of the summer Aleutian Low. Using additional mooring and shipboard data in conjunction with satellite fields, we investigate the implications of the reduction in transport of the boundary current. We argue that a significant portion of the mass and heat passing through Bering Strait in recent years has been advected out of Barrow Canyon into the interior Canada Basin – rather than entering the boundary current in the Beaufort Sea – where it is responsible for a significant portion of the increased sea ice melt in the basin.

Introduction

Pacific water flowing northward through Bering Strait has profound impacts on the physical state and ecosystem of the Western Arctic Ocean. The cold, dense water fluxed northward in winter and spring ventilates the upper halocline (Aagaard et al., 1981) and provides nutrients that fuel primary production each year (e.g. Codispoti et al., 2005). The warm Pacific water penetrating northward in summer and fall helps to melt back the seasonal ice cover (Weingartner et al., 2005a) and is contributing to the decline of the perennial ice pack (e.g. Steele et al., 2010). The summer water also supplies a significant quantity of freshwater to the Beaufort Gyre (Yang, 2006; Pickart et al., 2013a). As such, it is important to determine the pathways, mechanisms, and timescales by which the Pacific water penetrates the Arctic domain, and how these are changing in a warming climate.

The yearly average northward transport of Pacific water through Bering Strait is 0.8 Sv (Roach et al., 1995). After entering the Chukchi Sea the flow divides into three branches due the topography of the shelf (Fig. 1) (Weingartner et al., 2005a). Upon reaching the edge of the Chukchi Sea some of the water is channeled eastward and flows as a narrow shelfbreak jet in the Beaufort Sea (Pickart, 2004; Nikolopoulos et al., 2009). Farther down the slope Atlantic water also flows eastward as part of the large-scale cyclonic boundary current system of the Arctic Ocean (Rudels et al., 1994; Woodgate et al., 2001; Karcher et al., 2007; Aksenov et al., 2011). There is a pronounced seasonality of the Pacific water current. In summertime the flow is surface-intensified and advects two types of summer water masses (von Appen and Pickart, 2012). From early fall through winter the flow is bottom-intensified and the predominant water mass transported by the current is remnant winter water (Nikolopoulos et al., 2009). Finally, during spring and early summer, newly-ventilated Pacific winter water is

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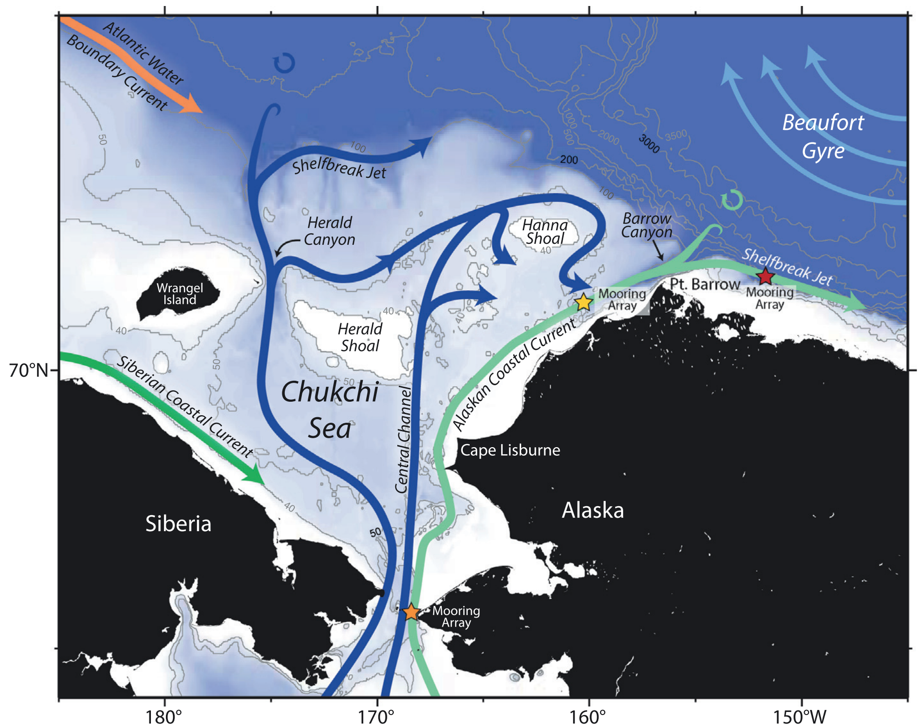

