

# Correlation of a strong Alaska Coastal Current with the presence of beluga whales *Delphinapterus leucas* near Barrow, Alaska

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**ABSTRACT:** Oceanographic features and physical processes in the ocean can create regions where prey, and therefore predators, may accumulate. Beluga whales *Delphinapterus leucas* are the most numerous cetacean in the Arctic. In the Alaskan Beaufort Sea, they prefer continental slope habitat in summer and autumn, presumably because such areas provide enhanced foraging opportunities. Passive acoustic detections of beluga whale calls, current velocity measurements, historical wind records, and 29 yr of beluga whale observations from aerial surveys were used to explore the hypothesis that the foraging success of beluga whales in Barrow Canyon and along the western Beaufort Sea slope is enhanced when the Alaska Coastal Current (ACC) is well-developed and flows east-northeastward and is diminished when the flow of the ACC and its shelf break extension are reversed. Aerial sightings of beluga whales, average observed beluga whale group size, and hours with whale vocalizations were more common when the ACC was well-developed and flowed east-northeastward. When the ACC flow is strong, it is separated from Arctic basin waters by a well-defined front that promotes aggregation of prey species. We speculate that the greater numbers of animals per group sighted and hours with recorded vocalizations may be indicative of enhanced foraging opportunities for beluga whales.

**KEY WORDS:** Beluga whale · *Delphinapterus leucas* · Alaska Coastal Current · Aerial survey · Passive acoustic monitoring

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## INTRODUCTION

The distribution of marine predators is influenced by physical processes and oceanographic features that combine to create fronts, eddies, and other relatively ephemeral regions where prey may be aggregated (e.g. Hunt 1991, Genin 2004, Bost et al. 2009, Costa et al. 2010). Many of the studies that examine such associations are based on correlating visual sighting, catch data, or satellite tracks of animals, whether fish, birds, or marine mammals, with satellite- or shipboard-derived measures of the environment (e.g. Russell et al. 1999, Croll et al. 2005, Zainuddin et al. 2006). The scales over which these

correlations have been made can be quite fine in space and time (meters and minutes; e.g. Lea & Dubroca 2003) or very broad (100s of kilometers and months; e.g. Stafford et al. 2009).

Demonstrating the linkages between animals and their environment can be especially challenging at high latitudes, where poor weather and remote habitat can make navigation and access to animals difficult, and cloud cover can adversely affect the acquisition of accurate satellite data. Technological advances in retrievable animal-borne data loggers have facilitated tremendous advances in understanding how pinniped and seabird species exploit their environment, including polar regions (Ream et al.

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2005, Bailleul et al. 2007, Cotté et al. 2007). These animals reliably spend part of their year out on land, at nesting sites or rookeries, and return to the same location, where they can be handled, so archival tags can be attached and then recovered after many months at sea. Such technology is more limited for cetaceans as tag attachment and placement is more difficult, tag durations are more variable, and the amount of data that can be transmitted is restricted. Therefore, understanding how Arctic predators capitalize on potential foraging opportunities in a dynamic environment requires a different approach.

One of the top predators in the Arctic is the beluga whale *Delphinapterus leucas*. Beluga whales are the most numerous cetacean in the Arctic. In northern Alaskan waters, they migrate north and east into the Beaufort Sea from wintering grounds in the Bering Sea to feed in spring, and they return in autumn (Seaman et al. 1982, Frost & Lowry 1984). During summer and autumn, belugas are broadly distributed in the Chukchi and Beaufort Seas and may travel far north into thick ice, but in general, they are found in waters over the upper continental slope as well as in deeper water in the Beaufort Sea (Clarke et al. 1993, Moore et al. 2000, Richard et al. 2001b, Suydam et al. 2005).

Beluga whales are a highly vocal species. While their echolocation frequencies are ultrasonic (30 to 120 kHz; Au et al. 1987), their frequency- and amplitude-modulated calls range from 2 kHz to 20 kHz and are audible to humans (Sjare & Smith 1986a, Belikov & Bel'kovich 2003). These vocalizations can be detected by hydrophones up to 8 km away in Arctic waters (Delarue et al. 2011), and the number of vocalizations recorded is positively correlated to the number of whales present (Simard et al. 2010). Beluga whales are more vocal when milling or socializing, behaviors that may indicate foraging, than when traveling (Sjare & Smith 1986b, Karlsen et al. 2002), and they have been documented to whistle when feeding (Mymrin et al. 1999).

