Progress in Oceanography 153 (2017) 50–65

Contents lists available at ScienceDirect

Progress in Oceanography

journal homepage: www.elsevier.com/locate/pocean

The Chukchi slope current

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ARTICLE INFO

Article history:
Received 3 August 2016
Received in revised form 15 March 2017
Accepted 4 April 2017
Available online 7 April 2017

Keywords:
Arctic Ocean
Chukchi Sea
Shelfbreak
Mass budget

ABSTRACT

Using a collection of 46 shipboard hydrographic/velocity transects occupied across the shelfbreak and slope of the Chukchi Sea between 2002 and 2014, we have quantified the existence of a current transporting Pacific-origin water westward over the upper continental slope. It has been named the Chukchi slope current, which is believed to emanate from Barrow Canyon. The current is surface-intensified, order 50 km wide, and advects both summer and winter waters. It is not trapped to a particular isobath, but instead is reminiscent of a free jet. There is no significant variation in Pacific water transport with distance from Barrow Canyon. A potential vorticity analysis suggests that the flow is baroclinically unstable, consistent with the notion that it meanders. The current is present during all synoptic wind conditions, but increases in strength from summer to fall presumably due to the seasonal enhancement of the easterly winds in the region. Its transport increased over the 12-year period of data coverage, also likely in response to wind forcing. In the mean, the slope current transports 0.50 ± 0.07 Sv of Pacific water. This estimate allows us to construct a balanced mass budget of the Chukchi shelf inflows and outflows. Our study also confirms the existence of an eastward-flowing Chukchi shelfbreak jet transporting 0.10 ± 0.03 Sv of Pacific water towards Barrow Canyon.

1. Introduction

The means by which Pacific water crosses the Chukchi Sea, and the locations where the water exits the shelf into the interior Arctic Ocean, directly impacts various aspects of the Arctic ecosystem. The three main pathways of Pacific water on the shelf are the western branch into Herald Canyon, the Central Channel branch which flows northward between Herald and Hanna shoals, and the coastal pathway (known as the Alaskan coastal current in summer and fall, Fig. 1). During winter and spring, cold Pacific water flows through Bering Strait into the Chukchi Sea (Woodgate et al., 2005). This water is high in nutrients (Lowry et al., 2015), and consequently helps spur primary production on the shelf (Hill et al., 2005; Arrigo et al., 2014). In late spring and summer, warmer and fresher Pacific waters enter the Chukchi Sea, which are believed to play a significant role in both melting and delaying the formation of pack-ice both on the shelf (e.g. Weingartner et al., 2005) and in the basin (Steele et al., 2010; Woodgate et al., 2012; Brugler et al., 2014). The Pacific water transported across the shelf is also believed to contribute significantly to the reservoir of freshwater offshore in the Beaufort Gyre (e.g. Pickart et al., 2013b).

The coldest type of Pacific water is known as newly-ventilated winter water (WW), which is near the freezing point. This originates from the northern Bering Sea (e.g. Muench et al., 1988), but can also be formed, or further transformed, locally on the Chukchi shelf in polynyas and leads (e.g. Weingartner et al., 1998; Itoh et al., 2012; Pickart et al., 2016; Pacini et al., 2016). As the season progresses, the temperature of this water moderates via solar heating and/or mixing with warmer ambient waters, at which point it is referred to as remnant winter water (RWW). (In the case of extreme warming, the WW can be converted to a weakly stratified summer water mass, Gong and Pickart, 2016.) During summer and early fall, the Chukchi Sea contains two different types of warm Pacific water masses. The first is Alaskan coastal water (ACW) which stems largely from fluvial runoff in the Gulf of Alaska. The second is a combination of Anadyr water and central Bering shelf water, which mix north of Bering Strait (Coachman et al., 1975) to form a water mass known as Bering summer water (BSW).

Recent studies have revised our understanding of the circulation of Pacific-origin water on the Chukchi shelf, including the partitioning of transport between the different flow pathways. While the notion of three main branches remains intact, it is now

