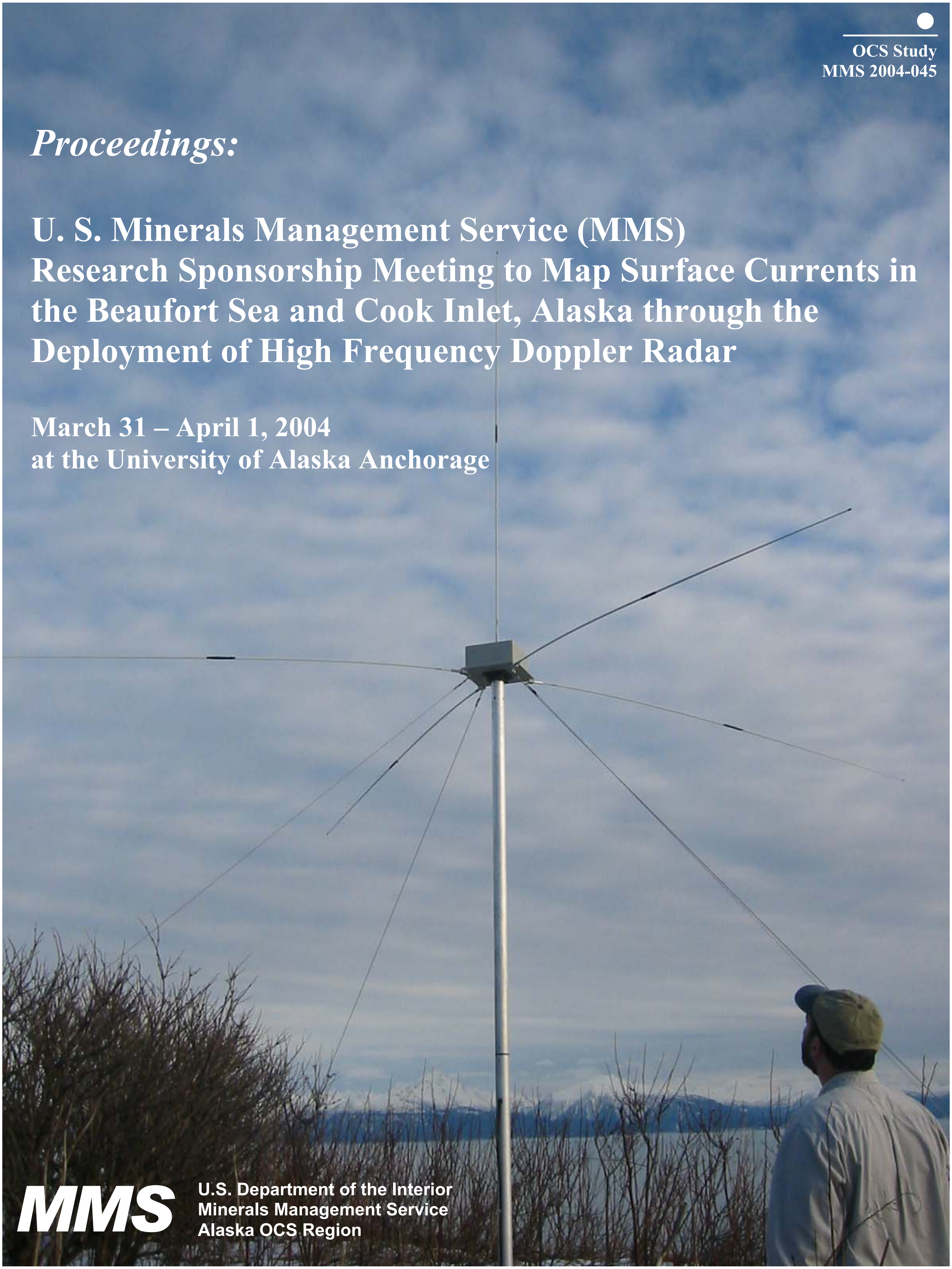
OCS Study
MMS 2004-045

Proceedings:

U. S. Minerals Management Service (MMS) Research Sponsorship Meeting to Map Surface Currents in the Beaufort Sea and Cook Inlet, Alaska through the Deployment of High Frequency Doppler Radar

March 31 – April 1, 2004
at the University of Alaska Anchorage



MMS
U.S. Department of the Interior
Minerals Management Service
Alaska OCS Region

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Prepared for:

**U. S. Department of the Interior
Minerals Management Service
Alaska OCS Region
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Cover: Scott Pegau from Kachemak Bay Research Reserve checks the installation of the HF radar receive antenna at Bluff Point in lower Cook Inlet. Photo courtesy of Hank Statscewich, SALMON Project, University of Alaska Fairbanks.

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EXECUTIVE SUMMARY

On March 31 and April 1, 2004, MMS convened a workshop to plan a pilot project in the Beaufort Sea and Cook Inlet to map surface currents using high frequency radar units. The one-and-a-half day workshop consisted of four presentations, a panel discussion by experts in Surface Current Mappers (SCMs), and working groups in breakout sessions.

Wednesday, March 31, 2004

On Wednesday morning and early afternoon, presentations on the theory, applications, interaction with models, and issues of implementation in Alaska were presented by Drs. Flament (University of Hawaii), Glenn (Rutgers University), Allen, (Oregon State University), and Musgrave (University of Alaska Fairbanks), respectively. The PowerPoint presentations are available from MMS.

Dr. Flament provided the background for understanding how HF radar can be used for surface current mapping including the theory of Bragg scattering, Doppler shift, range and bearing determination, frequency and band-width, signal-to-noise ratio, determination of wind direction and wave field, non-ideal antenna patterns, and detection of low-level aircraft.

Dr. Glenn presented applications of SCMs on the New Jersey and northeast US coasts, including tidal and sub-tidal analysis, trajectory analysis for search and rescue and oil spill response, over-the-horizon ship detection, and comparison of data from SCMs and in situ measurements from Acoustic Doppler Current Profilers (ADCPs). A major result of the root-mean-square differences between SCMs and ADCPs are 4 cm/sec when there is negligible horizontal or vertical shear.

Dr. Allen's presentation on use of data from SCMs with model included model-data comparison in a hindcast mode and assimilation of surface currents maps into models for hind-, now- and forecasts. His results from the Oregon coast show that estimation of subsurface tidal currents are more accurate when surface currents are assimilated into models.

Dr. Musgrave discussed the issues particular to Alaska coasts including permitting, vandalism by bears, constraints by local topography and coastline, shallow water, and remote site needs for power and data communication.

A panel fielded questions for about one-and-a-half hours from the participants on the theory and application of SCMs and their use in Cook Inlet, Beaufort Sea and, more generally, Alaska. The panel consisted of Scott Glenn, Pierre Flament, Alexander Kurapov (Oregon State University), Karen Grissom (NOAA), Brian Haus (University of Miami), Hank Statscewich (University of Alaska Fairbanks), and Dave Musgrave (moderator, University of Alaska Fairbanks).

Following the panel discussion the participants were divided into three breakout groups to discuss: 1) potential government and industry support in assisting the deployment and operation of MMS's proposed HF radar current mapping project for Alaska and development of Alaska radar surface current mapping users consortium and 2) statements by participants of their interest in the use of HF radar units to map surface currents, specifically:

- What financial support is available?
- What support is available in terms of sites, power, and data transmission?
- What logistical support is available in terms of shipping and transportation of personnel and equipment?

