Surface Circulation Radar Mapping in Alaskan Coastal Waters: Field Study Beaufort Sea and Cook Inlet

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LONG-TERM GOALS

Our long term goals are twofold. First want to obtain spatial and temporal surface circulation fields for lower Cook Inlet and the central Beaufort Sea shelf in regions of offshore marine industrial activities. These measurements will contribute to the baseline oceanography for these two regions where few *in situ* current measurements have been made, and will therefore help to promote the general understanding of surface currents in these areas. These investigations will be an important undertaking for the Minerals Management Service (MMS) future efforts to model potential oil spills and for possible spill response and oil spill contingency planning. The data can also be used by MMS for model comparison and validation, for both hydrodynamic models as well as general circulation models. By disseminating the data over the internet in real-time, these data will assist professional users with a need for information for ship tracking and touring, coastal zone management, sediment transport, search and rescue operations, oil spill and other pollutant response. Our second goal is to develop an understanding of the limitations of high-frequency (HF) surface current-mapping radars in seasonally ice-covered seas and the ability of these systems to function in relatively remote settings.

OBJECTIVES

An important objective is to evaluate the sensitivity of the instruments to measure surface currents within mixed ice and open water conditions (limited fetch conditions), under periods of high fresh water outflow from the river systems, during the development of spring/summer shore leads, and during the fall freeze-up and the formation of landfast ice in the nearshore Beaufort Sea. Oil spill trajectory models typically derive their wind measurements from either coastal meteorological stations or from satellite derived barometric pressure fields. These data do not provide true surface current measurements in mixed ice and open water conditions when fetch is limited. HF Doppler radar would provide significantly more accurate surface current measurements under these fetch-limited conditions.

Once the data is acquired, our analytical objectives include:

- Assessing effects of sea ice concentration and extent on collection of surface current measurements from HF Doppler radar.
- Validating the HF Doppler radar surface current data measurement by comparing these data against the subsurface current measurements from the Acoustic Doppler Current Profilers (ADCPs).
- Comparing and contrasting wind measurements from MMS or other adjacent coastal meteorological stations against the HF radar surface current measurements.
- Developing a web site and ground capability to monitor system integrity and performance and providing near real-time dissemination of surface current field data, vector maps, and surface current animations.
- Providing detailed analysis of current and tidal variability and system response from the HF Doppler radar. Determining the dynamics and variability of surface current circulation. Including any sea ice, bathymetry, meteorological, ADCP, drifter, tidal, sea surface temperature or other important comparative data that has been collected within the study area.

APPROACH AND WORK PLAN

This study consists of two seasons of HF radar deployments in the Beaufort Sea and one year in Cook Inlet. In the Beaufort Sea we have completed collection of HF radar surface current measurements between August and October in both 2005 and 2006. In November 2006, we moved the Beaufort Sea installations to lower Cook Inlet where they will be operating until November 2007. We have and continue to collect, analyze, disseminate over the Internet, and archive surface current vector measurements from these areas. In the Beaufort Sea, data were collected offshore from between 10-50 km (depending upon frequency) with a resolution of approximately 250 m to 3 km. These data are being used to resolve circulation patterns landward (inside) and seaward (outside) of any barrier islands (**Figure 1**). In Cook Inlet we are obtaining surface current vector measurements over a radial distance of 70 km from shore with a resolution of 1-3 km.

Scientific and technical personnel involved with the project from the University of Alaska Fairbanks (David Musgrave, Project Manager; Tom Weingartner, Oceanographer; Hank Statscewich, Technician; Rachel Potter, Deputy Program Manager; Tony D'Aoust and Andrew Bray; Technicians) and CODAR Ocean Sensors (Don Barrick, Brenda Lipa and Pete Lilleboe). Barrick, Lipa and Lilleboe, the founders of CODAR Ocean Sensors, are leaders in HF ocean remote sensing radars and pioneered the development and application of HF radars for mapping of ocean surface currents. Musgrave, Statscewich, Bray and D'Aoust are responsible for the deployment of the HF radars. Potter is responsible for the project web site, real-time data acquisition and display, physical oceanographic data programming and analysis. Weingartner will assist in data analysis, interpretation and comparison with moored in-situ measurements.

