Bureau of Ocean Energy Management

Alaska OCS Region

Technical Summary: OCS Study BOEM 2012-079

Application of High Frequency Radar to Potential Hydrocarbon Development Areas in the Northeast Chukchi Sea

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APPLICABLE PLANNING AREA(S): Chukchi Sea

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STUDY PRODUCTS: Final report, ASCII files of surface current, glider, and mooring data, summary statistics of surface currents, gliders, and mooring data

KEY WORDS: Physical Oceanography, Chukchi Sea, Ocean Currents, High Frequency Radar, Webb Slocum Gliders, AUVs, Moorings, Barrow Canyon Transport, Hydrography, Circulation

REPORT AVAILABILITY: A hard-copy of this report is available on paper from the Bureau of Ocean Energy Management, Public Information Office, 3801 Centerpoint Drive, Suite 500, Anchorage, AK 99503-5823, or can be downloaded from: http://www.boem.gov/BOEM-Newsroom/Library/Publications/Alaska-Scientific-and-Technical-Publications.aspx. Report copies are available free of charge, as long as the supply lasts, at the above address. Telephone requests may be placed at 1-800-764-2629 or (907) 334-5206. E-Mail requests may be sent to akwebmaster@boem.gov. Once the limited supply is gone, copies can be purchased from the National Technical Information Service at www.ntis.gov, borrowed through an Interlibrary Loan from the Alaska Resources Library & Information Services (ARLIS), or reviewed at participating selected Federal Depository libraries.

BACKGROUND:

The shallow (~50 m) Chukchi shelf extends ~800 km northward from Bering Strait to the shelfbreak along the 200 m isobath. Present understanding of the shelf circulation is based upon the distribution of hydrographic properties collected in summer and fall, numerical circulation

results, and a few long-term ocean current measurements. Although the mean flow is nominally northward over much of the shelf, sustained by a large-scale pressure gradient between the Pacific and Arctic Oceans, the bulk of the transport proceeds along three principal pathways with each pathway associated with a distinct bathymetric feature; Herald Canyon, the Central Channel, and Barrow Canyon.

A large portion of the water flushing the central and western Chukchi Sea moves eastward north of Hanna Shoal. According to numerical models, the shelf portion of this flow turns southward along the east side of Hanna Shoal and eventually enters the head of Barrow Canyon (although there are no observations in this area for model verification). Overall, much of the water that enters the Pacific sector of the Arctic Ocean ultimately ends up exiting the Chukchi shelf via Herald or Barrow Canyon to form an eastward-flowing shelfbreak jet along the Chukchi and Beaufort Seas.

The Chukchi Sea flow field is influenced by the winds; however, on average these blow from the east-northeast, so the mean flow tends to oppose the mean winds. Many of the historical current measurements were obtained from current meters installed ~10 m above the seabed in depths $\geq$40 m. Thus there has been concern that these measurements may not reflect the near-surface currents. This is crucial in considering the ultimate development of oil spill trajectory models for the Chukchi shelf.

OBJECTIVES:

In anticipation of potential offshore hydrocarbon development activities in the northeast Chukchi Sea, the overall goals of this program were to improve our understanding of the circulation and to provide an extensive data set that can be used to test and evaluate circulation models. Toward this end we focused on a number of specific issues that define the project objectives:

1. Determine whether the surface (upper 1 m) circulation reflects the sub-surface circulation as captured by historical current meter measurements. If not, determine if these differences are related to topographic gradients, seasonally-varying winds, stratification, and/or fronts.
2. Determine if there is a return (southwestward) flow between the western flank of Barrow Canyon and Hanna Shoal as predicted by circulation models. If so, determine the strength and persistence of these flows.
3. Determine if coastal polynyas generate a vigorous cross-shelf flux of dense water.

Additional project objectives were to:

4. Obtain a better understanding of the wave climate of the northeast Chukchi Sea;
5. Develop an infrastructure in Chukchi Sea coastal communities for supporting shore-based, high frequency surface current mapping radars. (This goal is also cost-effective since it will minimize costs associated with routine maintenance of the proposed radars);
6. Provide several useful oceanographic data sets for guiding the development and evaluation of oil spill trajectory models.

