Progress in Oceanography 132 (2015) 305–317

Contents lists available at ScienceDirect

Progress in Oceanography

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

Baffin Island and West Greenland Current Systems in northern Baffin Bay

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ARTICLE INFO

Article history:
Available online 19 April 2014

Keywords:
Circulation
Arctic
Geostrophy
Baffin Bay
Greenland

ABSTRACT

Temperature, salinity, and direct velocity observations from northern Baffin Bay are presented from a summer 2003 survey. The data reveal interactions between fresh and cold Arctic waters advected southward along Baffin Island and salty and warm Atlantic waters advected northward along western Greenland. Geostrophic currents estimated from hydrography are compared to measured ocean currents above 600 m depth. The Baffin Island Current is well constrained by the geostrophic thermal wind relation, but the West Greenland Current is not. Furthermore, both currents are better described as current systems that contain multiple velocity cores and eddies. We describe a surface-intensified Baffin Island Current seaward of the continental slope off Canada and a bottom-intensified West Greenland Current over the continental slope off Greenland. Acoustic Doppler current profiler observations suggest that the West Greenland Current System advected about 3.8 ± 0.27 Sv (Sv = 10^6 m^3 s^{-1}) towards the northwest at this time. The most prominent features were a surface intensified coastal current advecting 0.5 Sv and a bottom intensified slope current advecting about 2.5 Sv in the same direction. Most of this north-westward circulation turned southward in the Baffin Island Current System. The Baffin Island system was transporting 5.1 ± 0.24 Sv to the south-east at the time that includes additional contributions from Nares Strait to the north (1.0 ± 0.2 Sv) and Lancaster Sound to the east (1.0 ± 0.2 Sv). Net freshwater fluxes were 72 and 187 mSv for the West Greenland and Baffin Island Currents, respectively. Empirical uncertainty arises from unknown temporal variations at weekly time scales and pertubations introduced by unresolved eddies. Eddies with 10 km horizontal and 400 m vertical scales were common and recirculated up to 1 Sv. Our 2003 observations represent conditions when the North-Atlantic Oscillation index (NAO) was close to zero. Analysis of historical hydrographic data averaged along isobaths during NAO-positive years reveals a baroclinic circulation in Baffin Bay more intense than 2003 with stronger southward flow of fresher Arctic waters along Baffin Island and stronger northward inflow of saltier Atlantic waters along Greenland. During negative NAO years this cyclonic circulation weakens as evidenced by a 1979 synoptic survey of the hydrography along Baffin Island.

Introduction

Climate change over the North-Atlantic Ocean causes rising coastal sea level along the US eastern seaboard (Sallenger et al., 2012) and more varied weather (Francis and Vavrus, 2012) which combine to increase the risk of extreme flooding (Lin et al., 2012). Enhanced Arctic freshwater discharge (Serreze et al., 2006), melting of polar ice sheets (Shepherd et al., 2012), thinning and retreating glaciers (Münchow et al., 2014), and the dramatic decline of Arctic summer sea ice (Kwok and Rothrock, 2009) all provide evidence of change and positive feedbacks. We here focus on the flux of relative fresh ocean waters from the polar ocean to the south. We use the North-Atlantic Oscillation (NAO) index of Hurrell and Deser (2009) as a metric to place detailed observations from 2003 into a larger climatological context. First, however, we introduce our study area to the west of Greenland via a historical review of available data that relates to circulation.

On April 30, 1873 the sealer *Tigress* working off coastal Labrador plucked 12 men, 4 children, and 2 women off an ice floe. Fed by two Inuit hunters they had floated on ice for 6 months after the *USS Polaris* abandoned them in Nares Strait to the north of Baffin Bay (Berton, 1988). Inadvertently, they also mapped the surface circulation of western Baffin Bay, traveling on ice floes almost 3000 km at an average speed of about 0.2 m/s. Less fortunate were the 1502 passengers who perished aboard the *RMS Titanic* on April

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http://dx.doi.org/10.1016/j.pocean.2014.04.001
0079-6611/

15, 1912 when she was sunk by an iceberg off Newfoundland. Most likely, this iceberg originated from Greenland or northern Canada taking a path similar to that of the Polaris survivors. The dramatic loss of life in 1912 led to the formation of the International Ice Patrol that was charged with monitoring and predicting the location of ice and icebergs as they enter the busy sea lanes of the North Atlantic Ocean.

Starting with the 1928 Marion expedition, LCDR Eward H. "Iceberg" Smith of the US Coast Guard conducted pioneering studies of the frigid waters between Canada and Greenland that established the generally southward discharge of ice, icebergs, and buoyant surface waters from Baffin Bay via Davis Strait into the North Atlantic. Early hydrographic observations such as those taken during the Marion (Smith, 1931) and Gothaab (Kiilerich, 1939) expeditions in 1928 mapped water temperature and salinity of Baffin Bay, Davis Strait, and the Labrador Sea. Smith (1931) used these data to estimate circulation via geostrophy to predict iceberg motions. Furthermore, Smith (1931) developed a proxy for the North Atlantic Oscillation (NAO) to predict the number of icebergs emanating from Baffin Bay to impact shipping south of Newfoundland via a regression of past observations. He discovered that years of positive NAO correspond to higher iceberg counts off Newfoundland the following year. Dunbar (1951) collated early Canadian survey data to map water properties of Baffin and Hudson Bay, Labrador, and western Greenland.