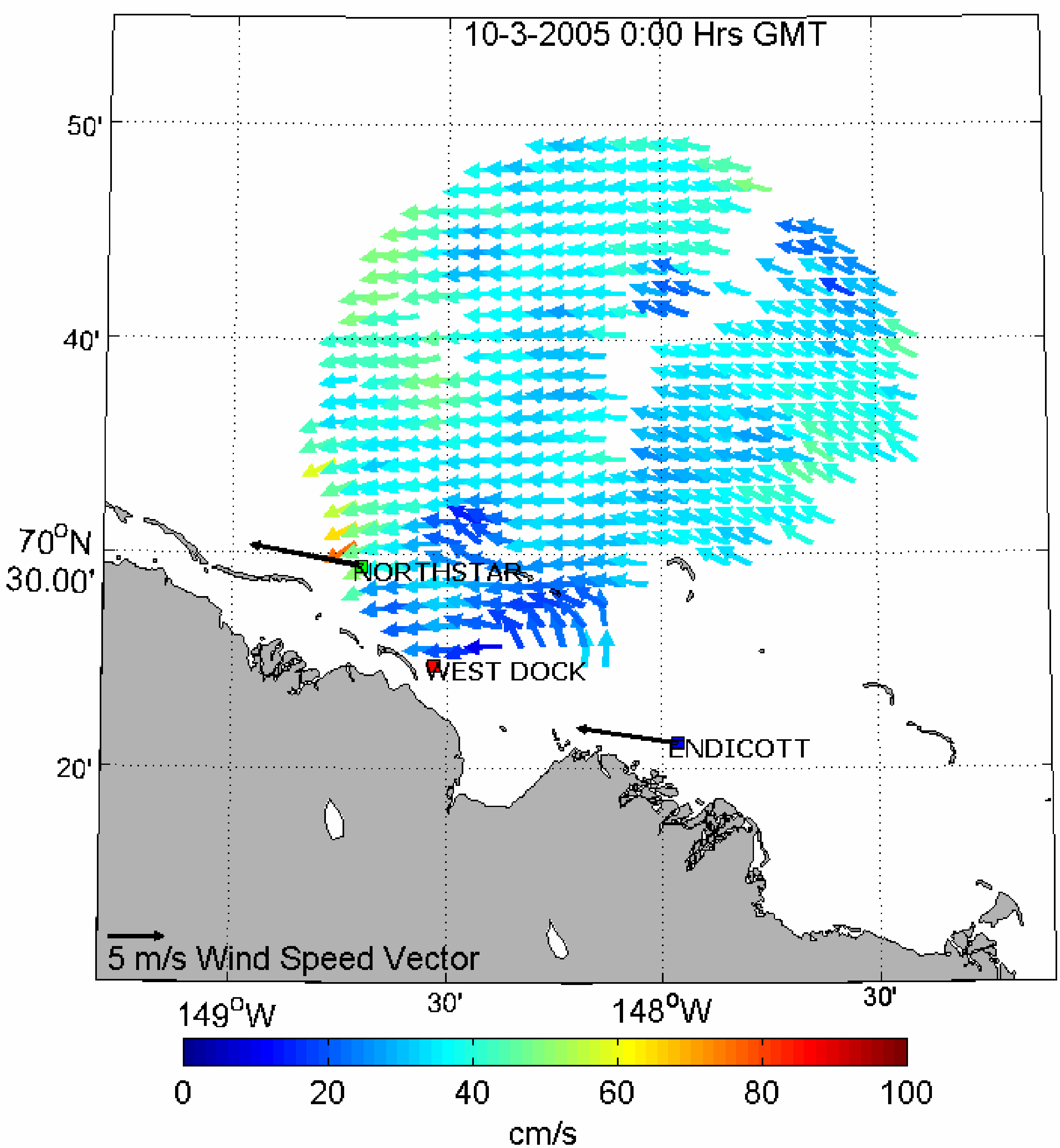

Figure 1. A map of the surface currents for 00:00 GMT on October 3, 2005, in the Beaufort Sea, which lies offshore of Prudhoe Bay, Alaska. This map shows the location of the West Dock and Endicott Island locations from which HF radar data were collected. The surface currents are given by the arrows that are color coded by magnitude. Wind vectors from meteorological stations at North Star and Endicott are given by the black arrows and the magnitude is given by the scale in the lower right.