The diet of belugas varies geographically and seasonally, and preferred prey can range in size from shrimp to salmon (Huntington et al. 1999, Mymrin et al. 1999). In the northern Bering and Chukchi Seas, the diet includes Arctic char *Salvelinus alpinus*, Arctic cod *Boreogadus saida*, salmon *Oncorhynchus* spp., and herring *Clupea pallasii* as well as numerous other fish species (Huntington et al. 1999). Although less is known about the diet of belugas in the western Beaufort Sea, Arctic cod is thought to be the most important food item, particularly from spring through autumn (Seaman et al. 1982, Frost & Lowry 1984, Moore et al. 2000, Loseto et al. 2009). Beluga whales,

like many marine predators (e.g. sea birds, pinnipeds, fish, and other cetaceans) are known to feed along oceanographic fronts, whether tidally, upwelling-, or density-driven (cf. Kinder et al. 1983, Russell et al. 1999, Moore et al. 2000, Bost et al. 2009).

Moore et al. (2000) reported that beluga whales selected continental slope (201 to 2000 m) habitat in the western Beaufort Sea in summer and autumn, habitat that is associated with current flow through Barrow Canyon and along the Beaufort shelf break. In this area, the dominant circulation feature is the Alaska Coastal Current (ACC; Paquette & Bourke 1974, Mountain et al. 1976) and its eastward extension, the Beaufort shelf break jet (Pickart 2004, Nikolopoulos et al. 2009). When Barrow area winds are weak to moderate, the ACC flows east-northeastward along the southern flank of Barrow Canyon. Moderate to strong winds from the eastern quadrant slow or reverse the flow of the ACC (Weingartner et al. 1998, Okkonen et al. 2009) and its shelf break extension (Nikolopoulos et al. 2009). During the summer and early autumn, the ACC carries relatively warm, fresh Alaska Coastal Water (ACW) that, under weak or downwelling-favorable winds, can occasionally extend to depths of ~90 m. Cold, saline Pacific Winter Water (PWW) is found in Barrow Canyon and over the western Beaufort slope in all seasons. During summer and early autumn, PWW lies adjacent to and beneath the ACW, creating a strong hydrographic front along the seaward edge of the ACC (Pickart 2004, Nikolopoulos et al. 2009).

Here, we use a multi-disciplinary approach to compare 2 yr of passive acoustic detections of beluga whale calls with concurrent current velocity measurements, shipboard survey oceanographic data, historical wind records, and beluga observations from aerial surveys to explore the hypothesis that potential foraging opportunities for beluga whales in Barrow Canyon and along the western Beaufort slope are enhanced during late summer and early autumn when the ACC is well-developed and flows east-northeastward and are diminished when the flow of the ACC and its shelf break extension are reversed.

## MATERIALS AND METHODS

### Mooring data

A single taut-line oceanographic mooring, instrumented with an AURAL hydrophone package (<http://multi-electronique.com/pages/auralm2en.htm>) with an HTI-96-min hydrophone (sensitivity of -164 dB

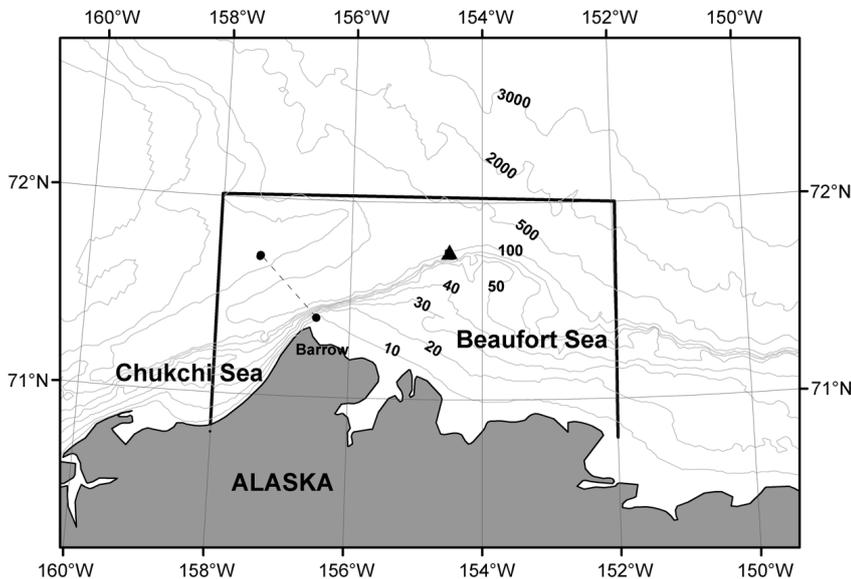


Fig. 1. Mooring location from 2008 to 2010 ( $\blacktriangle$ ). Aerial survey sightings of beluga whales from 1982 to 2010 were within the box, and the shipboard survey transect from August 2006 and 2007 is shown as a dashed line. Bathymetry is shown in 10 m contours until the shelf break, where it is shown in 100 m contours