DESCRIPTION:

We describe the results of a multi-year investigation of the circulation and hydrography of the northeast Chukchi Sea, involving moored oceanographic instruments that measure the sub-surface circulation, shore-based, high-frequency radars (HFR) capable of mapping the surface circulation in real-time, and gliders (also known as autonomous underwater vehicles, AUVs) that collected 3-dimensional hydrographic data over the northeast Chukchi shelf. HFR operations occurred during three open water seasons: September through November, 2009; July through November, 2010; and July through November 2011. Glider operations were based out of Wainwright and occurred in August and September of 2010 and 2011. The moorings were deployed year-round at the head of Barrow Canyon between August 2010 and August 2011.

Figure 1 is a bathymetric map of the study area, which includes place names, and the locations of the Statoil (Statoil), Burger (Shell), and Klondike (ConocoPhillips) areas of exploration interest. The figure also includes the nominal HFR radar masks and the locations of the current meter moorings deployed as part of this project. For clarity, we have not included the trajectories of the various glider missions conducted during the program.

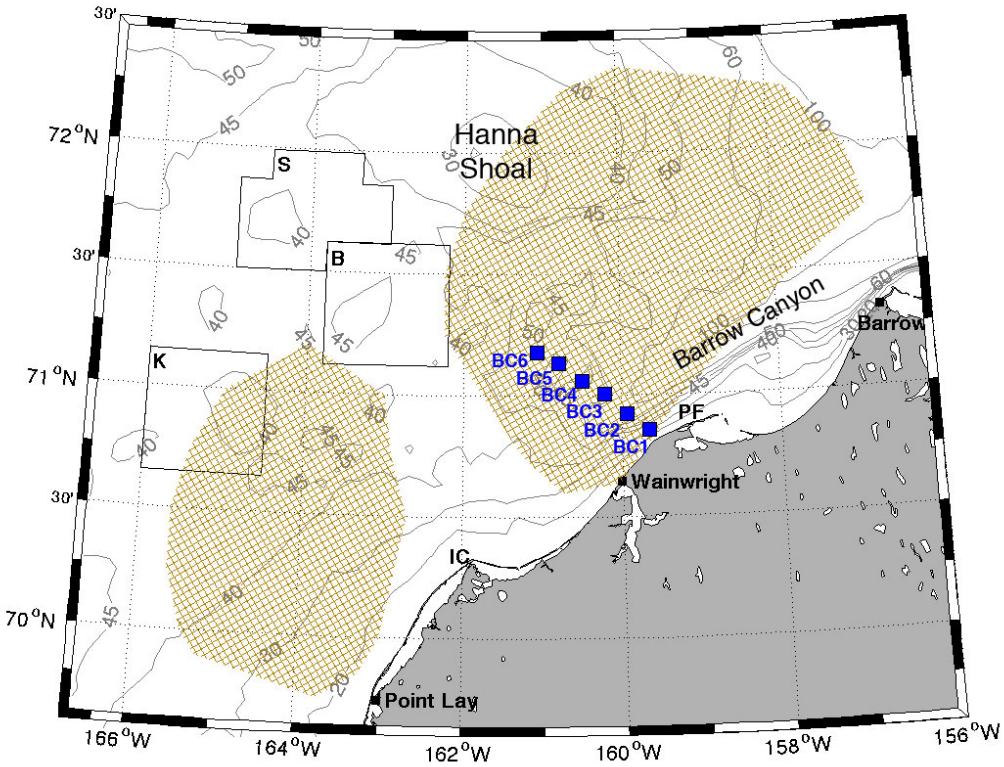

Figure 1. Map showing HFR coverage area (golden crosshatch) and mooring locations (blue squares) overlaid on bathymetric contours (m). Barrow, Wainwright, Point Lay, Hanna Shoal, Barrow Canyon, Icy Cape (IC), and Point Franklin (PF) are identified, as are industry study areas Klondike (K), Burger (B), and Statoil (S).