- What support is available for room and board of personnel?
- What support is available for personnel to help with on site issues (checking equipment, flicking switches, changing disks, etc.)?
- What is your interest in the use of the surface current maps?
- What is your interest in other uses of HF radar (waves, ship detection)?
- What is your region of geographic interest?

On Thursday morning, the results were presented from Wednesday afternoon breakout groups and listed on flip charts.

Results from Wednesday Breakout Groups

There was much in common as the breakout groups addressed the above questions. The answers to the questions were:

What financial support is available?

The groups suggested the following potential agencies or programs: Minerals Management Service, National Ocean and Atmospheric Administration, Cook Inlet Regional Citizens Advisory Council and associated partners, Environmental Protection Agency, United States Coast Guard (USCG), National Science Foundation, Exxon Valdez Oil Spill Trustee Council, North Pacific Research Board, Alaska Clean Seas, Barrow Arctic Science Consortium. It was noted that many of the listed agencies or programs require proposals for financial support that may or may not be successful in the time frame of the next few years. The Alaska Clean Seas has a charter agreement between the State of Alaska, BP, and Conoco-Phillips for research and development type projects and oil spill response. Funds have been designated for surface current mapping in the Beaufort Sea.

What support is available in terms of sites, power, and data transmission?

The two areas, Cook Inlet and Beaufort Sea, have different sources of support. In Cook Inlet, private property, local, state or federal lands or native owned lands were identified as potential sites. In the Beaufort Sea, the oil producers have control over most of the potential sites. Permitting is less burdensome on private property, industry controlled or native owned land. It was noted that in both regions remote power and data transmission may be required, although sites on the northeast side of Cook Inlet may have convenient access to power and phone lines for data transmission. The northeast shore is defined here as any place north of Nanwalek on the east side, since south of Nanwalek there is no road access.

What logistical support is available in terms of shipping and transportation of personnel and equipment?

In Cook Inlet, most of the sites on the northeast side are road accessible. However, access on the west side would require boats or air support. Entities identified that could provide boat support for Cook Inlet included Cook Inlet Spill Response Institute and the USCG. In the Beaufort Sea, Alaska Clean Seas could provide transportation to the sites by boat and truck. USCG may be able to provide helicopter support if needed.

What support is available for room and board of personnel?

In Cook Inlet, private residences or lodges, Kachemak Bay Research Reserve, and Kasitsna Bay (University of Alaska Fairbanks) were identified as potential places for room and board of personnel. The oil producers or Alaska Clean Seas may be able to supply room and board in the Beaufort Sea.

What support is available for personnel to help with on site issues (checking equipment, flicking switches, changing disks, etc.)?

Personnel at Kachemak Bay Research Reserve or the Cook Inlet Regional Citizens Advisory Council (Cook Inlet) or Alaska Clean Seas (Beaufort Sea) may be able to provide some on-site support. It was suggested that a technical group of on-site personnel be formed for training and information exchange.

What is your interest in the use of the surface current maps?

- United States Coast Guard: search and rescue, maritime safety, hazardous waste spill response.
- National Science Foundation: research in basic science.
- Mineral Management Service: validation of ocean circulation models for oil spill response and contingency planning, risk analysis (also mentioned by Alaska Clean Seas, Cook Inlet Regional Citizens Advisory Council, Oil Spill Recovery Institute, USCG).
- Others: in season fisheries management and larval transport

What is your interest in other uses of HF radar (waves, ship detection)?

- Wind direction, model verification, assimilation into models, oil spill risk analysis, and development of tidal models for Cook Inlet.

What is your region of geographic interest?

- USCG: Gulf of Alaska and Bering Sea.
- Mineral Management Service: mid and lower Cook Inlet and Beaufort Sea.
- National Science Foundation: Beaufort and Chukchi Seas.

Thursday Morning, April 1, 2004

Short backgrounds on the oceanography in the Cook Inlet and Beaufort Sea regions were presented by Scott Pegau and Jim Schumacher, respectively, in order to set the stage for breakout groups to discuss Workshop Recommendations for implementing pilot projects for SCMs in those regions.

Warren Horowitz gave a short presentation on MMS needs and priorities for SCMs in Alaska.

The rest of Thursday morning was taken up with the breakout session of two groups, one for Cook Inlet and one for the Beaufort Sea, to discuss the following issues associated with the pilot projects:

- Permits (land use and FCC)
- Remote power or data transmission
- Monostatic or bistatic systems
- Constellation of SCMs
- Frequency of HF radar (short, standard or long range)
- Ice issues and timing of deployment
- Phased timing of implementation
- Estimate of costs

The results from the two breakout groups were presented to all the participants.

Closing remarks were given by Cleve Cowles. He said that a user’s group of agencies, non-governmental organizations and other parties interested in SCMs in Cook Inlet and the Beaufort Sea was sought as well as follow-up meetings. MMS was trying to get cooperation from other federal agencies through the NOPP process. MMS will attempt to award a Surface Current Mapping project in Cook Inlet and/or the Beaufort Sea by September 30, 2004.

INTRODUCTORY REMARKS

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Welcome to the *MMS Alaska OCS Region Research Sponsorship Meeting on the Mapping of Surface Currents from High Frequency Radar in the Cook Inlet and Beaufort Sea.*

The essence of the MMS mission is to manage offshore oil and gas exploration and development in an environmentally sound manner. Within that mission the Environmental Studies Program has the goals of:

- Obtaining information needed for the prediction, assessment, and management of potential effects of offshore oil and gas development on the human, marine and coastal environment
- To enhance the leasing process by providing timely and appropriately formatted information
- To monitor in order to detect changes in the quality and productivity of potential affected human, marine, and coastal environments.

As a brief overview our ongoing studies program currently entails about 65 studies, encompassing the disciplines of endangered and protected species, other living resources, fate and effects of pollutants, physical oceanography and oil spill trajectory modeling, various multi-disciplinary monitoring projects, and, unique among agencies, a strong commitment to socio-economic research related to our mission. We work within our Annual Study Plan, which is highly participatory in its formulation. Our coordination and collaboration efforts go beyond planning, but in a variety of activities within and among various projects and disciplines. For our Arctic studies alone, we coordinate projects at informational or action levels across a breadth of at least 40 and probably more research-interest entities.

Our goal for this meeting is to bring together those in government agencies, public, non-profit, and private entities who might be interested in partnering with us in the deployment and operation of High Frequency Doppler Radar units. The general reason MMS seeks to initiate jointly funded research in this topic is because we hope the techniques and information yield will assist us in refining our understanding of physical oceanography and improvement of our circulation and trajectory models. We are, of course very happy to see so many of you willing to take the time to dwell on this subject also.

For important reasons, MMS is particularly interested in consideration of the Beaufort Sea and Cook Inlet for such research – that is that portions of these latter areas include proposed and active Federal offshore oil and gas leasing and production. The prospect of testing hypotheses in a research and analytical mode is particularly exciting to MMS while we also recognize that potential partners may have other goals that we can achieve to mutual benefit. At a minimum, we certainly expect that information presented at this meeting will help us collectively assess the feasibility of implementing jointly crafted activities.

As a charter member of the National Oceanographic Partnership Program (NOPP), MMS is striving to improve coordination across the oceanographic community; in part through co-sponsor of a number of NOPP affiliated research projects. Looking further into the future, MMS is also a member of the Executive Committee for Ocean.US. Stemming from a Congressional request for "a plan to achieve a truly integrated ocean observing system," NOPP established Ocean.US to serve as the Nation's focal point for developing an Integrated Ocean Observing System, or IOOS. On the side table, background on Ocean.US Integrated Ocean Observing System plans has been provided. Participation in the development of IOOS and its regional associations will help MMS to facilitate a clear line of communication between IOOS developers and eventual uses in the OCS oil and gas and marine minerals industries.