re  $1\text{V}/\mu\text{Pa}$ , flat frequency response from 2 Hz to 30 kHz), a Teledyne RDI 307 kHz acoustic Doppler current profiler (ADCP), a Seabird 37 conductivity-temperature (CT) sensor, and a string of HOBO temperature sensors, was deployed near  $71.75^\circ\text{N}$ ,  $154.5^\circ\text{W}$  in August 2008 (Fig. 1). The ADCP and CT sensor were used to measure current velocity and identify water mass characteristics, respectively, at the mooring location. The mooring was recovered in late July 2009. The ADCP stopped logging in December 2008 due to a faulty cable connected to the external battery pack. The instruments were replaced, and the mooring was redeployed at the same location on 30 July 2009. The mooring was subsequently recovered in September 2010. However, both the AURAL and ADCP stopped logging in mid-August 2010 after exhausting their batteries.

The hydrophone operated on a 30% duty cycle (9 min of every 30 min) and recorded from 0.1 to 4.1 kHz from August 2008 to August 2010. A spectrogram of each data file was visually scanned for the presence of beluga whale vocalizations using the program *Ishmael* (FFT 1024, 50% overlap, Hann window; Mellinger 2001). Over 5200 h of data over 2 yr were examined visually. Each hour that had  $\geq 1$  beluga whale vocalization was noted, and a daily sum of hours

with vocalizations was recorded. The ADCP acquired velocity measurements within the water column in 1.0 m bins at 30 min intervals. The current velocities (direction and speed) were vertically averaged between 90 and 10 m depth at each time step, and daily averages of these water-column velocities were computed for comparison with the hydrophone data. Data records from the AURAL hydrophones and ADCPs are summarized in Table 1.

### Environmental data

Wind speed and direction measurements at Barrow were obtained from the Climate Monitoring and Diagnostics Laboratory (<ftp.cmdl.noaa.gov/met/hourlymet/brw/>) for years 1982 to 2006 and from the Atmospheric Radiation Measurement website ([www.archive.arm.gov](http://www.archive.arm.gov)) for years 2007 to 2010. Time series of daily-averaged wind speed and direction were generated for use as the working data sets.

### Aerial survey data

Beluga whales were counted during line-transect aerial surveys conducted from September to October 1982 to 2010 as part of the Bowhead Whale Aerial Survey Project (BWASP; Clarke et al. 2011). The Barrow study area ( $70.8^\circ$  to  $72^\circ\text{N}$ ,  $152^\circ$  to  $158^\circ\text{W}$ ; Fig. 1) represents a subset of the BWASP data; the surveys were conducted annually over a much larger geographic area, so the survey effort in the study area varied among years (ranging from 2 to 18 surveys per year in the study area). Aerial surveys were conducted in the study area on 265 different dates over 29 yr. Beluga whales were observed dur-

Table 1. Mooring deployment and data acquisition dates

Mooring deployment dates	AURAL and CTD data acquisition dates	ADCP data acquisition dates
05:30 UT, 09 August 2008 to 02:30 UT, 28 July 2009	16 August 2008 to 28 July 2009	09 August 2008 to 07 December 2008
03:15 UT, 30 July 2009 to 17:00 UT, 12 September 2010	02 August 2009 to 15 August 2010	30 July 2009 to 17 August 2010

ing surveys conducted on 130 of these dates. Surveys were generally conducted when cloud ceilings were  $>335$  m, visibility was  $>3$  km, and the Beaufort wind scale was less than or equal to Beaufort 5. Sighting data were limited solely to those collected while on transect. Surveys were flown in Grumman Turbo Goose, de Havilland Twin Otter, or Aero Commander aircraft at 305 to 460 m altitude, maintaining a speed of 220 to 300 km h<sup>-1</sup>. From 1982 to 2008, transects were oriented approximately north-south and located between randomly determined start and end points. The transect design was altered in 2009 for the area 157 to 158°W, with transects positioned perpendicular to the coast. Two primary observers maintained a continuous watch for marine mammals, one on each side of the aircraft, while a third observer/data recorder entered data into a computer for each sighting and whenever survey conditions changed or every 5 to 10 min. A computer interfaced with a custom built aerial survey program and portable navigation system (global navigation system [GNS, or GPS]) routinely logged effort, time, location, and number of animals sighted. Additional details of the survey protocol are provided elsewhere (e.g. Clarke et al. 2011).

### Shipboard survey data

Oceanographic surveys conducted during August 2006 and 2007 from the coastal research vessel RV 'Annika Marie' acquired hydrographic and current velocity data across Barrow Canyon to measure *in situ* oceanographic conditions of both strong and weak ACC frontal systems intersecting the vessel survey track line.

