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Currents and transport on the Eastern Bering Sea shelf: An integration of over 20 years of data

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ABSTRACT

More than 20 years of data from moorings, satellite-tracked drifters and hydrographic surveys are integrated to provide a comprehensive view of currents and transport on the eastern Bering Sea shelf. The major sources of water onto the eastern Bering Sea shelf are North Pacific water flowing through Unimak Pass and Bering Slope water flowing onto the shelf usually via the canyons that intersect the shelf break. Absolute geostrophic transport through Unimak Pass varies from an average of $0.25 \times 10^6\ m^3\ s^{-1}$ (Sv) in the warm months to 0.43 Sv in the cold months. Flow along the 50-m isobath is weak, with a transport of <0.1 Sv (calculated from current meters) in summer and fall. The transport along the 100-m isobath measured at two locations is more than twice that along 50-m isobaths; in the summer at the Pribilof Islands it was 0.2 Sv and during spring and summer at 60°N the northward geostrophic transport (referenced to the bottom) was 0.31 Sv. Northward transport along the 100-m and 50-m isobaths accounts for approximately half of the transport through Bering Strait. A typical transit time from Unimak Pass to Bering Strait is >13 months and from Amukta Pass to Bering Strait via the Bering Slope Current is >8 months. Consequently, the source of most of the heat transported into the Arctic through Bering Strait is a result of air–sea interactions local to the northern Bering Sea. Analysis of the currents and water properties on the southern shelf indicates that $\sim$50% of the shelf water is exchanged with slope water during October–January each year. This exchange elevates the October mid-shelf average nitrate level from 6 μM to 14–16 μM by the end of January.

1. Introduction

The Bering Sea stretches >1200 km from Bering Strait to the Alaska Peninsula, and 500 km from the coast of Alaska to the continental shelf break. While the shelf break is cut by a number of large canyons, including Bering Canyon in the south and Pribilof and Zhemchug Canyons farther north (Fig. 1), the eastern Bering Sea shelf itself is relatively flat (typical slope of 4×10^{-4}) with a maximum depth of 180 m at the shelf break.

The large horizontal spatial scales, and low bathymetric relief contribute to the relatively weak ($<5\ cm\ s^{-1}$) mean currents over much of the shelf (e.g., Kinder and Schumacher, 1981; Coachman, 1986). Exceptions to the weak flow on the southern shelf include flow along the 50-m and 100-m isobath (Schumacher and Stabeno, 1998; Reed, 1998) and anti-cyclonic tidally rectified circulation around the Pribilof Islands (Kowalik and Stabeno, 1999; Stabeno et al., 2008). North of $\sim$60°N, flow intensifies along the east coast of Siberia forming the Anadyr Current (Kinder et al., 1986), and in the approach to Bering Strait, where the large (0.8 Sv ($1\ Sv = 10^6\ m^3\ s^{-1}$)) volume flux into the Arctic (Woodgate and Aagaard, 2005) is constricted by coastlines.

Much of the background flow field on the northern Bering shelf is set by the net Pacific–Arctic pressure head (Stigebrandt, 1984; Aagaard et al., 2006), which determines the mean northward flow through Bering Strait and the location of the western-intensified Anadyr Current (Kinder et al., 1986). Wind stress drives the dominant portion of the synoptic-scale (35–100 h) variability in the coastal domain and north of 62°N (Danielson et al., 2012a, 2014).

The wind's influence manifests itself through both direct and remote forcing – surface Ekman transport drives coastal convergences and divergences that can trigger continental shelf waves, which rapidly propagate away from the generation region (Danielson et al., 2014). In addition to the magnitude of the wind stress, the