We are fortunate to have many out of town participants who were able to come a long way to on relatively short notice to attend this meeting. Special welcome is extended to attendees who traveled from out-state-to present and participate.

MMS does not consider this a decision meeting but instead an opportunity to exchange ideas and perspectives and stimulate consideration of them. After the meeting MMS will follow-up with attendees as we proceed with MMS planning and prior to our continued coordination with NOPP.

Mr. Warren Horowitz, Oceanographer, will introduce the objectives we envision for this workshop and related discussions of HF Radar Current Mapping, and Dr. Dave Musgrave, Associate Professor of Marine Sciences, University of Alaska, Fairbanks, will be the Chairperson for the meeting.

Discussion

No discussion.

MEETING GOALS AND OBJECTIVES

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The U.S Minerals Management Service (MMS) is in the early phase of planning two pilot projects to collect surface current data using High Frequency (HF) Doppler Radar. The pilot study areas will be located in the Lower Cook Inlet (Figure 1), overlapping part of the planned Federal OCS Cook Inlet Lease Sale, and in the Beaufort Sea, within the vicinity of the Northstar Production Island (Figure 2). The meeting objectives are:

General Background Information:

- Describe the historical background behind the collection of surface current data from High Frequency (HF) Doppler Surface Radars
- Describe the various system hardware and software configurations, operation, resolution, and footprint
- Describe the multiple uses associated with the collection and distribution of the surface current data
- Describe the applied research associated with the collection of surface current data from High Frequency (HF) Doppler Surface Radars

Beaufort Sea and Cook Inlet Pilot Project

- Define the course of action required to deploy and maintain the High Frequency (HF) Doppler Surface Radars within the Lower Cook Inlet and Beaufort Sea to map, analyze, and disseminate surface current data
- Identify the technical and logistical issues associated with the deployment and maintenance of the instrument hardware and software, in addition to the dissemination of data to the regional users
- Identify yearly costs associated with purchase, deployment, and maintenance of the (HF) Doppler Surface Radar Units in the Beaufort Sea and Cook Inlet, and dissemination of the surface current data to the regional users
- Obtain user input on system design, and work towards a system that is potentially integrated in design and function, and mutually beneficial with the needs of other co-sponsors of these projects.
- Identify those potential users interested in providing their technical, logistical, or monetary support towards the successful implementation and maintenance of these pilot projects

Discussion

No discussion.

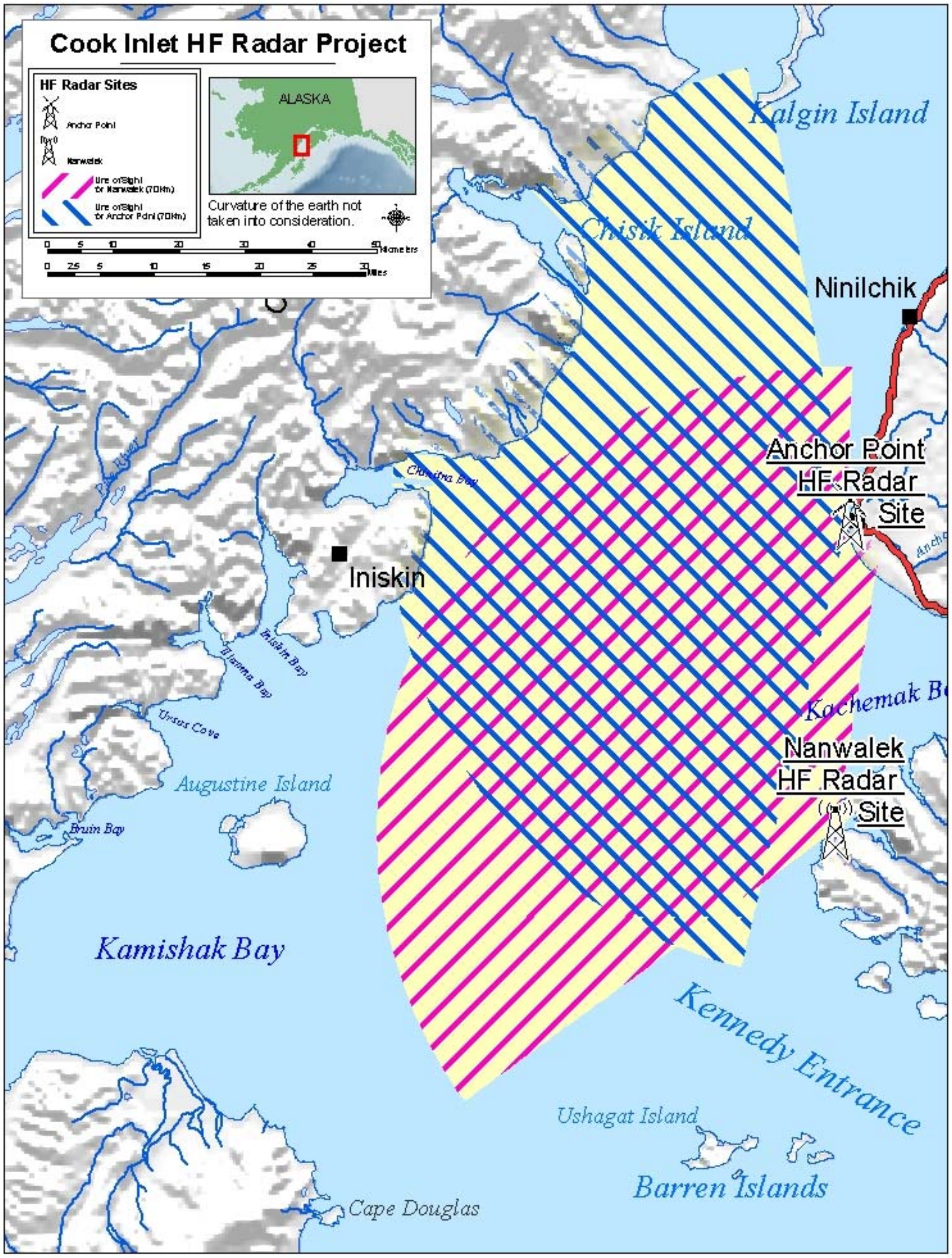

Figure 1. Two proposed locations for high frequency radar surface current mapping units for Lower Cook Inlet at Anchor Point and Nanwalek. The radial range of a medium frequency range system (12 MHz) is shown by the diagonal lines and where the two overlap, two-dimensional velocity vectors are possible. Possibly a third system would be located on the west side of Cook Inlet to further enhance coverage.