An Acrobat (Sea Sciences) towed vehicle, equipped with a Seabird SBE 49 conductivity-temperature-depth (CTD) recorder, was towed behind the vessel and acquired high-resolution measurements of temperature and salinity across the canyon in the upper water column (to ~45 to 50 m depth). The Acrobat's vertical excursions, executed at typical towing speeds of  $\sim 3$  m s<sup>-1</sup> ( $\sim 6$  knots), provided water column profiles at a horizontal spacing of  $\sim 1$  km. At the same time, a Teledyne RDI 307 kHz downward-looking ADCP with bottom tracking was towed alongside the vessel to acquire water column profiles of current speed and direction to a depth of  $\sim 130$  m. The water column velocities were acquired at 3 m vertical resolution within the canyon. Spatial averaging of the towed ADCP data resulted in  $\sim 0.35$  km horizontal spacing of the water column velocities. A Seabird 19plus CTD

acquired surface-to-bottom profiles of temperature and salinity in August 2007 to provide hydrographic measurements in water depths greater than those sampled by the Acrobat-borne CTD (individual CTD casts were not conducted in the 2006 crossing of Barrow Canyon). Spacing between successive CTD casts was  $\sim 6$  km and, as such, only coarsely resolved the deep horizontal hydrographic structure within Barrow Canyon. These cross-canyon hydrographic (Acrobat and individual cast) data were interpolated to a regular 1 km horizontal by 1 m vertical grid.

### Statistical analyses

To determine if wind was a suitable proxy for current, the time series of daily-averaged, along-isobath currents (65° to 245° True [T]) derived from the 2008 to 2010 mooring ADCP data was correlated with the coincident time series of daily-averaged winds using a linear least squares fit to the projected wind and 1 d-lagged projected current pairs. This allows a longer term comparison between beluga whale occurrence and current direction by including the 29 yr record of BWASP beluga whale aerial survey observations.

Daily beluga whale acoustic detections (h d<sup>-1</sup>) and aerial sightings (number of animals per group) were divided into 2 groups based on the daily values of projected wind velocity ( $>6.4$  m s<sup>-1</sup> and  $<6.4$  m s<sup>-1</sup>) and principal current directions (convergent: 50° to 80°T, and divergent: 250° to 280°T). These data accounted for 265 of 307 available days. The remaining 42 d were not used in the analysis. The resulting data had unequal variances and were not normally distributed; therefore, they were rank transformed, and *t*-tests were used on the transformed data to test the null hypotheses that (1) the mean number of beluga whales per group sighted on aerial surveys and (2) the mean number of hours per day with beluga whale calls were the same whether the ACC was flowing east-northeastward or reversed.

## RESULTS

### Correlation between beluga whale vocalizations and Alaska Coastal Current velocities

Beluga whale calls were detected from mid-April until early November in both deployment periods (Fig. 2). Springtime detections are likely from animals that are migrating northward from wintering grounds in the Bering Sea. In mid-autumn, beluga

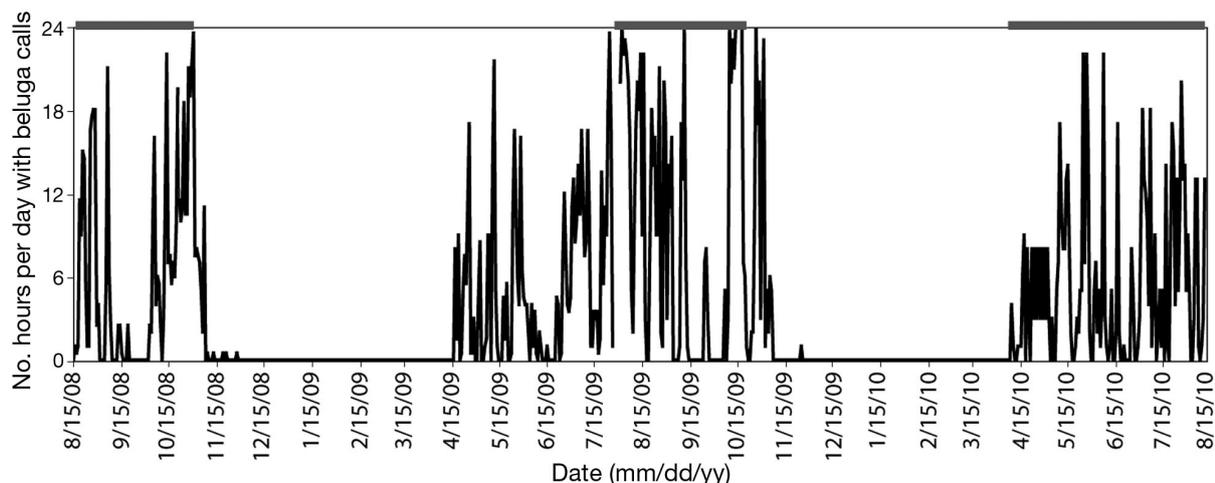


Fig. 2. Time series of hours per day with at least 1 beluga whale vocalization. Gray bars indicate the 3 periods when concurrent oceanographic data were available (see Table 2)

whale detections declined markedly, suggesting that the onset of winter ice formation may be a cue to migrate southward.