Fig. 1. Schematic showing the major currents in the Chukchi and Beaufort Seas and the geographical place names for the region. The location of the Beaufort slope mooring array is indicated by the red star, the Barrow Canyon mooring array is indicated by the yellow star, and the Bering Strait mooring array is indicated by the orange star. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

advected in a bottom-intensified jet (Spall et al., 2008). While these seasonal configurations seem to occur each year, the variation in timing and spatial distribution of the different water masses from year to year is presently unknown.

In order to accurately determine how the Pacific water impacts the Arctic system, it is necessary to understand the detailed structure and variability of the shelfbreak jet. Not only is the current the major conduit by which Pacific water exits the Chukchi Sea, but it represents the interface between the shelf and the Arctic Ocean interior. Exchange across the Beaufort shelfbreak occurs in two ways: through hydrodynamic instability of the boundary current (Spall et al., 2008; von Appen and Pickart, 2012), and via wind-forcing. The shelfbreak jet is both baroclinically and barotropically unstable and is known to spawn eddies that transport Pacific water offshore. Such eddies are found throughout the interior Canada Basin (Plueddemann, 1999). Upwelling driven by easterly winds is common and occurs in all seasons and under varying ice conditions (Schulze and Pickart, 2012). Pickart et al. (2013b) showed that a single strong storm can result in a substantial off-shelf flux of heat and freshwater, and a significant on-shelf transport of nutrients. The salt, nutrients, and zooplankton brought to the shelves via upwelling are thought to play an important role in the productivity and state of the local ecosystem (Pickart et al., 2013b). Such storms are also thought to release a significant amount of CO_2 to the atmosphere (Mathis, 2012).

For much of the past decade the Pacific water boundary current has been measured using moorings in the Alaskan Beaufort Sea, deployed roughly 150 km to the east of Pt. Barrow. The main goal of this paper is to use these data to quantify both the seasonal and interannual variability of the current over this time frame, and to investigate the physical drivers responsible for these changes. We begin with a description of the mean state of the current and a characterization of the water masses that it advects. The seasonal signal is then quantified, followed by an investigation of the interannual variability. Next we describe the large-scale atmospheric conditions during the study period, and then consider the local wind forcing, lateral boundary conditions, and sea ice concentration near the mooring site. We find that profound changes have occurred in the Pacific water boundary current over the last 10 years, much of which can be explained by atmospheric forcing. Finally, we discuss how these changes in the current can divert heat away from the shelf edge and contribute to ice melt in the interior Canada Basin.

Data

Mooring array data from 2002 to 2004

An array of 8 moorings was deployed across the Beaufort shelfbreak and slope near 152°W as part of the Western Arctic Shelf-Basin Interactions (SBI) program from 2002 to 2004 (Fig. 2). The array was aligned perpendicular to the local bathymetry, and the moorings were spaced 5–10 km apart. The moorings were named BS1–BS8 (onshore to offshore), although the shoreward-most mooring is not considered in this study. Hydrographic variables on moorings BS2–BS6 were measured using a motorized conductivity-temperature-depth (CTD) profiler known as a Coastal Moored Profiler (CMP). The CMPs provided vertical traces over a nominal depth range of 40 m to just above the bottom 2–4 times a day with a vertical resolution of 2 m. To measure velocity, upward-facing acoustic Doppler current profilers (ADCPs) were used for moorings BS2–BS6. The ADCPs provided hourly profiles of velocity with a vertical resolution of 5–10 m. Moorings BS7 and BS8 used McLane moored profilers (MMPs) for measuring the hydrographic variables, and acoustic travel-time current meters (attached to the MMPs) for measuring the velocity. The reader is referred to Spall et al. (2008) and Nikolopoulos et al. (2009) for a

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