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Water properties, heat and volume fluxes of Pacific water in Barrow Canyon during summer 2010

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ABSTRACT

Over the past few decades, sea ice retreat during summer has been enhanced in the Pacific sector of the Arctic basin, likely due in part to increasing summertime heat flux of Pacific-origin water from the Bering Strait. Barrow Canyon, in the northeast Chukchi Sea, is a major conduit through which the Pacific-origin water enters the Arctic basin. This paper presents results from 6 repeat high-resolution shipboard hydrographic/velocity sections occupied across Barrow Canyon in summer 2010. The different Pacific water masses feeding the canyon – Alaskan coastal water (ACW), summer Bering Sea water (BSW), and Pacific winter water (PWW) – all displayed significant intra-seasonal variability. Net volume transports through the canyon were between 0.96 and 1.70 Sv poleward, consisting of 0.41–0.98 Sv of warm Pacific water (ACW and BSW) and 0.28–0.65 Sv of PWW. The poleward heat flux also varied strongly, ranging from 8.56 TW to 24.56 TW, mainly due to the change in temperature of the warm Pacific water. Using supplemental mooring data from the core of the warm water, along with wind data from the Pt. Barrow weather station, we derive and assess a proxy for estimating heat flux in the canyon for the summer time period, which is when most of the heat passes northward towards the basin. The average heat flux for 2010 was estimated to be 3.34 TW, which is as large as the previous record maximum in 2007. This amount of heat could melt 315,000 km^2 of 1-meter thick ice, which likely contributed to significant summer sea ice retreat in the Pacific sector of the Arctic Ocean.

1. Introduction

Pacific water enters the Arctic Ocean via Bering Strait and flows northward across the wide and shallow Chukchi Sea. The long-term mean annual transport measured at the strait is 0.8 Sv (1 Sv $=10^6\ \text{m}^3\text{s}^{-1}$) (Roach et al., 1996; Woodgate et al., 2006), although recently this has increased to more than 1 Sv (Woodgate et al., 2012). The Pacific water influences the Arctic basin in a number of important ways. The cold winter water ventilates the interior halocline (e.g. Pickart et al., 2005) and provides nutrients that spur primary production (e.g. Codispoti et al., 2005). The summer water is a predominant source of heat and freshwater (e.g. Shimada et al., 2001; Yamamoto-Kawai et al., 2008). Over the last decade the heat and freshwater flux through Bering Strait has increased (Woodgate et al., 2012) and the warm Pacific water, which typically resides just below the surface mixed layer in the Canada Basin, has significantly contributed to both sea-ice melt in summer and a decrease in sea-ice formation during winter (Shimada et al., 2006). As such, the warm Pacific water has attracted great attention in recent years.

After entering the Chukchi Sea, the Pacific water follows three topographically steered branches across the shelf before reaching the deep Arctic basin (Fig. 1). The eastern branch flows adjacent to the Alaskan coast before exiting the Chukchi Sea through Barrow Canyon (Weingartner et al., 1998, 2005; Pickart et al., 2005). The middle branch flows through Central Channel between Herald and Hanna Shoals (Weingartner et al., 2005), and the western branch progresses

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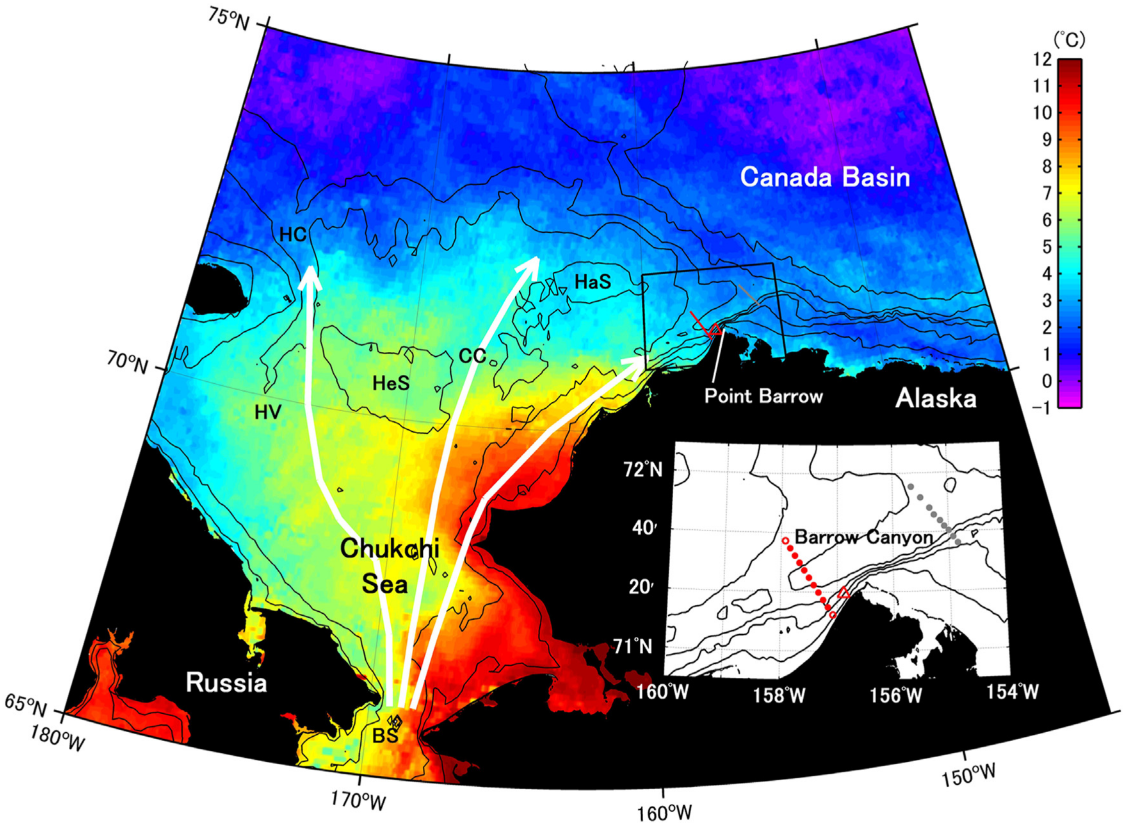