Owing to the absence of beluga calls during winter and the lack of current-meter data from December 2008 through July 2009, there were 3 periods (16 August to 8 November 2008, 2 August to 7 November 2009, and 14 April to 15 August 2010) totaling 307 d during which there were coincident daily records of beluga vocalizations and average currents at the mooring location (Table 2). Here, we excluded days in November after and including the first day for which there were no vocalizations. A comparison of hours with beluga vocalizations with coincident ADCP-measured current velocities at the mooring location shows that there were significantly more hours with vocalizations when the ACC was flowing to the east-northeast, particularly during the open water months, than when it was reversed ( $p$ -value = 0.005, 1-tailed  $t$ -test; Fig. 3).

This relationship between hours with beluga vocalizations and current direction in Barrow Canyon is

Table 2. For each of the 3 time periods in the 2008 to 2010 record, the time series of daily-averaged, along-isobath currents ( $65^\circ$  True [T]) were correlated with concomitant time series of daily-averaged winds. For the correlations, the current lagged the wind by 1 d for each period

Period	n	Correlation ( $r^2$ )	Wind direction axis of maximum correlation ( $^\circ$ T)
2008, 16 Aug to 08 Nov	85	0.44	$24^\circ - 204^\circ$
2009, 02 Aug to 07 Nov	89	0.54	$49^\circ - 229^\circ$
2010, 14 Apr to 15 Aug	124	0.52	$33^\circ - 213^\circ$

shown in Fig. 4. There are 2 principal circulation modes during which beluga whale vocalizations were recorded. The dominant mode is associated with currents flowing toward the east-northeast and occurs  $\sim 67\%$  of the time (207 of 307 daily-averaged currents). The most prevalent of these currents are directed ENE (toward  $65 \pm 5^\circ$ T), roughly flowing along the isobaths. The second mode is associated with current reversals to the west, occurring  $\sim 19\%$  (58 of 307) of the time (Fig. 4a). When the ACC flows to the east-northeast, beluga vocalizations are recorded, on average, between 7 and 10  $\text{h d}^{-1}$  (mean  $\pm$  standard error [SE]:  $8.4 \pm 0.56$ ,  $n = 207$ ), and when the current is reversed to the west, beluga vocalizations are recorded, on average, between 4 and 6  $\text{h d}^{-1}$  ( $4.7 \pm 0.72$ ,  $n = 58$ ; Fig. 4b).

#### Relationship between wind speed and direction and ACC flow direction

During the mooring deployment periods listed in Table 2, the principal currents ( $65^\circ$  to  $245^\circ$ T) were well-correlated with the preceding-day winds projected along the southwest-northeast axis (mean axis =  $36^\circ$  to  $216^\circ$ T), and as such, the projected winds are a reasonable proxy for the ACC velocity at the mouth of Barrow Canyon. The linear least squares fit of the currents to the projected winds indicated that the current ( $C$ ) responded to the projected wind ( $W$ ) as follows:

$$C = 0.052W + 0.334 \quad (1)$$

for which  $R^2 = 0.50$ . Setting the current speed to zero in Eq. (1) and solving for the wind speed indicates