WORK COMPLETED

During fiscal year 2006, our work consisted of:

1. Site visit to Beaufort Sea in anticipation of an August 2006 deployment.
2. Acquiring, testing, and shipping a HF Radar system to Prudhoe Bay, Alaska, in July 2006.
3. Deploying, installing, calibrating, and maintaining the HF Radar system in Beaufort Sea from August through October 2006
4. Re-deploying the system in Lower Cook Inlet in November 2006,
5. Developing and maintaining a web site where real-time surface current data are displayed
6. Compiling and submitting a Bibliographic Database of HF Radar resources.

We deployed and fine tuned two HF radar systems that can be switched between 12 and 24 MHz, at West Dock and Endicott Islands. An example of the data collected is shown in **Figure 1**, which shows the domain of coverage operating at 12 MHz. The use of two different frequencies permits us to tune the radars depending on environmental conditions: when the fetch is small we expect the wave field to have more energy in shorter waves, which can be detected with the 24 MHz radar. When the fetch is larger, presumably under ice-free conditions, longer waves will be generated allowing us to increase the range of measurements by shifting to the 12 MHz frequency (**Figure 2**). This represented the first attempt to use a switchable dual frequency system in an operational setting and we successfully accomplished this task.

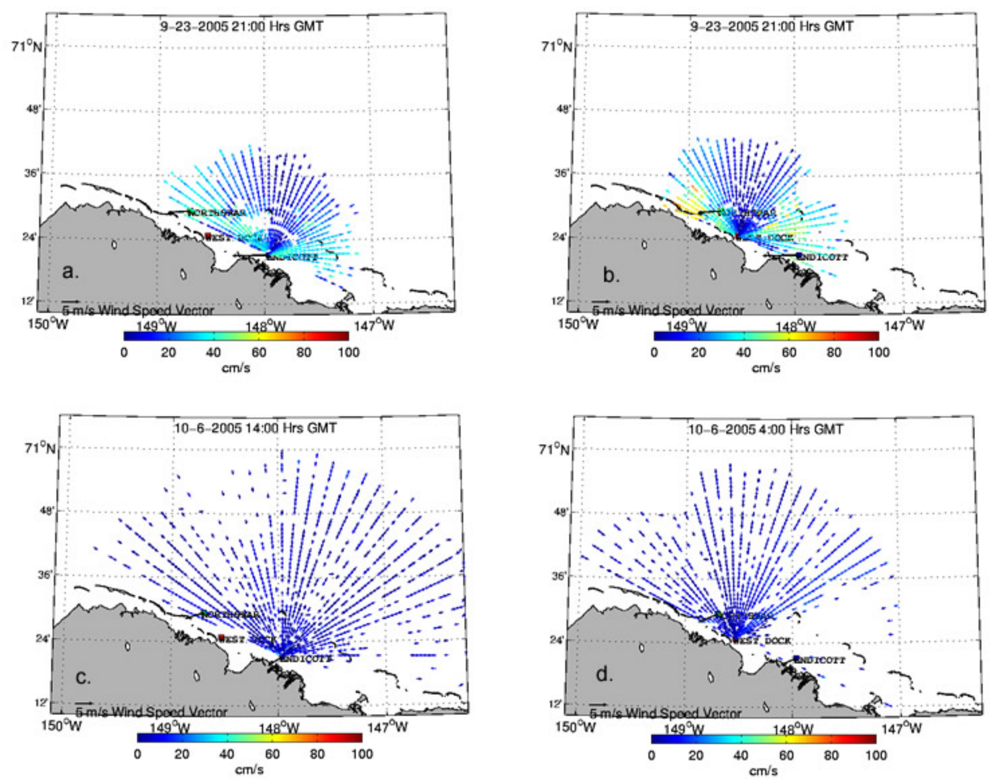

Figure 2. Maps of the radial surface currents from systems at West Dock (right panels) and Endicott Island (left panels. (Radial velocities are from each site are added vectorally to give the total two dimensional velocity vectors as shown in **Figure 1**). The upper panels are from September 23 and the lower panels are from October 6, when the system was operating at 24 MHz and 12 MHz at those times, respectively. The 24 MHz system has half the range (30 km) of the 12 MHz systems.