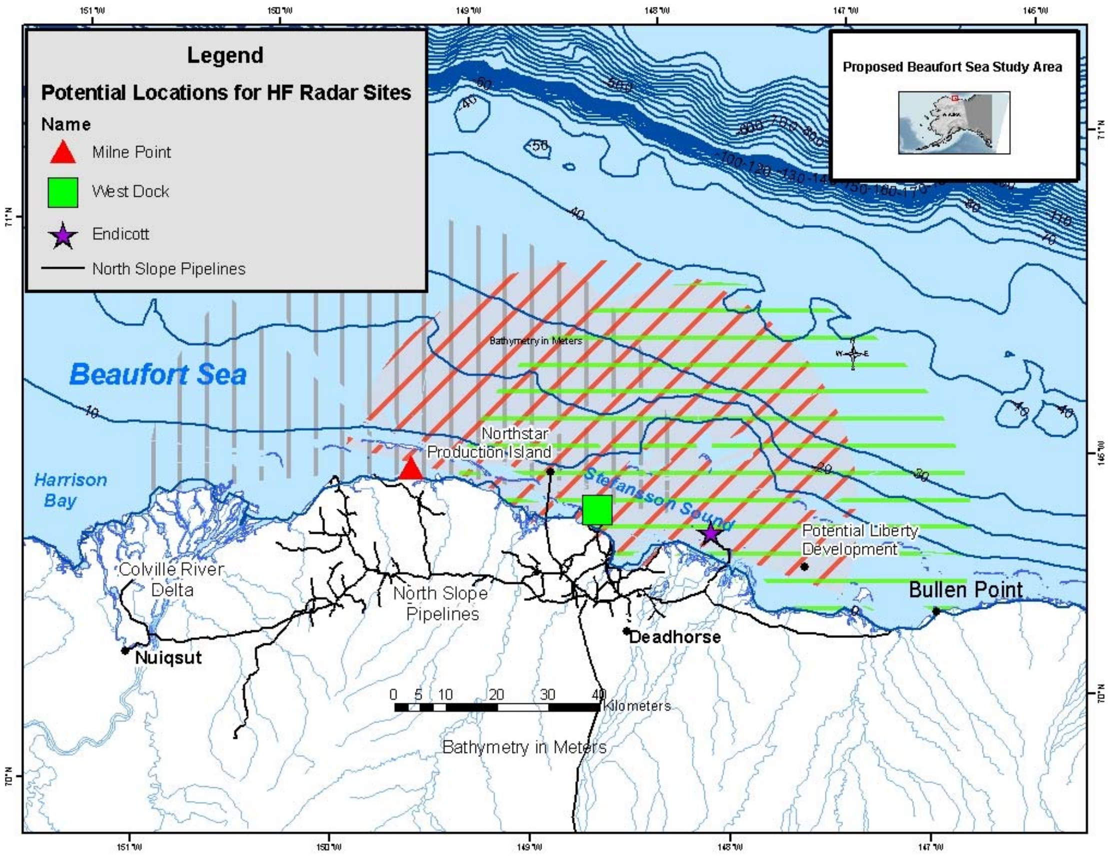

Figure 2. Three proposed locations for high frequency radar surface current mapping units for the Beaufort Sea. The radial range depicts a medium frequency range system (12 MHz) during open water conditions. Depending upon environmental conditions, higher frequencies may be utilized for this study with shorter ranges and greater nearshore surface current resolution.

BASIC CONCEPTS AND LINEAR-PHASED ARRAYS WITH A NOTE ON WIND SPEED MEASUREMENTS

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Measuring surface currents using HF radar relies on the principle of Bragg scattering of an incident electromagnetic (EM) wave by a surface wave of half the wavelength of the EM wave. The incident wavelength depends on the EM frequency, typically in the 5-50 Megahertz (MHz) range, which is close to the very high frequency (VHF) of television broadcasts. The output power is around 40 watts; thus there is no environmental or health hazard associated with this technology. Typically, the transmit and receive antennas are collocated on land adjacent to seawater and the conducting medium of seawater acts as a wave guide for transmission of a ground wave along the surface of the water. This is different than the sky wave that is simultaneously transmitted, which only propagates along the line-of-sight. Thus, the ground wave permits over-the-horizon views of the surface current field and other reflecting objects such as ships.

The echo from the scattered EM wave is Doppler-shifted in frequency from the transmitted frequency due to two things: the phase speed of the surface water wave and the magnitude of the surface current in a direction along radials from the transmit/receive site. The Doppler shift can be computed with insignificant error given the surface wavelength and peaks in the frequency spectrum of the wave echo appear plus or minus the Doppler shift of the transmitted frequency depending on whether the wave is propagating toward or away, respectively, from the transmit/receive site. Any additional shift in frequency (Δf) beyond the Doppler shift is due to the surface current and is equal to $2v/\lambda$, where v, is the surface current speed along radials, and λ is the frequency of the transmitted EM wave.

Since the surface current is only measured along radials from any one site, two sites are required to calculate two-dimensional currents. However, it should be noted that even radial information from one site, in theory, could be assimilated into circulation models thus increasing their accuracy. The precision of the two-dimensional surface vectors is spatially inhomogeneous due to the errors in the radial velocity estimate, but also due to geometry of the intersecting radial velocities (called the geometric dilution of precision, GDOP). For example, on a line between two sites the radial velocities from each site give redundant information on the velocity along that line, but there is no information on the velocity perpendicular to the line. One the other hand, where the radials intersect at 90º, there is no GDOP. Optimal angles are between 60º and 120º.

At any one site, the Bragg wave is received from many targets over a large range of distances and directions. Modern techniques using frequency chirping resolve the range to the target. This is different than older methods of pulsing of the power and timing the return signal to calculate range and is more efficient in terms of power. The angle is more difficult to estimate and much error in surface current mapping is due to errors in determining angle. Two approaches are used for angle determination: one is using a compact array of antennas and the geometry of the antenna patterns to estimate angle of the target, and the other is using a linear phased array of antennas with varying amplitudes and phases in a beam-forming mode. One of advantage of the compact array (and a "direction-finding" algorithm) is that much less beach front is required since the linear phased arrays nominally require about 100 m of shoreline, total, for up to 10 antennas. There are over 100 direction-finding systems and about 10 of the linear phased arrays deployed worldwide.

Spatial resolution of surface currents is dependent on the frequency bandwidth allotted by the Federal Communications Commission (FCC). The range of HF radar for surface current mapping depends on frequency: the lower the frequency the longer the range. The frequency range most often used is between 5 and 15 MHz, which have ranges of between 200 and 70 km, respectively. The range is also dependent on the proximity to the ocean, salinity of the water body, and wave height. Lower salinity seawater attenuates the signal more rapidly. The amplitude of the waves at the Bragg frequency must be at some minimal level (on the order of a few centimeters) but too much of a wave field attenuates the signals.

Comparison of HF radar surface currents with *in situ* observations yields root mean squared (RMS) differences of about 8 cm/s.

HF radar can be used for other environmental products such as mapping wind direction and significant wave height. Signals from low flying airplanes have also been found in Hawaii.

The costs of HF radar systems were addressed by the Ocean.US Surface Current Mapping Initiative Steering Committee. The hardware costs for installation of one site are $110–150K and the installation costs are $40-70K.The annual operating cost depends on the number of technicians required per site, but assuming something like two technicians for every three sites, the cost per site would be $80-120K.

Examples of the linear phased arrays were presented from Hawaii and Italy.

Discussion

Experience in estimating wave directional spectrum using SeaSonde CODAR (compact antenna arrays) versus linear-phased arrays was brought up. At Rutgers, a wave directional spectrum from the CODAR system compares well with that from a wave-rider. However, it was discussed that the CODAR system may not resolve the azimuth, whereas a linear-phased array could.

The antenna pattern of the receive antennas differ from the idealized pattern calculated theoretically. It has been shown that the accuracy of the surface currents can be increased significantly by measuring the real antenna pattern. This is done by transmitting from a boat along a semicircle centered on the receive antenna with a radius of about a kilometer. This takes about an hour and the measured pattern is used to correct the ideal antenna pattern.