An array of six current-meter moorings each spaced about 13 km apart, was deployed across the entrance to Barrow Canyon. Moorings were of similar construction and included Teledyne Acoustic Doppler Current Profilers (ADCP) and temperature/conductivity/pressure (T/C/P) recorders. In addition to hourly velocity sampling, the ADCPs on moorings BC1 and BC6 included the capability to measure the directional wave spectrum once every three hours.

Hourly surface currents in the northeast Chukchi Sea using shore-based 5 MHz HFR systems, manufactured by CODAR Ocean Sensors. Field sites were located on native corporation lands in the villages of Barrow, Wainwright, and Point Lay, Alaska. HFR system locations allowed for data collection within 200 km of the coastline over an area of ~30,000 km^2. Current vectors were calculated at 6 km spatial resolution and represent the upper 1 - 2 m of the water column.

We deployed three Teledyne Webb Slocum gliders, a special class of autonomous vehicle that propel themselves by changing their buoyancy compared to ambient water and generate forward propulsion by gliding on wings attached to the body. This results in a relatively slow forward motion (~30 – 40 cm s^{-1}) but is extremely energy efficient compared to a propelled AUV. Gliders equipped with alkaline batteries have a typical mission duration of 30 days, whereas Lithium battery powered gliders can operate continuously for >3 months.

SIGNIFICANT CONCLUSIONS:

The current meter and HFR data show that the Alaskan Coastal Current is a narrow (~40 km) swift flow, centered over the axis of the Canyon. The record-length transport is northeastward (downcanyon) at 0.3 Sv, ~40% of the long-term mean transport through Bering Strait. Transport variations are moderately correlated with the local along-shore winds, with the correlation stronger in winter than in summer.

The flow in the canyon can upwell slope waters onto the shelf. Mooring and HFR data suggest that upwelling events exceeding ~5 days may transport slope waters over a broad area of the northeast Chukchi shelf.

Temperature and salinity characteristics of the water masses flowing into the canyon indicate that Bering Sea summer waters are confined to the central and eastern side of Barrow Canyon, whereas flow along the western side of the Canyon frequently consists of winter waters that may originate along the east side of Hanna Shoal.

HFR data suggests that the shelf circulation includes an eastward flow between 70.5°N and 71.5°N that transports waters toward Barrow Canyon. These flow characteristics hold under all wind conditions, as long as wind speeds are <6 m s^{-1}. When westward winds are >6 m s^{-1} the surface circulation over much of the northeast Chukchi shelf is westward, while within ~40 km of the coast, the flow is southwestward.

About 15% of the open water period the onshore surface flow diverges with one branch flowing downcanyon and the other turning southwest toward Point Lay. This flow divergence occurs when the winds are moderate, suggesting that the along-shore pressure gradient south of

Wainwright is weaker than the along-shore pressure gradient within the canyon.

Offshore of Point Lay, the circulation patterns suggest frequent exchanges between near and offshore waters, which may involve anticyclonic eddies.

North of 71.5°N, and between Hanna Shoal and Barrow Canyon, the surface circulation is comparatively weak and more variable in direction than that south of 71.5°N. Although there are occasional suggestions that it includes a clockwise flow around Hanna Shoal, this feature is not consistently evident.

Glider data suggest there is a west/east trending front at 71° - 71.5°N in summer through at least early fall. The front separates weakly stratified or well–mixed Bering Sea summer waters to the south from a strongly stratified, 2-layered system to the north. The stratified waters include a fresh, cool, ~20 m deep surface layer and a near-freezing, saline bottom layer of ~20 m. Our results suggest that south of this front the HFR data is probably a good proxy for the flow throughout the water column. North of the front, the HFR surface currents may only reflect the upper 20 m of the circulation field.

Reversals in the shelf circulation may bring very cold (~0°C) water southward onto the shelf from east of Hanna Shoal. Should these reversals be prolonged and occur in early fall, they may accelerate the formation of ice due to air-sea heat exchanges.