A photograph of one of the HF radar sites (at Endicott Island) is shown in **Figure 3**.

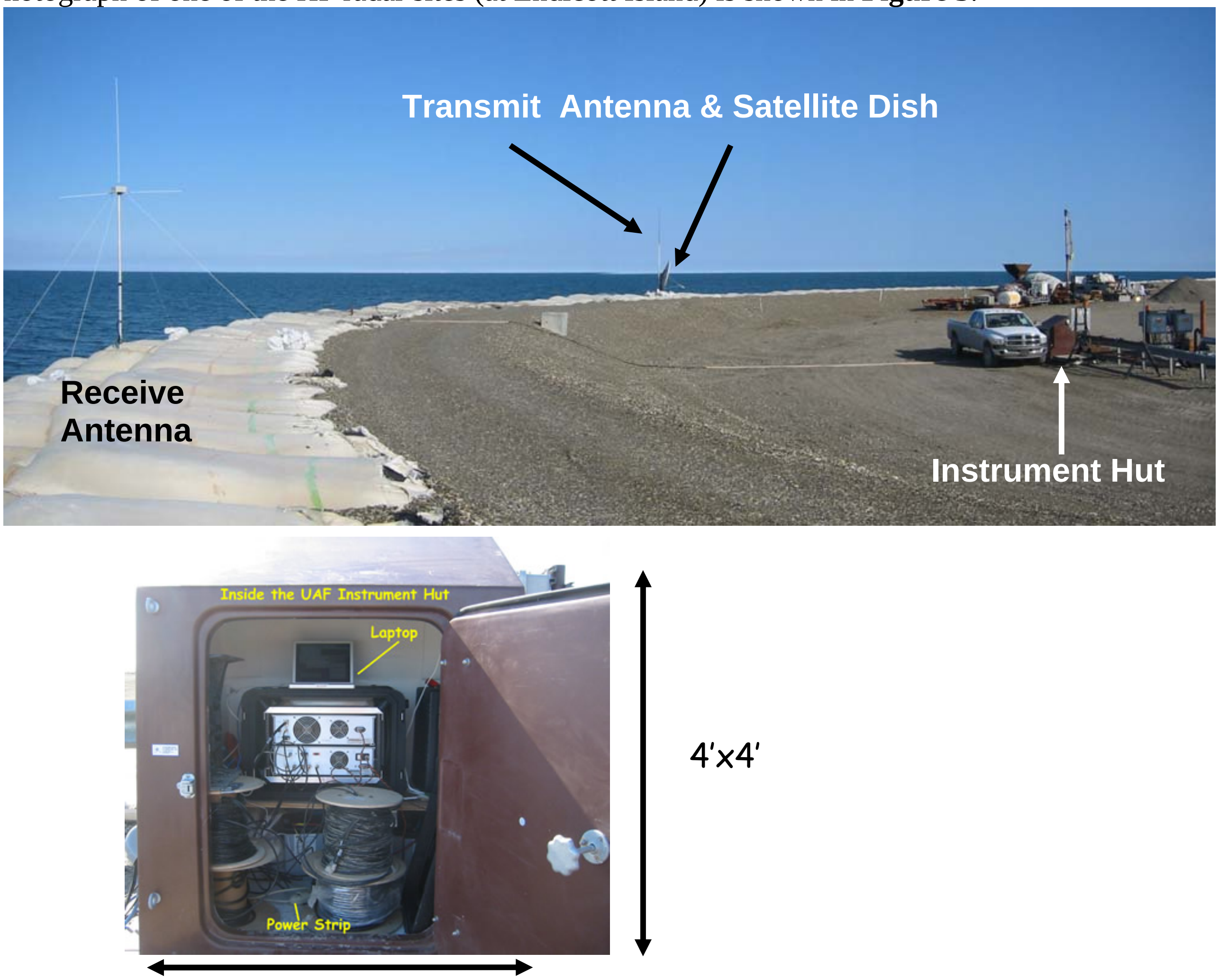

Figure 3. Photograph of the HF radar site at the Endicott facility. The inset shows a detail of the instrumentation hut that includes HF electronics. Data are transmitted in near-real time to the central site in Fairbanks, Alaska, via the satellite dish that is part of the Starband communication system.