CODAR HF RADAR NETWORK DEVELOPMENT FOR LONG-TERM ECOSYSTEM OBSERVATORY, NEW JERSEY SHELF OBSERVING SYSTEM, REGIONAL NORTH EAST OBSERVING SYSTEM, AND SURFACE CURRENT MAPPING INITIATIVE

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Sponsors: Office of Naval Research, National Science Foundation, National Oceanographic Partnership Program, National Oceanic and Atmospheric Administrations, Counter-NarcoTerrorism Technology Program Office, and Dept. of Homeland Security.

New Jersey coastal waters have several scales of bathymetry, including a broad shallow shelf crossed by a deep valley, 50 km scale topographic highs associated with ancient river deltas, and the ubiquitous ridge and swale topography of the shore oblique sand ridges. Coastal ocean processes occur on similar scales, resulting in the development of a nested grid of coastal research observatories, including the Long-Term Ecosystem Observatory (LEO-15) cabled observatory for time series at a point in space, the LEO Coastal Predictive Skill Experiments to collect the spatial datasets required for model assimilation, New Jersey Shelf Observation System (NJSOS) as the sustained spatial shelf-wide observatory, and North East Observing System (NEOS) as a mechanism to develop a linked regional network for the Northeast.

For NJSOS, the three primary technologies, L-Band and X-Band satellite receivers, nested multi-static CODAR HF radars, and a long-duration autonomous underwater glider fleet are operated from a single observatory control room. The present CODAR network includes 25 MHz high resolution and 5 MHz long-range systems, with new 13 MHz systems scheduled for installation by summer. The compact CODAR systems typically consist of a single transmit antenna, and a cross-looped receive antenna on a separate post. Electronics are usually deployed in an environmentally sealed box. They have been installed and continuously operated in a variety of locations around the world, including sustained operations in New Jersey since 1999.

One of the first research projects with the 25 MHz NJ systems was to determine what affects the antenna beam patterns, and how the beam patterns affect ocean current estimates. By comparing different antennas deployed in different locations, system hardware was found to have little effect on the measured beam pattern. The dominant source of distortion was the environment, including buildings, power lines, and other conducting materials within the antenna near field (about one wavelength). Using measured beam patterns improved the ability of the antennas to place the current vectors in the proper directional bins. This enables antennas to be set up in an even wider variety of places. Antenna pattern measurements are also being adopted by the phased array operators, most notably those running the Michigan multi-frequency system.

Antenna calibration, followed by tidal analysis, GDOP constraints, and percent coverage statistics led to the development of a high quality research dataset for seasonal responses, storm responses, and upwelling events. The datasets have been used by the U.S. Coast Guard (USCG) for search and rescue and National Oceanic and Atmospheric Administration (NOAA) HazMat for oil spill response. Nearshore directional wave spectra also are available and are regularly used by NOAA.

In 2000, the first of a series of four long-range (5 MHz) systems was deployed on the New Jersey coast to form a nested array. As usual, the first study was a validation study, and initial results indicated that horizontal shear, not just vertical shear, is an important contributor to the observed RMS difference between subsurface Acoustic Doppler Current Profiler (ADCP) point measurements and the spatially averaged surface CODAR measurements. RMS differences between vertical ADCP bins and between ADCPs deployed several km apart are found to be the same as the difference between CODAR and ADCPs. After accounting for the same time averaging, interpolating adjacent directional bins to the point of the ADCP, and choosing time period with a tight mid-depth thermocline but little stratification in the upper layer, the minimum CODAR/ADCP RMS difference was 2.58 cm/sec, and the RMS difference due to horizontal shear between two ADCPs during the same time period was 2.82 cm/sec. This comparison was conducted using the Tuckerton 5 MHz long-range site, which has our most distorted beam pattern. Thus we conclude that the difference between the CODAR surface currents and the ADCP is real, and associated with a combination of both horizontal and vertical shear.

Measured beam patterns, tidal analysis, GDOP maps and percent coverage maps are now being used to produce a similar research quality dataset. Annual and seasonal variability of the shelf-wide circulation is being studies, with two preferred cross-shelf transport pathways for the Hudson Estuary and Delaware Bay identified for the first time. Storms can now be studied at the synoptic scale. The shelf-wide maps are being used in combination with satellite imagery to direct a fleet of long-duration gliders to study such features as the cross-shelf transport pathways.

The next major improvement in current mapping will be the ability to run CODAR systems in both standard monostatic backscatter mode, and in bistatic mode, where the transmitter is physically separated from the receiver. In this case, constant time delay circles are stretched into ellipses, and the radial current components are now measured along hyperbolas. Multi-static operations turn N radars into N^2 radars, extending coverage nearshore and offshore, further decreasing GDOP, and providing the potential to get the vital cross-shore component of the flow out of estuaries from an offshore platform. Several types of bistatic transmitters have been developed and tested, including shore-to-shore transmissions linking standard backscatter systems through GPS synchronization, boat to shore tests with bistatic transmitters, buoy to shore tests with self-contained bistatic transmitters, and shore-to-shore transmissions with portable bistatic transmitters.

Long-range CODAR systems have now been deployed along most of the Northeast coast, nearly filling in the envisioned regional backbone. This is one prototype for the proposed national HF Radar network currently being proposed by the Ocean.US Surface Current Mapping Initiative. One of the greatest challenges, that of sharing and continuously updating the radial datasets from the numerous sites in this network is being addressed by Scripps Institution of Oceanography.

A third application of HF Radar is that of vessel tracking. It is easy for a vessel to hide from a single radar by making its speed toward or away from the radar similar to that of the Bragg waves. However, a ship cannot simultaneously hide in the Bragg peaks of multiple radars. Thus multistatic networks for small radars provide an attractive alternative to single large vessel tracking radars. Vessel tracking involves three steps, detection of the vessel peaks above a time and spatially varying background noise, association of a series of detections with a specific vessel, and fitting of a model track to the associated detection data. The simplest track model breaks the track into a series of linear segments of constant course and speed. It is found that once the Kalman filter locks on the track, it is good at holding the track. Similar to the experiences of submarine tracking, Kalman filters are found to be good track keepers, but not good track finders.

To improve the ability to find that track, to aid in the association step in a multi-ship environment, and to improve the range of detection for smaller vessels, new superdirective compact antennas are being constructed and tested.

Discussion

The effect of hard targets (ships) in the field of view of the surface current can affect the estimation of surface currents. But they are not moving at the speed of the Doppler-shifted Bragg peak and their signal is smaller than the Bragg peak. If you know the position of the ship you can ignore the current measurement from that location until the ship moves to a new position. Ships usually move at speeds that would take them from one bin to the next over the period of averaging (nominally 15 minutes).

The Department of Homeland Security has funded research into using HF radar for ship detection.

The Rutgers group is providing data to the University of Connecticut which runs a prediction model, the output of which goes to the USCG in North Carolina for search and rescue operations.

A short note on the use of various types of information and methods that the USCG uses for search and rescue was brought up. Any information available (winds, currents, etc.) is used by the person in charge of the rescue to estimate conditions and location of a rescue target.