STUDY RESULTS:

The current meter and HFR data show that the Alaskan Coastal Current is a narrow (~40 km) swift flow, centered over the axis of the Canyon. The record-length transport is northeastward (downcanyon) at 0.3 Sv, ~40% of the long-term mean transport through Bering Strait. Transport variations are moderately correlated with the local along-shore winds, with the correlation stronger in winter than in summer. The correlation is weaker than expected and may be due to remote wind-forcing over the southern Chukchi/northern Bering Seas, differential along-shore surface stress dependent upon the ice distribution function and ice mobility, non-linear processes (as suggested by the cross- and along-shore Rossby numbers that are occasionally >0.1), and/or forcing over the Chukchi/Beaufort shelfbreak. The flow in the canyon can upwell slope waters onto the shelf. Mooring and HFR data suggest that upwelling events exceeding ~5 days may transport slope waters over a broad area of the northeast Chukchi shelf. Temperature and salinity characteristics of the water masses flowing into the canyon indicate that Bering Sea summer waters are confined to the central and eastern side of the canyon, whereas flow along the western side of the canyon frequently consists of winter waters that may originate along the east side of Hanna Shoal.

HFR data suggests that the shelf circulation includes an eastward flow between 70.5°N and 71.5°N that transports waters toward Barrow Canyon. These flow characteristics hold under all wind conditions, including westward winds as long as westward wind speeds are <6 m s^{-1}. When westward winds are >6 m s^{-1} the surface circulation over much of the northeast Chukchi shelf is westward, while within ~40 km of the coast, the flow is southwestward. About 15% of the time

the onshore flow diverges with one branch flowing downcanyon and the other turning southwest toward Point Lay. This flow divergence occurs when the winds are moderate, suggesting that the along-shore pressure gradient south of Wainwright is weaker than the along-shore pressure gradient within the canyon. Offshore of Point Lay, the circulation patterns suggest frequent exchanges between near and offshore waters, which may involve anticyclonic eddies. North of 71.5°N, and between Hanna Shoal and Barrow Canyon, the surface circulation is comparatively weak and more variable in direction. Although there are occasional suggestions that it includes a clockwise flow around Hanna Shoal, this feature is not consistently evident.

The glider data suggest that there is a west/east trending front at 71° - 71.5°N in summer through at least early fall. The front separates weakly stratified or well–mixed Bering Sea summer waters to the south from a strongly stratified, 2-layered system to the north. The stratified waters include a fresh, cool, ~20 m deep surface layer and a near-freezing, saline bottom layer of ~20 m. Our results suggest that south of this front the HFR data is probably a good proxy for the flow throughout the water column. North of the front, the HFR surface currents may only reflect the upper 20 m of the circulation field. Nevertheless, the horizontal density gradients across these fronts are weak over most of the shelf, except in Barrow Canyon, so that the geostrophic shear over most of the shelf is feeble.

Our results have important implications regarding the prediction of ice formation, given the highly advective nature of the Chukchi Sea shelf. Through summer and fall the mean circulation provides an oceanic heat flux convergence that may exceed in magnitude the loss of heat to the atmosphere and so delay ice formation. On the other hand reversals in the shelf circulation may bring very cold (~0°C) water southward onto the shelf from east of Hanna Shoal. Should these reversals be prolonged and occur in early fall, they may accelerate the formation of ice due to air-sea heat exchanges.

PROJECT PUBLICATIONS:

Timmermans, M.-L. and P. Winsor, 2012. Scales of horizontal density structure in the Chukchi Sea surface layer. *Cont. Shelf. Res*., 52, 39-45, doi:10.1016/j.csr.2012.10.015.

Weingartner, T., E. Dobbins, S. Danielson, P. Winsor, R. Potter, and H. Statscewich (2013) Hydrographic variability over the northeastern Chukchi Sea shelf in summer-fall 2008–2010. *Cont. Shelf. Res*., Accepted, doi:10.1016/j.csr.2013.03.012.