Initially, in 2005, we experienced d a variety of problems associated with troubleshooting the new switchable system, issues of power supply, and antenna patterns. These were largely alleviated in 2006, although there were time periods when low winds or construction activities interfered with data collection. Nevertheless we were able to collect two dimensional velocity vectors from early September through late October 2006. Early fall 2006 witnessed heavier nearshore ice concentrations than in 2005 and extended periods of calms which contributed to relatively gappy data early in the season. However, the relatively heavy ice concentrations are allowing us to understand the performance characteristics of the HF radar in partially ice-covered seas. We were also able to map mesoscale flow features associated with ice edges as well as strong wind-driven currents that developed later in the season.

Preliminary results indicate that the winds drive the circulation (**Figure 4**). The complex correlation amplitude between the winds and the surface velocity at one point in the domain (just outside the barrier islands) is a maximum (accounting for 60% of the variance) when the surface velocity lags the winds by 2 hours. The surface currents are rotated 18° clockwise from the winds at a two hour lag. We have computed empirical orthogonal functions based on data from the 2005 season. These show that more than 90% of the current variance is captured by the first mode indicating a relatively coherent along-shore flow field. We note however, that wind and ice conditions in 2005 were much different than in 2006. Winds were stronger and, for most of the season, the sea ice was far offshore and out of range of the HF radar mask. Our preliminary analyses of the data in 2006 suggest far more complex flow field due to ice-edge fronts and weaker winds.