ASSIMILATION OF SURFACE VELOCITIES INTO OCEAN CIRCULATION MODELS OFF OREGON

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Results from a project to study assimilation of HF radar surface current measurements off Oregon in coastal ocean models are presented. Two complementary approaches have been taken. In one approach, an optimal, variational, generalized inverse data assimilation technique has been utilized in a simplified linear, frequency-domain, three-dimensional primitive equation model to investigate the characteristics of the M_2 internal tide (Kurapov, et al., 2003). The inverse model is applied to a 38 km x 57 domain off the mid-Oregon coast. Most of the baroclinic signal comes from outside the computational domain and so data assimilation (DA) is used to restore baroclinic currents at the open boundary. Harmonic analysis of currents from HF radars and an acoustic Doppler profiler (ADP) mooring off Oregon for May–July 1998 reveals substantial intermittence of the internal tide, both in amplitude and phase. Assimilation of the surface current measurements captures the temporal variability and greatly improves the model agreement with the unassimilated depth-dependent ADP measurements. Despite significant temporal variability, persistent features are found for the period studied; for instance, the dominant direction of baroclinic wave phase and energy propagation is always from the northwest. At the surface, baroclinic surface tidal currents (deviations from the depth-averaged current) can be 10 cm s^{-1}, two times as large as the depth averaged current. Overall, the inverse solution provides a uniquely detailed picture of the temporal and three-dimensional spatial variability of the M_2 internal tide that could not reasonably be obtained in any other way.

In the second approach, a data assimilation system (DAS) based on a sequential optimal interpolation scheme for the full nonlinear, three-dimensional primitive equations is developed and applied to studies of the sub-inertial frequency, wind-forced, mesoscale circulation (Oke, et al., 2002). The DAS assimilates low-pass filtered HF radar current velocity measurements. Inhomogeneous and anisotropic estimates of the forecast error covariances required for the assimilation are assumed to be proportional to typical cross-correlations between modeled variables. These correlations are estimated from an ensemble of model simulations for 18 different summers. A time-distributed averaging procedure that effectively low-pass filters the model forecast for comparison with the observations and introduces the corrections to the model state gradually over time is used in order to overcome problems of data compatibility and initialization. The correlations between direct subsurface current measurements and subsurface currents obtained from model-only and assimilation experiments for the summer of 1998 are 0.42 and 0.78, respectively, demonstrating the effectiveness of the DAS. Estimates of the error covariances are shown to be appropriate through a series of objective statistical tests. Analysis of the term balances of the model equations show that the dominant modeled dynamical balances are preserved by the DAS and that uncertainties in the spatial variability of the wind forcing are likely to be one source of model error. Planned future research includes efforts to merge the two approaches by developing a DAS that utilizes a variational assimilation scheme with the full nonlinear primitive equations.

References

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Oke, P. R., J. S. Allen, R. N. Miller, G. D. Egbert, and P. M. Kosro, 2002. Assimilation of surface velocity data into a primitive equation coastal ocean model. *J. Geophys. Res.*, **107**(C9), 3122, doi:10.1029/2000JC000511, 2002.

Discussion

It was mentioned that less sophisticated modeling methods exist than data assimilation into numerical ocean circulation models. For example, simple Lagrangian models based on hourly surface current maps have been used for search and rescue and oil spill trajectory analysis.

POWER, DATA TRANSMISSION, AND SITE SUITABILITY ASSOCIATED WITH THE BEAUFORT SEA AND COOK INLET

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Siting issues in Cook Inlet and the Beaufort share some common issues with those in other, more populated areas of the US. However, the remoteness of these areas and the large amount of public land near these waters may require special attention. The main areas of concern are permitting and land ownership, coastal topology, remote power and data transmission, vandalism, uses of short, standard or long range HF radar systems, bathymetric issues, and use in waters where ice is present.

A permit from the FCC is required for each HF radar site but this is usually not a very difficult hurdle and the process usually requires about 3-6 months.

Many potential sites on public property are eliminated due to the nature of the restrictions on the public lands, e.g., national marine reserves, or wilderness areas. Other potential sites on public property (local, state, or federal) may require a site-use permit, which could take up to a year or more. The permit process may involve site-visits by a number of interested agencies. The permit may address provisions for minimum visual impact, restricted vertical extent and footprint area, and minimization of potential environmental risk. For example, in the case where autonomous power from generators is required, propane may provide less environmental risk, even though diesel is cheaper. The permanent sites require a more complicated and time consuming permit process than temporary sites.

Alaska has a very complicated coastline, which means that the field of view may be obscured by headlands. Headlands may offer the largest field of view, but in Alaska this advantage is often offset due to the very rugged topography of the Alaska coast that often has mountains that come very steeply right into the water. Thus a site that may offer a tremendous field of view may not have usable locations that are close enough to the water or level enough for remote power generation and operation of the transmit/receive antennas and associated hardware. Many areas of the coast have offshore islands that may limit the range of the HF radar. However, some islands are low enough that the signal can propagate over the island, e.g., Kalgin Island in Cook Inlet.

The topography and coastline geometry of Cook Inlet and the Beaufort Sea are very different. Cook Inlet has steep mountains on the west side and somewhat flatter topography on the east side although there is generally a 100 – 400 ft bluff on the east side. There are very few islands to obstruct the field of view of the HF radars. The cross-inlet distance is nominally between 40 km to 120 km in upper and lower Cook Inlet. Based on ranges, thus the 6 and 12 MHz systems would be appropriate for the upper and lower Cook Inlet respectively (ranges of 70 and 200 km). The large tides in Cook Inlet yield large tidal flats that may attenuate the range during low tide.

The Beaufort Sea is on a coastal plain that is much flatter than Cook Inlet. Thus locating closer to the water may be easier than in Cook Inlet. The tides are inconsequential and attenuation due to exposed tidal flats may not be an issue. However, the offshore barrier islands may attenuate the signal. These are very low islands and based on experience in Cook Inlet (Kalgin Island) they may not present a significant problem.

In many sites, no power grid is available and a remote power supply must be installed. The power used by a site is about 2.5 kilowatts (kw). This includes the power required for cooling the electronics associated with the transmitter and receiver. New HF radar designs operate on 24 VDC power and have reduced the power requirement to about 500 w, which does not include cooling for an additional 500 watts (w) for heating in the winter in Alaska. The Sea-Air-Land-Monitoring-and-Observing Network (SALMON Project) has developed a remote site system that includes a 5 kw liquid cooled propane generator, batteries to store energy, and optional wind turbine or solar panels. We estimate that the power from wind turbines or solar panels alone is not sufficient to supply the 500-1000 watts required for a HF radar site. In order to run such a system autonomously, we have developed a monitoring system for the power generation system that provides real-time data on power generation, usage and battery charge status, and permits remote intervention from a central site.

Although some uses of HF radar for surface current maps may not require real-time data transmission, the ability to monitor and assure the collection of the data in real time is invaluable. There are several methods for remote data transmission. Wireless networks can sometimes extend 2-10 miles although at any particular site, this may vary wildly. The SALMON Project uses StarBand satellite connection to the Internet with a 1.8 m dish and we have obtained download speeds of 54 kbps, and upload speeds of 144 kbps. The initial cost is about $2,000, not including installer's time and operating costs are about $1,000/year.

The electronics for the HF radar transmit/receive chassis, Starband modem, computers, and power generator monitoring system are housed in an insulated three-piece Plaschem Volcano Hut (5 ft x 5 ft x 5 ft).

Many of the issues of remote power and data transmission can be solved by large budgets. For example, the USCG radio repeaters, which use 250 watts, cost about $250K versus our system of about $25-50K. The estimated operating costs of our system, including travel for refueling and troubleshooting, is about $50K per year, not including personnel costs.

Human and non-human vandalism are potential problems in Alaska. The non-human vandalism can be from large mammals, particularly bears, or small rodents. The bear problem is a particularly acute problem and electrified fences around the hut, generator, and transmit antenna may solve the problem, but our experience shows that they cannot be used around the receive antenna.