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http://dx.doi.org/10.1016/j.pocean.2017.04.005
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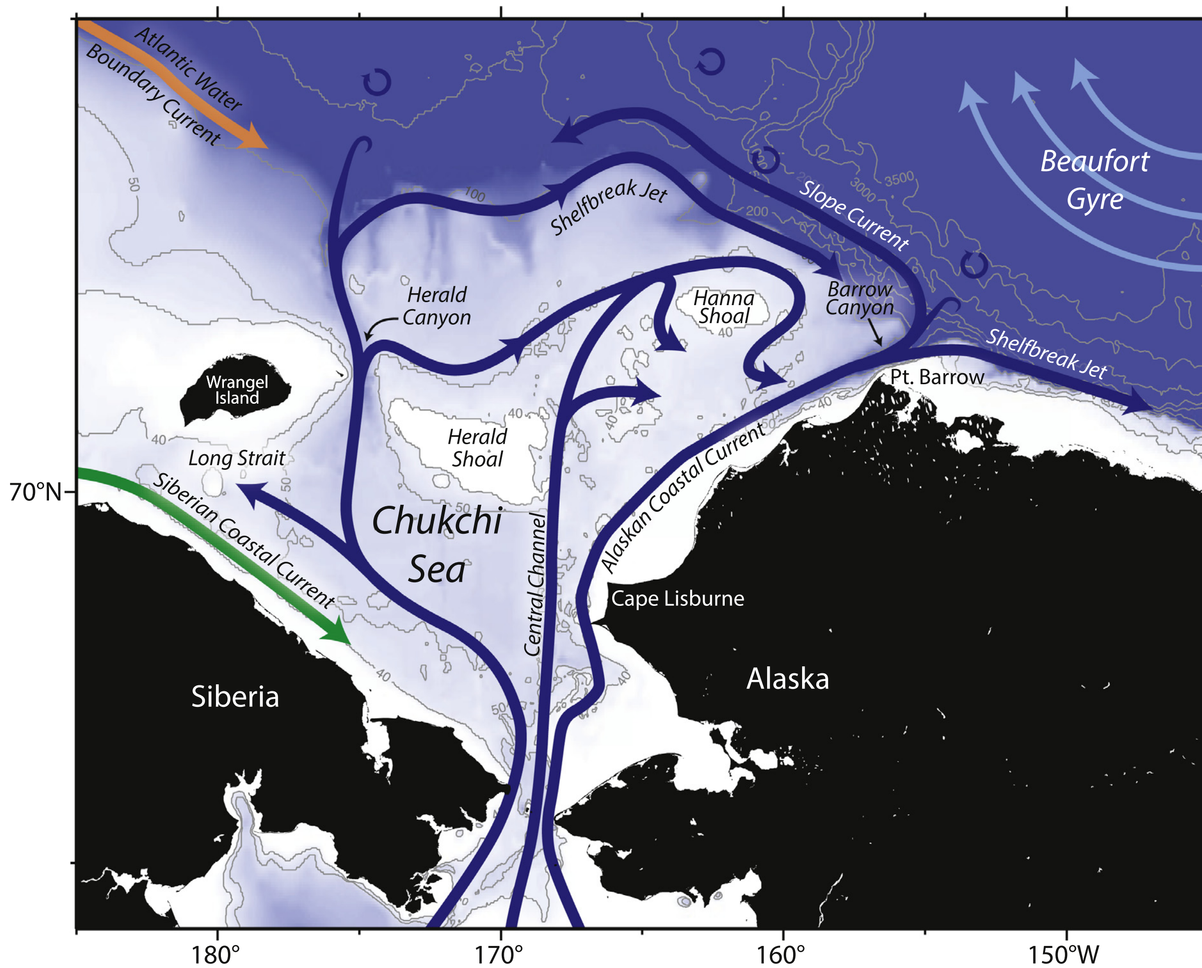

Fig. 1. Revised schematic of the circulation of the Chukchi Sea and western Beaufort Sea from Brugler et al. (2014), including an extended Chukchi shelfbreak jet and the newly-described Chukchi slope current based on the results of this study.

believed that, as the Pacific water progresses across the shelf, it divides into a number of smaller branches or filaments on the northeast part of the shelf (Pickart et al., 2016). Among other things, this impacts the timing of the advection of the high-nutrient WW across the shelf, which in turn has ramifications for primary production (Lowry et al., 2015). With regard to transport, the yearly averaged volume flux in each of the three main flow branches is thought to be comparable (Woodgate et al., 2005). However, recent data suggest that, at least during the summer months, much of the Pacific water entering Bering Strait drains into Barrow Canyon in the northeast part of the shelf (Itoh et al., 2013; Gong and Pickart, 2016; Pickart et al., 2016).

Presently, the mechanisms by which Pacific water exits the Chukchi shelf into the Canada basin—and the geographical locations where this occurs—are not fully understood. It is known that some portion of the outflowing Pacific water ends up as a shelfbreak jet that, in the mean, flows eastward along the edge of the Beaufort Sea (Nikolopoulos et al., 2009). While the configuration of this jet changes seasonally (surface-intensified during late-summer/early-fall, bottom-intensified over the remainder of the year), the current is a year-round feature. There is also evidence of a shelfbreak jet along the edge of the Chukchi Sea, that, in the absence of wind forcing, flows to the east (Pickart et al., 2005; Mathis et al., 2007; Llinás et al., 2009; Pickart et al., 2016). The source of this is believed to be the outflow from Herald Canyon (Pickart et al., 2010). However, the data are largely anecdotal, and there are no published estimates of the transport of this shelfbreak flow.

Notably, the volume transport of Pacific water in the Beaufort shelfbreak jet is only a small fraction of what enters the Chukchi Sea through Bering Strait. Using data from seven moorings deployed across the current from 2002–3, Nikolopoulos et al. (2009) calculated the mean volume flux of Pacific water to be 0.13 ± 0.08 Sv, which is only about 15% of the long-term transport through Bering Strait (0.83 Sv, Roach et al., 1995). Furthermore, while the northward volume flux through Bering Strait has increased in recent years to just over 1 Sv (Woodgate et al., 2012), the eastward transport of Pacific water in the Beaufort shelfbreak jet has decreased to 0.021–0.041 Sv (Brugler et al., 2014). This implies that the jet now only accounts for less than 5% of the Pacific water that enters the Chukchi Sea. (The summertime transport of the Beaufort shelfbreak jet increases to approximately 0.25 Sv (Brugler et al., 2014), still far less than the transport through Bering Strait.)

This begs the question, where and how does the bulk of the Pacific water exit the Chukchi Shelf? As noted above, Woodgate et al. (2005) argued that each of the three main branches transports a similar amount of Pacific water. However, a significant portion of the water in the western branch is diverted to the east just north of Herald Shoal (Pickart et al., 2010), progressing along the northern Chukchi shelf and joining the central branch (Spall, 2007; Pickart et al., 2016, see Fig. 1). This combined central/western branch is then believed to flow into Barrow Canyon, adding to the puzzle regarding the small transport of the Beaufort shelfbreak jet. Brugler et al. (2014) attributed the recent decrease in strength of the Beaufort shelfbreak jet to enhanced easterly winds. This is