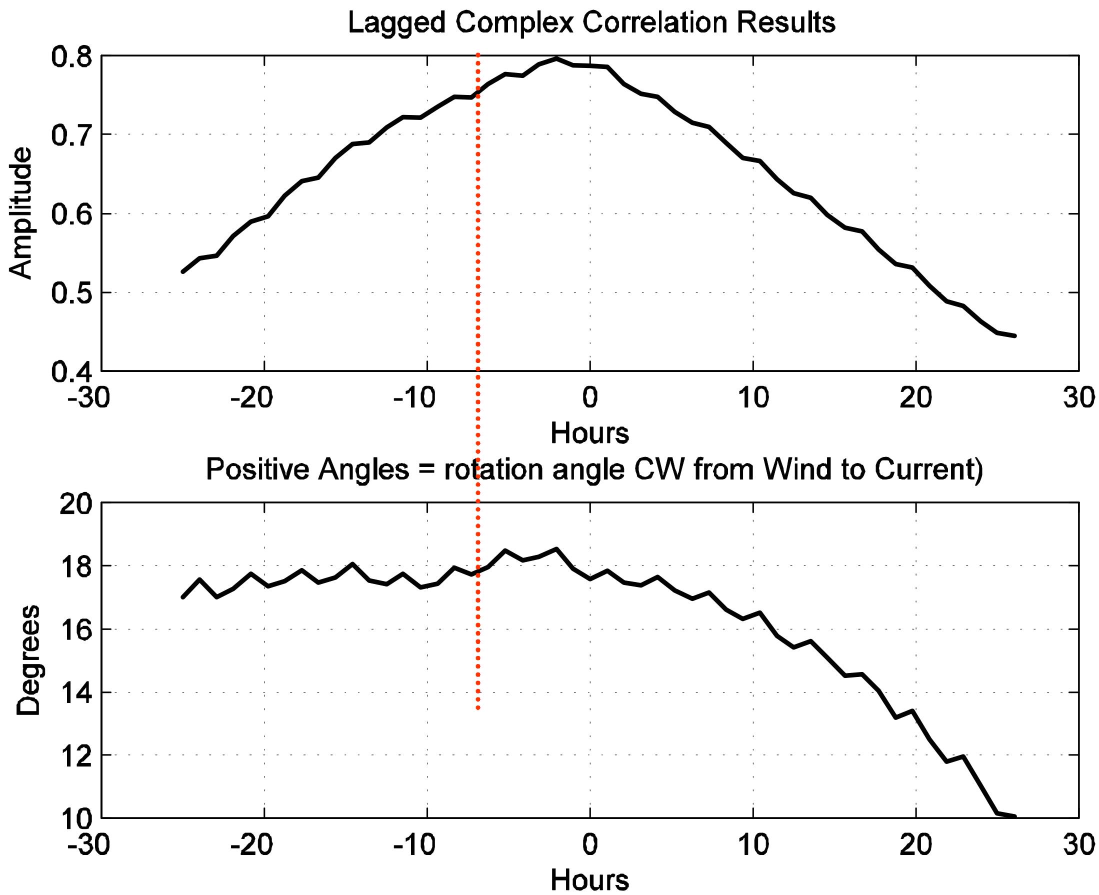

Figure 4. Lagged complex correlation between winds at Endicott Island and surface velocity at a point just outside the barrier islands.

We are also in the process of analyzing the HF radar current vectors in conjunction with concurrent Synthetic Aperture Radar (SAR) imagery. This will allow us to ascertain HF radar data quality as a function of ice concentration. In addition, although the SAR imagery is available only once every three days, we are better able to assess the circulation fields by overlaying the surface current vectors onto SAR images (**Figure 5**).

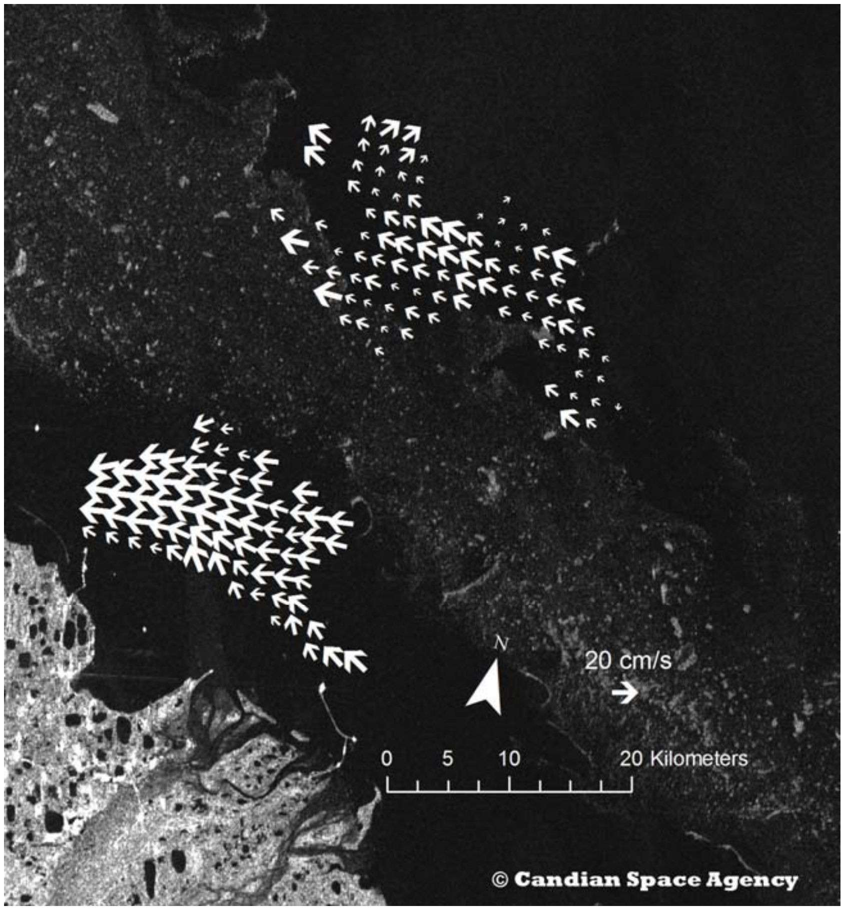

Figure 5. HF-radar surface current vectors overlain on a Synthetic Aperture Radar (SAR) image for September 17, 2006.