Bathymetry can be an issue since the calculation of wave speed at the Bragg frequency assumes that the depth of the water must be greater than one-fourth of the surface wavelength. Thus for the long range HF radar (6 MHz), the depth must be greater than 8 m. For the short range (25 MHz) the depth must be greater than 1.5 m, which may be an issue in the Beaufort Sea. However, with detailed bathymetry, one does not have to use the deep-water approximation for calculation of wave speed. In Cook Inlet the depths are sufficient to use the deep-water approximation.

Waters that contain ice are common in Alaska. It is not clear how the HF systems will operate in these areas. If the under-ice wave field is manifested at the ice surface, then the Bragg scattering will occur although the wave speed calculation would have to be changed to include ice over water. It is not clear if the signal would propagate over ice to any extent, thus limiting the useful range.

In the Beaufort Sea, there is only a limited season of open water. During June, July, and August, there are leads of open water but ice is still present. Freeze-up ensues in October. Operation of HF radars during these periods when the ice coverage is less than 100% may clear up questions about the use of HF radar for surface current mapping when ice is present. Cook Inlet usually has ice present in the upper inlet during the winter months and there is a lot of interannual variability. In the winter of 2003, we did not encounter any ice during our deployment, but this is extremely rare.

Discussion

There were questions regarding the operation of HF radar for surface current mapping during periods when ice is present. The following discussion was mostly speculative since very few studies have been done. There will be a Bragg reflection due to any feature that has the Bragg wavelength, such as ice ridges or under-ice waves that are expressed at the ice surface. These will be Doppler shifted depending on the speed of the ice or the wave. It is not clear if ice will attenuate the HF radio wave, but it is certainly not a conducting medium and is more like fresh water in this sense and may attenuate the signal. It was not considered informative to collect data during the winter season for the purposes of MMS.

It was mentioned that HF radar could be used to map the bottom bathymetry.

PANEL DISCUSSION

Panel members included Scott Glenn, Pierre Flament, Alexander Kurapov (Oregon State University), Karen Grissom (NOAA), Brian Haus (University of Miami), Hank Statscewich (University of Alaska Fairbanks), and Dave Musgrave (moderator, University of Alaska Fairbanks).

What is the usefulness of long-term surface current mapping for Alaskan waters?

Climate change over interannual, pentadecadal, and decadal times could be addressed.

Could we get the kind of information on a large enough scale to address large-scale issues of importance to Alaska, such as fisheries?

The Arctic is one place where climate change is expected to be the greatest. Any long-term information about surface currents, even though over small spatial scales, can be used to interpret such things as changes in temperature.

In terms of fisheries, larval transport can be addressed with surface current maps.

Can sufficient information be obtained from surface current maps to address issues like larval transport?

Surface current mapping has the power of mapping spatial variability of surface currents that other methods, like current meters, cannot do as inexpensively. Surface current mapping is part of a suite of techniques that can be used to observe the ocean environment.

On the east coast, the New Jersey Observing System has had surface current mappers in for several years and is developing information on seasonal interannual variability over large scales.

Chesapeake Bay has had discontinuous surface current mappers since 2001.

A short-term deployment, several months, will yield the tidal constituents, but what else is to be gained by longer-term deployments?

In Chesapeake Bay, the early record did not show any upwelling but longer-term deployments caught these events.

Preferred pathways for the variability of cross-shelf transport become apparent with longer-term deployments. To understand the variability of the longer temporal scales, measurement over longer spatial scales is required.

What is the ability for surface current mappers to resolve small-scale spatial variability, for example, the tidal rips in Cook Inlet that have scales of 100 m or less.

The use of higher frequencies may help as long as sufficient bandwidth can be obtained from the FCC. Long-term averaging may bound the region of small scale variability but individual realizations at any one time will be difficult. Additionally, the period of temporal averaging may have to be decreased to account for real temporal variability of the location of fronts. Microwave radar may be better at resolving small spatial scales. Any one system could be tuned to decrease the area and time over which the data is averaged and therefore obtain greater resolution in time and space. However, the errors associated with the higher resolution data will be greater. The system can be tuned to higher resolution when collecting the data or during post-processing of the data. The spatial resolution is determined by the bandwidth assigned by the FCC. In Alaska, there may be less competition for bandwidth and therefore a greater possibility of obtaining more bandwidth. However, interference can come from distant parts of the world so local interference in a low demand area like Alaska may not be the issue when requesting bandwidth.

Can you address non-stationary processes?

The signal to noise ratio is increased by averaging over longer periods but then any real variability is smoothed. Other ancillary observations with higher resolution, such as Synthetic Aperture Radar imagery, could be used with surface current mappers to develop products that could address small spatial scale variability. Surface current mappers combined with other observations could be used with models to address short time and space scales.

Can CODAR help with the modeling effort in Cook Inlet?

Acoustic Doppler Current Profilers and surface current mappers may help, but there are more questions that need to be answered first. What is the necessary resolution? What are the dominant forcing fields? How does the spatial pattern vary with the internal tide?

To answer these questions, one could develop a process study model, and then utilize model and data**.**

Is HF radar the best way to increase model accuracy?

It is difficult to know that now. Detailed information the on horizontal and vertical stratification and current shear is needed.

Has HF radar been used in ice areas?

Yes. Donald Barrick did this in the early in the 1960s or 1970s but used transponders on the ice to detect ice movement. The real question is whether there are any waves at the Bragg peak. A discussion ensued regarding the possibility of waves or period phenomena, such as ice ridging, at the Bragg peak: for example, under ice waves.

The Japanese have had several microwave radars off Hokkaido tracking ice, but they are limited in range to about 600 m. However, the microwave radars are expensive and are being decommissioned. HF radar will not be as good at ice tracking. The Canadians are tracking icebergs off George's Bank with HF radar.

There is still an issue of accurate surface current maps in regions where ice is partially present.

Also the issue of fetch is important since in partially ice-covered waters there may not be enough fetch to generate a wave field for the Bragg reflection. Smaller wavelengths are more likely to be generated in such an environment, so high frequencies would be better.

What is the realistic cost of operation and maintenance? How many people does it take to run a system?

A discussion about the number of people per radar site led to various estimates. If two people can maintain three radars, then that is between \$100,000 - \$150,000 in salaries (with benefits, etc.). The Ocean.US Surface Current Mapping Initiative had a range of three to five sites serviced by two people. The number of people and the cost for logistics will be greater in Alaska. This assumes a 24/7 operation. If it is somewhat less reliable, the cost will go down.

What are the capitalization costs and how often does a system have to be replaced?

Every five years for the HF radar hardware and every two years for generators.

Is MMS interested as part of their initiative in other measurements such as in situ current profiles from ADCPs?

Other measurements for the validation of surface current mappers are ADCPs. In fact, if one is interested in subsurface currents and there is vertical shear, as exists in Cook Inlet, then *in situ* measurements are necessary. Assimilation of surface current maps into circulation models may lead to estimates of subsurface currents for practical use in oil spill response or search and rescue.

Gliders have been used in other regions for validation but the tidal currents in Cook Inlet are too large for their use.

Horizontal shear is also important especially in Cook Inlet. For validation purposes you would want located auxiliary measurements in regions of low shear, but for measuring horizontal variability you would want measurements in regions of different currents.

MMS may have limited funds available for this initiative and therefore may limit the observations to a minimum.