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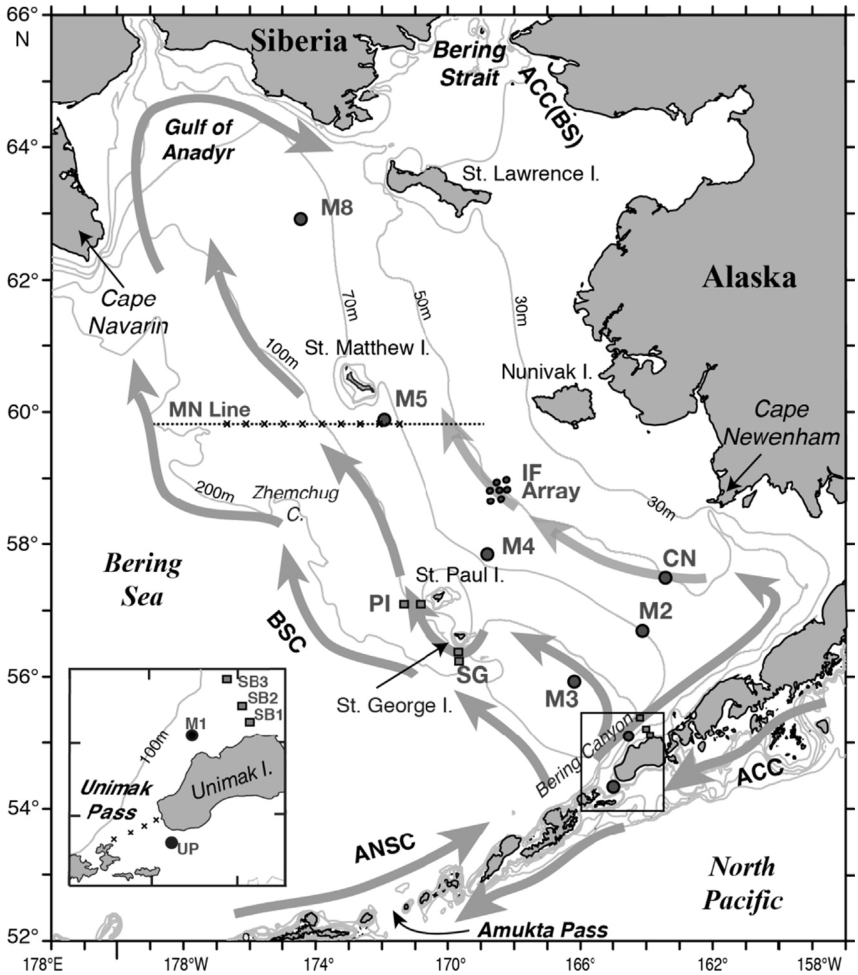

Fig. 1. Map of the eastern Bering Sea shelf showing the place names and mooring sites (circles and squares) listed in Table 1 (e.g. IF, CN, M2). The multiple sites at IF, SB, SG and PI are indicated by smaller symbols. The vectors summarize the findings of this paper. The three primary currents on or near the southern shelf are: the 50-m isobath flow, the 100-m isobath flow, and the Aleutian North Slope Current/Bering Slope Current. Each hydrographic station in Unimak Pass (insert) and on the MN transect are indicated by "x".

relative orientation of the wind with respect to the orientation of the shelf break and coastline is critical for determining the response of the shelf currents to wind forcing (Danielson et al., 2012a, 2012b). Together, these determine how the synoptic wind-forced flows modify the mean flow field.

Aagaard et al. (2006) estimated that the source of approximately half of the flow on the Bering Sea shelf is the Gulf of Alaska's (GOA) Alaska Coastal Current (ACC). The ACC originates at the head of the GOA and flows southwestward along the southern coast of the Alaska Peninsula. Average ACC transport in the northern GOA is ~1 Sv of which ~30% enters the Bering Sea through Unimak Pass, providing relatively warm, fresh and nutrient-poor water to the southeastern Bering Sea shelf (Stabeno et al., 2002, in press; Aagaard, et al., 2006). This water mixes with slope water from Bering Canyon and then most of it eventually flows northward along either the 50-m or 100-m isobath (Reed, 1998; Stabeno et al., 2002). While flows concentrated along the 50-m and 100-m isobaths have long been known (e.g., Kinder and Schumacher, 1981; Coachman, 1986), measurements providing estimates of the magnitude of transport have been limited and the continuity of these flows has not been examined.

This paper uses extensive data sets from moorings, satellite-tracked drifters and hydrographic transects collected over a 20+ year period to examine currents on the eastern Bering Sea shelf. The goal is to spatially integrate our knowledge of flow on the shelf including transport along the 50-m and 100-m isobaths, transit times and the organization of the weak flow over the middle shelf. Using a map of currents derived using >400 trajectories from satellite-tracked drifters, estimates of how long it takes a parcel of water to transit from Aleutian Islands to Bering Strait are made. Transports through Unimak Pass, and along the 50-m and 100-m isobaths (two of the primary currents on the Southeastern Bering Sea shelf) are then derived. The organization of the weak flows on the middle domain is then examined. Utilizing the ~20 years of data collected at M2, estimates of nutrient replenishment on the southern shelf are calculated. Section 4 provides a summary of the results and conclusions.

2. Data and methods

2.1. Sea ice

Two sources of sea-ice data were used. The first source was the National Ice Center (NIC; http://www.natice.noaa.gov/), with data available from 1972 to 2005; the second source was the Advanced Microwave Scanning Radiometer EOS (AMSR; http://nsidc.org/data/amsre/) with data available from 2002 to 2014. These two data sets cover the entire period in which high quality data of sea-ice extent and areal concentration are available.

NIC data from 1972 to 1994 are from their publically available CD of data on a 0.25° grid. Later data (1995–2005) were

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