IMPACT AND APPLICATIONS

Economic Development

The Beaufort Sea borders the Arctic coastal plain and is important to MMS and the oil industry, in part because of its potential for offshore oil gas production. The adjacent North Slope coastal plain region produces over 20% of the United States oil from mostly onshore State of Alaska oil fields. Offshore, oil is produced from Northstar Production Island, a joint state/federal production unit and numerous offshore leases are planned or actively undergoing exploration. This oil is transported to shore via a subseabed pipeline where it is connected to the larger Prudhoe Bay pipeline infrastructure.

Over the past 25 years, HF Doppler radar has been developed and improved so that detailed, gridded, two-dimensional maps of surface current circulation can be recoded in real time. Currents would play a critical role in the transport and fate of spilled oil. Current meters provide data at specific points and not at the water surface, where most oil would be advected. HF Doppler radar provides a measured equivalent of a gridded circulation model and can be used as input to validate and to assimilate into oil spill trajectory models.

Electromagnetic remote sensing of ocean currents provides a mapping capability that appears to be a very most cost-effective solution for nearshore coastal current measurements. Although our results are preliminary, discussions with the oil industry indicates that they are considering using HF radar as routine components of their offshore activities in the Beaufort Sea.

Quality of Life

These data will assist professional users with a need for information for coastal zone management, sediment transport, search and rescue operations, oil spill and other pollutant response. Also, subsistence hunting is a very important cultural activity for the Native population that resides along the Arctic coastal plain. Subsistence hunters hunt the bowhead whale, polar bear, ringed seal, fish, etc. which are found within the waters and on top of the ice in the Beaufort Sea. They could benefit from knowledge of the surface currents.

Science Education and Communication

There is a limited amount of information to resolve the spatial and temporal surface currents circulation patterns in the Beaufort Sea and Cook Inlet. The sites where current meters have been placed, in either area, have not resolved the complexity of the surface currents. Our present knowledge of surface currents is limited and can be improved. Time series observations of surface current measurements over extensive regions are essential for understanding ocean circulation dynamics. High Frequency (HF) Doppler radar systems are ideal for accomplishing this task. The tidal range measured in Cook Inlet is one of the largest in the world, and the short season of open water conditions in the Beaufort Sea is followed by a period of growth and seaward spread of landfast ice, followed by pack ice incursion, ice ridging, opening and closing of leads, spring overflooding, opening of the shoreline leads, and melting of the land fast ice which leads to the short open water season. HF Doppler radar will provide important new information on the changing surface current measurements within these unique and dynamic environments. While data analyses are ongoing, several presentations have been given (or will be shortly) on this work. These include presentations by Weingartner to both the North Slope Science Initiative (a joint federal, state, municipal, and industry consortium for the North Slope of Alaska) in October 2006 at BLM headquarters in Fairbanks and to BP, ConocoPhillips, and Shell in December 2006 at BP offices in Anchorage, Alaska. R. Potter will make additional presentations in January 2007 at the Alaska Marine Science Symposium in Anchorage and another at the International Arctic Research Center in Fairbanks in February, 2007.

TRANSITIONS

Economic Development

These investigations will be an important undertaking for the Minerals Management Service (MMS) future efforts to model potential oil spills and for possible spill response and oil spill contingency planning.

Quality of Life

By disseminating the data over the internet in real-time, these data will assist professional users and the public with information useful for ship tracking and touring, coastal zone management, sediment transport, search and rescue operations, pollution response, and marine ecosystem studies.

Science Education and Communication

The data can be used by MMS for model comparison and validation, for both hydrodynamic models as well as general ocean circulation models.

RELATED PROJECTS

A similar study is being conducted in Prince William Sound, Alaska, by the same University of Alaska Fairbanks research group. The HF Radar system provides insight on the circulation of Prince William Sound. Examples of the application of HF radar to these various sites are found at the following website: http://www.ims.uaf.edu/salmon/research/hf_radar/index.html. In addition, under a separate contract, MMS is funding year-round measurements of nearshore currents in the Beaufort Sea. These are pointwise measurements made from ADCPs deployed on the seabed. Those measurements, being made by Co-PI Weingartner, will be integrated into this project.