WORKSHOP RECOMMENDATIONS
FROM THURSDAY MORNING BREAKOUT GROUPS

The Cook Inlet group identified three primary sites for locating SCMs. Nanwalek and Anchor Point are south and north, respectively, of Kachemak Bay on the east side and the Silver Salmon Creek Lodge owned by David Coray is on the west side. Both Nanwalek and Anchor Point have been used as sites for SCMs in 2003. The Nanwalek site is on tribal land and permission could be easily obtained if some financial support and training on the use of the interpretation of the data was available. The Anchor Point site may be private or local, state or USCG land. All sites probably have power and data communication capabilities.

Other potential secondary sites in Cook Inlet were Ninilchik, Humpy Point and other points to the north to increase coverage to the north. A pair of high frequency (25-50 MHz) systems is desirable for Kachemak Bay.

The cost of three standard range (12 MHz) systems were estimated to be $500,000 to purchase and install the systems and $250,000 per year for full support, including some funding for local support and for centralized equipment and technicians. Local support for basic maintenance is available in lower Cook Inlet.

The Beaufort Sea breakout group identified three sites for locating standard range (12 MHz) SCMs at Endicott, West Dock, and northeast of Oliktok Point. These locations have power and possibly data communication capabilities. The deployment of SCMs should occur from just before the ice goes out until it returns. Costs estimates were similar to those of the Cook Inlet group: $500,000 initially and $250,000 per year for full support.

APPENDIX A

ATTENDEE LIST

MMS Research Sponsorship Workshop
March 31 and April 1, 2004
Anchorage, AK
Final Attendee List

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APPENDIX B

AGENDA

FINAL AGENDA

Minerals Management Service (MMS)-Alaska OCS Region Research Sponsorship Meeting on the Mapping of Surface Currents from High Frequency Radar in the Cook Inlet and Beaufort Sea, Alaska

Wednesday, March 31, 2004

Time	**Title of Presentation and Speakers**
8:00 am	Registration: (coffee, tea and other items)
8:30 am 8:45 am	Minerals Management Service (MMS) Introduction *Cleve Cowles, Ph.D., Chief Environmental Studies Section (ESS), MMS*
8:45 am 9:00 am	Minerals Management Service Meeting Goals and Objectives for MMS's HF Radar Current Mapping Project for Cook Inlet/Beaufort Sea *Warren Horowitz, ESS, Alaska OCS Region*
9:00 am 10:00 am	Basic Concepts and Linear-Phased Arrays with a Note on Wind Speed Measurements *Pierre Flament, Associate Professor, Department of Oceanography, University of Hawaii*
10:00 am 10:15 am	Break
10:15 am 11:15 am	CODAR HF Radar Network Development for LEO, NJSOS, NEOS, and SCMI *Scott Glenn, Professor, Institute of Marine and Coastal Sciences, Rutgers University*
11:15 am 12:00 pm	Assimilation of Surface Velocities into Ocean Circulation Models off Oregon *John Allen, Professor Emeritus, College of Ocean and Atmospheric Sciences, Oregon State University*
12:00 pm 1:00 pm	Lunch (on your own)
1:00 pm 2:00 pm	Power, Data Transmission, and Site Suitability Associated the Beaufort Sea and Cook Inlet *Dave Musgrave, Associate Professor, University of Alaska Fairbanks*
2:00 pm 3:00 pm	Panel Discussion on Applications of HF radar for surface current mapping in Cook Inlet and Beaufort Sea. Participants*: Scott Glenn, Pierre Flament, Alexander Kurapov, Karen Grissom, Brian Haus, Hank Statscewich, and Dave Musgrave (moderator)*
3:00 pm 3:15 pm	Break
3:15 pm 4:00 pm	Breakout Group Discussion on Potential Government and Industry Support in Assisting the Deployment and Operation of MMS's Proposed HF Radar Current Mapping Project for Alaska and Development of Alaska Radar Surface Current Mapping Users Consortium. *(Meeting Participants such as MMS, AOOS, NOAA, OSPRI, UAF, Office of Naval Research, and others)*
4:00 pm 5:00 pm	Breakout Group Discussion on Statements by Participants of their Interest in the Use of HF Radar Units to Map Surface Currents in Cook Inlet and Beaufort Sea. *(MMS, AOOS, NOAA, OSPRI, KBRR, UAF, Office of Naval Research, NSF, and others)*
5:00 pm	Adjourn for Evening
Time	**Thursday, April 1, 2004**
8:00 am	Registration: (coffee, tea and other items)
8:30 am 8:45 am	Review of Previous Day, *Dave Musgrave, University of Alaska Fairbanks*
8:45 am 11:00 am	Breakout Group Discussion on Workshop Consensus Recommendations on How to Proceed Toward the Development of HF Radar Systems for Cook Inlet and Beaufort Sea. *(All Participants)*
10:00 am 10:15 am	Break
11:00 am 12:00 pm	Summary of Workshop and Future Directions, *Dave Musgrave, University of Alaska Fairbanks*
12:00 pm	Adjourn Meeting

Additional notes:

Drs. Flament and Glenn will be presenting basic background on the theoretical principles regarding the use of HF Radar for surface current measurements.

Dr. Flament will cover:
- The principles of Bragg scattering
- Frequencies and wavelengths
- Ground waves versus sky waves
- Doppler shifting due to wave speed and current speed
- Configuration of linear-phased arrays and beam-forming for determining bearing to target
- Experiences with linear-phased arrays and the *WERA* (proprietary) HF radar systems

Dr. Glenn will cover:
- Configuration of collocated receive antennas and direction finding algorithms
- Bistatic versus monostatic sites
- Comparison of *in situ* data with Surface Current Mappers.
- LEO-15 experience with data assimilation of surface currents into models
- Using surface currents maps for trajectory analysis
- Federal Surface Current Mapping Initiative

Dr. Allen will present and in depth analysis of assimilating surface currents into ocean circulation models off the Oregon coast.

Dr. Musgrave will present issues of concern in implementing Surface Current Mappers in Alaska including:
- Permitting (FCC and site use)
- Footprint
- Remote power and data transmission
- Coastline constraints
- Coastal topographic constraints
- Bathymetric constraints
- Ice constraints
- Issues specific to Cook Inlet and Beaufort Sea

The Panel Discussion is designed to give participants an opportunity to ask questions about the theory and use of HF radar for surface current mapping. The panel members all have experience in operating SCMs or the use of SCM data in models.

Since there will be up to forty participants, it will be more efficient to use four breakout groups of about ten participants each to discuss interests, support and the workshop consensus recommendations. A discussion leader and rapporteur will be selected for each group. Specific questions will be provided for the groups to consider:

Breakout Session Potential Government and Industry Support:
- What financial support is available?
- What support is available in terms of sites, power, and data transmission?
- What logistical support is available in terms of shipping and transportation of personnel and equipment?
- What support is available for room and board of personnel?
- What support is available for personnel to help with on site issues (checking equipment, flicking switches, changing disks, etc.)?

Breakout Session on Participants Interests:
- What is your interest in the use of the surface current maps?
- What is your interest in other uses of HF radar (waves, ship detection)?
- What is your region of geographic interest?

Breakout Session on Workshop Recommendations:

- What are the steps in implementing a pilot project for SCMs in Cook Inlet and the Beaufort?
  - Permits (land use and FCC)
  - Remote power or data transmission
  - Monostatic or bistatic systems
  - Constellation of SCMs
  - Frequency of HF radar (short, standard or long range)
  - Ice issues and timing of deployment
  - Phased timing of implementation
  - Estimate of costs

Plenary sessions reviewing the results of the breakout groups will be presented Thursday morning at 8:30 am and at the end of the meeting at 11:00 am.

MARCH 3, 1849

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil, and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely, and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States, and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.