Two main circulation features emerge from past hydrographic, modeling, and mooring studies of Baffin Bay. A cold and buoyant near-surface Baffin Island Current advects Arctic ice, waters, and properties southward towards Davis Strait (LeBlond, 1980; Fissel et al., 1982; Tang et al., 2004) and a warm and salty subsurface West Greenland Current advects Atlantic water northward towards Cape York in northern Baffin Bay (Bourke et al., 1989; Muench, 1971). A summary and synthesis of mostly Canadian mooring and hydrographic efforts in Baffin Bay from 1978 through 1989 is given by Tang et al. (2004) while Cuny et al. (2005) provides a similar synthesis for Davis Strait. The net volume flux out of Davis Strait is given as 2.6 ± 1.0 Sv by Cuny et al. (2005) who use current meter mooring records below 150-m and geostrophically estimated velocity shear above this depth. Measurements from a year-long 2004/05 deployment resulted in 2.3 ± 0.7 Sv which includes directly measured currents both in the upper 100-m of the water column and on the shelves (Curry et al., 2011). Using only hydrographic observations, Muench (1971) estimate the net transport across a section of northern Baffin Bay to vary between 1.5 and 2.7 Sv which agrees with the Davis Strait estimate. Ingram et al. (2002) reviews earlier work in northern Baffin Bay in relation to the North Water polynya (Dumont et al., 2009) and references Addison (1987) who distinguishes Baffin Island Current volume flux contributions to consist of 0.3 Sv from Nares Strait, 0.3 Sv from Jones Sound, 1.1 Sv from Lancaster Sound, and 0.5 Sv from a recirculating West Greenland Current to give a total southward transport of 2.3 Sv. These values represent snapshots based on the generally untested assumptions that the flows at northern passages are both baroclinic and geostrophic. Rudels (2011) fully exploits these assumptions to derive volume and freshwater flux estimates for the entire region to the west of Greenland as well as sensitivities to additional freshwater inputs from Greenland's ice sheet.

These earlier measurements provide first descriptions of the larger basin-wide circulation features and ice drift climatology, however, they do not always resolve dynamically relevant vertical and horizontal scales of motions associated with both steeply sloping topography and baroclinic eddies. Hence it is unclear that geostrophically estimated volume fluxes associated with the cyclonic circulation are adequately resolved at both (small) spatial and (long) temporal scales. For example, hydrographic observations from which to estimate geostrophic shear do not resolve seasonal cycles. These cycles vary substantially across Davis Strait and Baffin Bay in both amplitude and phase (Zweng and Münchow, 2006) on account of different time histories of forcing of the West Greenland and Baffin Island Currents, respectively. Furthermore, the assumption of geostrophic balance is rarely tested and can break down near topography (Rabe et al., 2012).

We here discuss and analyze ocean data from the most recent expedition of the US Coast Guard to northern Baffin Bay in 2003. We made direct velocity measurements along several sections using a vessel-mounted acoustic Doppler current profiler (ADCP). These data allow evaluation of geostrophically estimated currents and, more importantly, they demonstrate mesoscale spatial variability. Enhanced delivery of fresher and colder waters from the Arctic along the shelves and slopes of Baffin Island and Labrador contributes to vertical stratification as far south as the Gulf of Maine and the Mid-Atlantic Bight where interannual ecosystem variability appears to correlate with upstream conditions (Greene et al., 2008). While our present study cannot address seasonal cycles of the salinity, temperature, and density for lack of sufficient data, we do test the assumption of geostrophy and investigate the spatial scales of velocity, salinity, and density fields in northern Baffin Bay. Our synoptic observations from the 2003 summer surveys reveal that the cyclonic circulation exhibits substantial spatial variability in the form of eddies generated via instabilities near sloping topography.

Study area and data

Baffin Bay is a semi-enclosed, seasonally ice-covered basin between northern Canada and Greenland. It is linked to the Atlantic Ocean across a 640 m deep sill in Davis Strait and to the Arctic Ocean via Lancaster Sound, Jones Sound, and Nares Strait with sill depths of about 125, 190, and 220 m, respectively (Melling et al., 2008). Fig. 1 shows locations. These channels and straits vary in minimal width from 320 km (Davis Strait), 65 km (Lancaster Sound), to 25 km (Nares Strait). They thus are generally wider than the local internal deformation radius that is about 10 km (Münchow et al., 2006). Hence even the narrowest channel can accommodate opposing baroclinic flows on each side (LeBlond, 1980). Baffin Bay contains wide and gently sloping shelf areas off Greenland in the east and narrower, more steeply sloping shelves off Baffin Island in the west. All shelves are disrupted by deep troughs and canyons that connect the continental slope and basin to the ice caps via fjords in mountainous terrain.

We primarily use data from the 2003 expedition of the USCGC Healy to northern Baffin Bay and Nares Strait. This ship contains a 75 kHz phased array ADCP that provides continuous profiles of instantaneous horizontal velocity along the ship track from about 20 m below the sea surface to about 300–600 m depth. For absolute positioning we use the ships's military grade p-code differential GPS as well as an AshTech GPS that also provides accurate heading, pitch, and roll information. For details on calibration, performance, and processing, we refer to Münchow et al. (2006) and Münchow et al. (2007) where the system, data processing, and results from Nares Strait north of 78 N are discussed. We note that data are obtained in 15 m vertical bins every 2 min. These data are further averaged in space along the track into roughly 3-km horizontal bins for display as sections. Tidal currents are initially removed using predictions from the barotropic model of Padman and Erofeeva (2004) at the location and at the time of our measurements, but prove insufficient off Baffin Island on account of large vertical variations of tidal currents that are not contained in the barotropic model. Instead, we determine tidal ellipse parameters at each vertical bin independently using the method of least