Fig. 1. Average sea surface temperature (color, °C) from the Moderate Resolution Imaging Spectroradiometer (MODIS) during 5 – 11 September 2010. The major topographic features of the Chukchi Sea from the International Bathymetric Chart of the Arctic Ocean (IBCAO, version 1.0) are overlaid. The black lines denote the 20, 40, 60, 80, 100, 500 and 2000 m isobaths. Bering Strait, Central Channel, Herald Canyon, Herald Valley, Herald Shoal, and Hanna Shoal are denoted by BS, CC, HC, HV, HeS, and HaS, respectively. The white arrows show schematic pathways of the Pacific water across the shelf. The black rectangular region indicates the region of the enlarged map around Barrow Canyon. Solid and open red circles indicate the stations of the DBO-5 repeat hydrographic transects conducted by the international research vessels listed in Table 1. Volume, freshwater and heat fluxes listed in Table 2 and heat and freshwater contents listed in Table 3 were integrated over the stations indicated by solid red circles. The location of the mooring Stn. B1 used in the study is denoted by the red triangle. Gray circles mark the location of transport measurements at the mouth of Barrow Canyon used in Fig. 6a.

through Herald Canyon on the western shelf (Woodgate et al., 2005; Pickart et al., 2010). In summer and early fall, when the volume and heat fluxes through Bering Strait increase to their maximum values, much of the inflowing water flows along the eastern branch as the Alaskan Coastal Current (ACC) (Paquette and Bourke, 1974). Furthermore, part of the Central Channel branch is believed to be diverted to the northeastern part of the shelf (Weingartner et al., 2013). Itoh et al., (2013) argued that the transport through Barrow Canyon accounts for roughly 94% of the Bering Strait transport during the months of July – September, and Gong and Pickart (2015) came to a similar conclusion using velocity data across the shelf. Therefore, Barrow Canyon is an ideal location to monitor Pacific water during the summer, especially for evaluating the heat flux into the Arctic basin.

Barrow Canyon represents a deep (extending to 300 m) and wide (50 km) incision into the Chukchi shelf that runs nearly parallel to the coastline of northwest Alaska. During the summer season, a number of Pacific-origin waters from Bering Strait can be found in the canyon (see for example Munchow and Carmack, 1997; Gong and Pickart, 2015), which can be divided into summer and winter waters. The two summer waters are the warm and fresh Alaskan coastal water (ACW, e.g. Paquette and Bourke, 1974) and the generally cooler and saltier summer Bering Sea water (BSW, e.g. Steele et al., 2004)[1]. Two classes of winter water have been distinguished in the literature based on a temperature criterion (e.g. Gong and Pickart, 2015), but in this study we make no such distinction and consider a single cold, relatively saline water mass referred to as Pacific winter water (PWW, e.g. Weingartner et al., 1998; 2005). The ACW flows predominantly along the coastal pathway, while the BSW is advected both near the coast and in the central pathway (Gong and Pickart, 2015). These two water masses are generally found in the upper part of the water column. During the summer months PWW drains into the canyon from the central shelf, constituting the last vestiges of the previous winter's convective product (E. Shroyer, pers. comm., 2014). This dense water is typically found at depth in the canyon below the summer waters, even as late as August (Pickart et al., 2005; Itoh et al., 2012).

Mooring observations in Barrow Canyon have revealed persistent northward flow that is strong in summer and weak in winter (Aagaard and Roach, 1990; Weingartner et al., 1998; 2005). The mean flow through Barrow Canyon is primarily forced by the sea-surface pressure gradient between the Pacific and Arctic Oceans, with variations mainly caused by changes in local wind (Weingartner et al., 2005; Woodgate et al., 2005; Itoh et al., 2013). During summer and fall, ship-based synoptic observations of the hydrography and circulation in Barrow Canyon were examined by Munchow and Carmack (1997), Weingartner et al. (2005), Pickart et al. (2005), Okkonen et al. (2009), Shroyer and Plueddemmann (2012), and Itoh et al., (2013). Furthermore, the seasonal and interannual variation of volume, freshwater, and heat flux through Barrow Canyon was examined using mooring observations at the mouth of the canyon from 2000 to 2008 (Itoh et al., 2013). The year-to-year variation in heat flux (relative to the

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[1] Summer Bering Sea water has also been called western Chukchi summer water (Shimada et al., 2001) and Chukchi summer water (von Appen and Pickart, 2012).