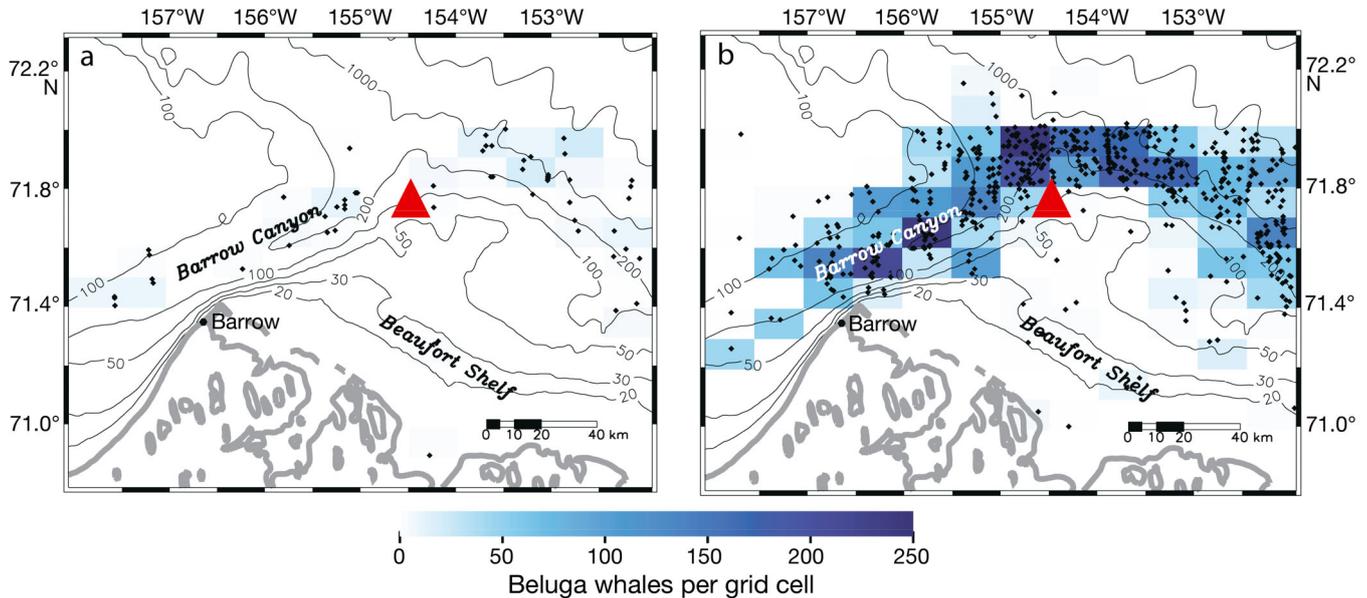


Fig. 5. Locations (◆) and aggregate numbers of beluga whales (shaded grid cells) observed during aerial surveys (1982 to 2010) following (a) winds having a moderate-to-strong ( $>6.4 \text{ m s}^{-1}$ ) component from the northeast and (b) winds from the southwest or winds having a weak-to-moderate ( $<6.4 \text{ m s}^{-1}$ ) component from the northeast. ▲: mooring location

ceding day's wind conditions promoted a northeastward-flowing ACC (Fig. 5b). The differences in group sizes between these 2 wind conditions were statistically significant, with significantly more whales per group when wind conditions promoted a northeastward-flowing ACC ( $p = 0.004$ , 1-tailed  $t$ -test). These proxy-based results are not only proportionately similar to the calling rate-current speed/direction results but also extend those results in time and beyond the vicinity of mooring location. Collectively, these results suggest that beluga whale group sizes are roughly twice as large in Barrow Canyon and along the shelf break in western Beaufort Sea when the ACC flows east-northeastward compared to when flow in Barrow Canyon is reversed.

#### Oceanographic conditions and convergent currents

Shipboard measurements of oceanographic conditions associated with a well-developed, northeastward-flowing ACC near Point Barrow are shown in Fig. 6a,b. Average winds are weak and from the north at  $0.7 \text{ m s}^{-1}$ . ADCP-measured current vectors show that the width of the ACC extends across much of Barrow Canyon. Strong, cross-isobath convergent currents occurring in association with inclined isopycnals above the southeastern flank of the canyon indicate the presence of a strong front. In contrast, Fig. 6c,d show oceanographic conditions associated

with weaker, reversed currents in Barrow Canyon. Average winds are from the northeast at  $7.5 \text{ m s}^{-1}$ , strong enough to reverse the flow of the ACC. Although hydrography was only acquired in the upper portion of the water column, the more horizontally oriented isopycnals and weaker convergent currents indicate the absence of a strong front.

#### DISCUSSION

Based on both passive acoustic and aerial survey visual data, the number of hours with vocalizations, number of beluga whales, and average beluga whale group size in Barrow Canyon and along the western Beaufort slope appear to respond to changes in the flow direction of the ACC and associated frontal structure. In general, the ACC flows to the east-northeast and has well-defined frontal structure when winds are weak or from the southwest. Moderate-to-strong winds from the northeastern quadrant cause the ACC to be displaced seaward from the southern flank of Barrow Canyon, the flow to reverse to the west or southwest, and the associated front to dissipate. On days when the ACC and associated frontal structure were strong, there were, on average, twice as many hours with beluga calls (8.4 h) than during days when the current reversed and frontal structure dissipated (4.7 h). Similarly, the average size of beluga whale groups observed during aerial surveys

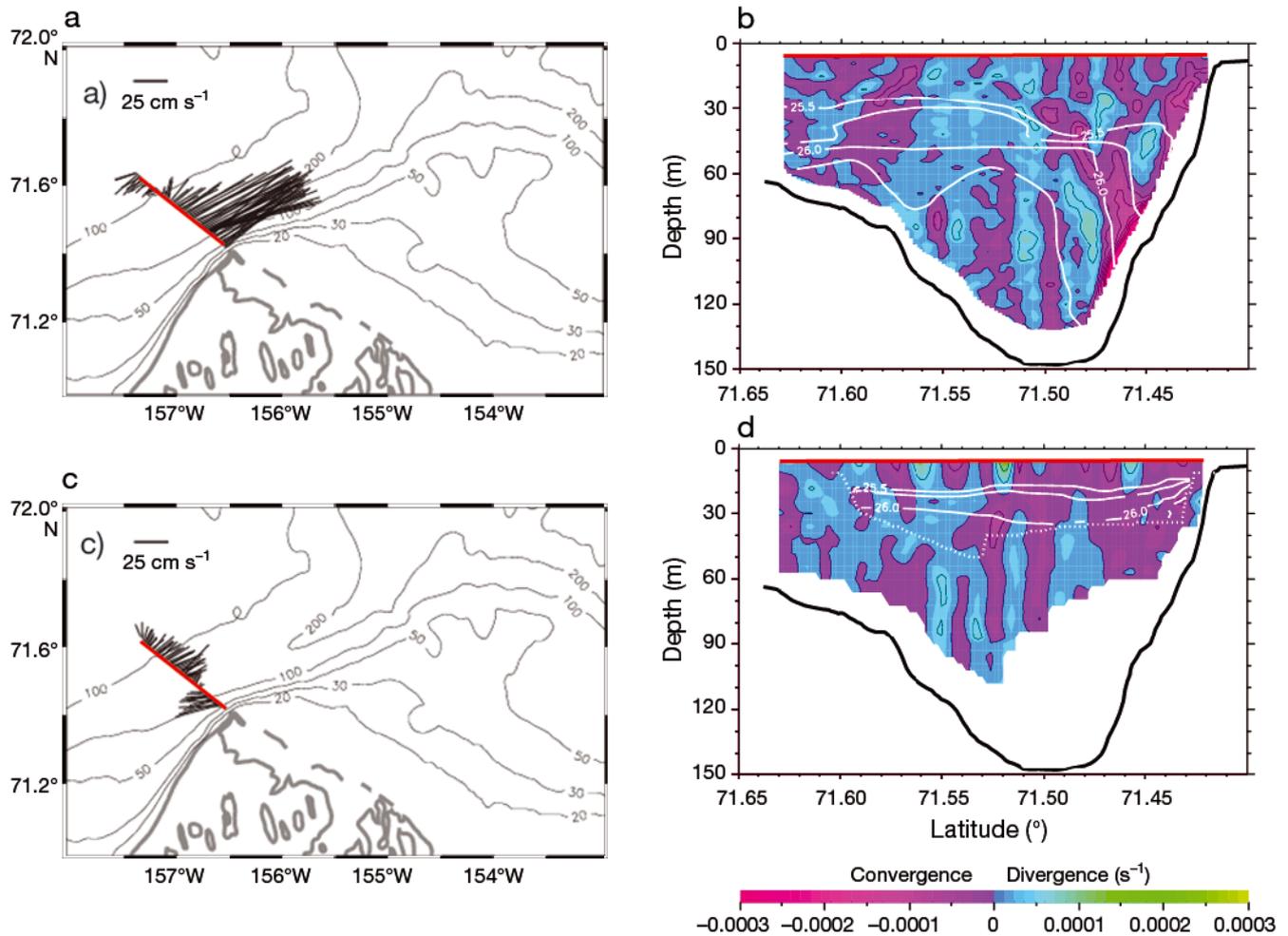


Fig. 6. (a,c) Stickplots of ADCP-measured near-surface currents across Barrow Canyon; (a) 22 August 2007 and (c) 21 August 2006. (b,d) Horizontal derivatives of the ADCP-measured cross-isobath currents from the transect shown in red in (a,c). Convergent currents are colored shades of purple to red. Divergent currents are colored shades of blue to green. Contour interval is 0.00005 s<sup>-1</sup>. White contour lines show coincident density ( $\sigma$ -t) structure. Contour interval is 0.25 kg m<sup>-3</sup>. The white dotted line in (d) shows the maximum depths at which density data were acquired by the Acrobat towed vehicle. No individual CTD casts were taken during the 21 August 2006 survey

immediately following wind conditions promoting an east-northeastward-flowing ACC was twice as large as the average size of beluga whale groups observed immediately following wind conditions promoting a reversal of the current (6.8 and 2.9 whales per group, respectively). The correlation of more beluga whales with a well-developed, east-northeastward flowing ACC suggests that this current regime may enhance beluga foraging opportunities. We posit that these enhanced opportunities result from stronger convergent currents within the ACC.

Hydrographic fronts are known to accumulate aggregations of prey and predators. The convergent currents that promote the accumulation of zooplankton prey along hydrographic fronts typically arise near where the slope of the underlying bathymetry changes, such as the changes in association with sea

mounts, shelf breaks, and canyons (Genin 2004). Whether higher trophic level consumers, such as fish, marine birds, and mammals, target actual prey aggregations or perceive environmental discontinuities, such as temperature or density gradients, is unknown. Clearly, though, such regions are repeatedly targeted by marine predators (e.g. Hunt 1991, Russell et al. 1999, Genin 2004, Bost et al. 2009). One predator species encountered along the boundaries of Arctic water masses is Arctic cod (Logerwell et al. 2011).

Arctic cod are widespread throughout the high Arctic, and although often associated with sea ice, the species occupies many different habitats throughout the year (Welch et al. 1993, Crawford et al. 2012). For instance, the abundance of Arctic cod in trawl surveys near Prudhoe Bay, Alaska, in the summers of 1978 and 1979 varied with changes in local water

masses. During that time, a warmer, low-salinity layer overlays a dense, cold, salty layer. The densest aggregations of Arctic cod were found at the boundary of these 2 water masses (Moulton & Tarbox 1987). In Barrow Canyon, the highest concentrations of cod were found in shallow, upwelled waters during an early autumn hydroacoustic survey (Crawford et al. 2012). In both winter and summer, schools of Arctic cod were associated with warm, low-salinity water associated with the ACC (Moulton & Tarbox 1987, Benoit et al. 2008, Crawford et al. 2012). Marine mammals, including beluga whales, may follow schools of fish (including Arctic cod; Welch et al. 1993, Mymrin et al. 1999, Hobbs et al. 2005).

Wherever they are found in the Arctic and sub-Arctic, beluga whales preferentially associate with hydrographically dynamic areas. Off Svalbard, Norway, beluga whales spend most of their time near glacial faces, which are known to be highly productive (Lydersen et al. 2001), and in Cook Inlet, Alaska, Peel Sound, Canada, and the Mackenzie Delta, Canada, they forage at river mouths (Richard et al. 2001a,b, Hobbs et al. 2005). In the western Beaufort Sea in summer and autumn, beluga whales tend to be distributed north of the shelf break, in deep water, and aligned with the axis of Barrow Canyon (Clarke et al. 1993, Moore et al. 2000, Suydam et al. 2001).

Because beluga whales are less vocal when traveling but more so when socially active, the acoustic activity described above is likely associated with social and possibly foraging behavior (Sjare & Smith 1986b, Karlsen et al. 2002, Belikov & Bel'kovich 2003). Foraging behavior is difficult to observe or distinguish from other social interactions. However, associations of sea birds with milling marine animals, high vocalization rates (Karlsen et al. 2002), and increased click trains during observations of socially interactive animals support a link between social and foraging behavior (Sjare & Smith 1986b). Further, indigenous hunters have reported that beluga whale vocalizations are audible while belugas are foraging and that beluga whales feed in groups (Mymrin et al. 1999). Other species of odontocetes have shown similar associations between non-echolocation vocalizations and foraging behavior. Both pilot whales *Globicephala melas* and fish-eating killer whales *Orcinus orca* are quite vocal when foraging, and these vocalizations may be used to coordinate foraging movements or maintain group cohesion while foraging (Steiner et al. 1979, Weilgart & Whitehead 1990, Jensen et al. 2011).

Because our acoustic data compare the number of hours per day with beluga whale calls, not the num-

ber of calls per hour, they only provide an indication of when vocally active beluga whales are in the area. Although we can say nothing about call rates or numbers of animals present from the acoustic data, increases in the mean number of hours per day with calls indicates that vocal whales are spending more time in the area, twice as much time when the ACC sets up a strong front in the Beaufort than when it does not.

That the positive associations of current direction with either the numbers of whales seen or numbers of hours with calls recorded are similar shows that a single hydrophone can be used in the absence of supporting visual data to monitor changes in the occurrence of beluga whales. Aerial survey data are limited to days with good weather (lower wind speeds and good visibility) and adequate daylight and in a few months of the year. The surveys cover different geographic regions on different days and fly relatively quickly over an area. In contrast, passive acoustic monitoring, while limited in areal extent, can provide data all year, even under heavy ice and in poor weather. Animals can be detected at all hours of the day if they are vocalizing. Therefore, in the absence of visual data (in the winter and early spring), a single, suitably located hydrophone can provide similar, although not identical, information on beluga whale occurrence at hydrographic fronts.

When combined with oceanographic and wind data, the results of 2 years of year-round passive acoustic monitoring and nearly 3 decades of autumn aerial surveys identify a preference for Barrow Canyon and offshore waters; that preference appears to be related to a mechanism by which oceanographic conditions influence local foraging opportunities. Beluga whales associate in larger groups (aerial survey data) and for longer detection periods (acoustic data) in the Barrow Canyon area when the ACC is well-developed in the summer and autumn.

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