Coastal Marine Institute

University of Alaska

Annual Report No. 14

Federal Fiscal Year 2007

OCS Study MMS 2008-014

Submitted by
Michael Castellini
Director
University of Alaska Coastal Marine Institute

to

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

October 2007

Minerals Management Service
Department of the Interior

and the

School of Fisheries & Ocean Sciences

University of Alaska Fairbanks

This study was funded in part by the U.S. Department of the Interior, Minerals Management Service (MMS), through Cooperative Agreement No. 0102CA85294, Task Order No. 72929, between the MMS, Alaska Outer Continental Shelf Region, and the University of Alaska Fairbanks.

Contact information

email: sharice@sfos.uaf.edu
phone: 907.474.7208
fax: 907.474.7204
Coastal Marine Institute
School of Fisheries and Ocean Sciences
University of Alaska Fairbanks
P. O. Box 757220
Fairbanks, AK 99775-7220

Contents

Introduction

The University of Alaska Coastal Marine Institute (CMI) was created by a cooperative agreement between the University of Alaska and the Minerals Management Service (MMS) in June 1993, with the first full funding cycle beginning late in (federal) fiscal year 1994. CMI is pleased to present this 2007 Annual Report, our fourteenth annual report and the fifth and final one under MMS Cooperative Agreement 0102-CA-85294.

The Minerals Management Service administers the outer continental shelf (OCS) natural gas, oil, and marine minerals program overseeing the safe and environmentally sound leasing, exploration, and production of these resources within our nation's offshore areas. The Environmental Studies Program (ESP) was formally directed in 1978, under Section 20 of the OCS Lands Act Amendments, to provide information in support of the decisions involved in the planning, leasing, and management of exploration, development, and production activities. The research agenda is driven by the identification of specific issues, concerns, or data gaps by federal decision makers and the state and local governments that participate in the process. ESP research focuses on the following broad issues associated with development of OCS gas, oil, and minerals:

- What are the fates and effects of potential OCS-related pollutants (e.g., oil, noise, drilling muds, and cuttings, products of fuel combustion) in the marine and coastal environment and the atmosphere?

- What biological resources (e.g., fish populations) exist and which resources are at risk? What is the nature and extent of the risk? What measures must be taken to allow extraction to take place?

- How do OCS activities affect people in terms of jobs and the economy? What are the direct and indirect effects on local culture? What are the psychological effects of the proposed OCS activites?

Because MMS and individual states have distinct but complementary roles in the decision-making process, reliable scientific information is needed by MMS, the state, and localities potentially affected by OCS operations. In light of this, MMS has developed a locally managed CMI program. CMI is administered by the University of Alaska Fairbanks School of Fisheries and Ocean Sciences. Alaska was selected as the location for this CMI because it contains some of the major potential offshore oil and gas producing areas in the United States. The University of Alaska Fairbanks is uniquely suited to participate by virtue of its flagship status within the state and its nationally recognized marine and coastal expertise relevant to the broad range of OCS program information needs. In addition, MMS and the University of Alaska have worked cooperatively on ESP studies for many years. Research projects funded by CMI are required to have at least one active University of Alaska investigator. Cooperative research between the University of Alaska and state agency scientists is encouraged.

Framework Issues were developed during the formation of CMI to identify and bracket the concerns to be addressed:

- Scientific studies for better understanding marine, coastal, or human environments affected or potentially affected by offshore oil & gas or other mineral exploration and extraction on the outer continental shelf;

- Modeling studies of environmental, social, economic, or cultural processes related to OCS oil & gas activities in order to improve scientific predictive capabilities;

- Experimental studies for better understanding of environmental processes or the causes and effects of OCS activities;

- Projects which design or establish mechanisms or protocols for sharing of data or scientific information regarding marine or coastal resources or human activities to support prudent management of oil & gas and marine minerals resources; and

- Synthesis studies of scientific environmental or socioeconomic information relevant to the OCS oil & gas program. Projects funded through CMI are directed toward providing information which can be used by MMS and the state for management decisions specifically relevant to MMS mission responsibilites.

Projects must be pertinent to either the OCS oil and gas program or the marine minerals mining program. They should provide useful information for program management or for the scientific understanding of potential environmental effects of resource development activities in arctic and subarctic environments.

Initial guidelines given to prospective researchers identified Cook Inlet and Shelikof Strait, as well as the Beaufort and Chukchi seas, as areas of chief concern to MMS and the state. Primary emphasis has subsequently shifted to the Beaufort Sea, and to the Chukchi Sea as it relates to the Beaufort Sea. Upcoming interest in the North Aleutian Basin will also begin to see information needs.

The proposal process is initiated each summer with a request for proposals to addressing one or more of the Framework Issues. This request is publicized and sent to researchers at the University of Alaska, to various state agencies, and to relevant profit and non-profit corporations. The proposals are reviewed both externally and by MMS internally. The CMI technical steering committee then decides which proposals should be recommended to MMS for funding.

Successful investigators are strongly encouraged to publish their results in peer-reviewed journals as well as to present them at national meetings. In addition, investigators report their findings at the CMI's annual research review, held at UAF in February. Some investigators present information directly to the public and MMS staff in seminars.

Alaskans benefit from the examination and increased understanding of those processes unique to Alaskan OCS and coastal waters because this enhanced understanding can be applied to problems other than oil, gas, and mineral extraction, such as subsistence fisheries and northern shipping.

Many of the CMI-funded projects address some combination of issues related to fisheries, biomonitoring, physical oceanography, and the fates of oil. The ultimate intent of CMI-related research is to identify the ways in which OCS-related activities may affect our environment, and potential economic and social impacts as well.

On-Going Studies:

Pre-migratory Movements and Physiology of Shorebirds Staging on Alaska's North Slope

Abby N. Powell

ffanp@uaf.edu
Institute of Arctic Biology and USGS Alaska Cooperative Fish and Wildlife Research Unit
University of Alaska Fairbanks
Fairbanks, AK 99775-7020

Audrey R. Taylor

ftart@uaf.edu
Department of Biology and Wildlife
University of Alaska Fairbanks
Fairbanks, AK 99775

Richard B. Lanctot

Richard_Lanctot@fws.gov
U.S. Fish and Wildlife Service
Migratory Bird Management
1011 East Tudor Road, MS 201
Anchorage, AK 99503

Task Order: 35269

Abstract

This project was initiated to gain a better understanding of the abundance, distribution, phenology, movements, and physiology of post-breeding shorebirds during the staging period, and to aid in assessing how future industrial and human activity across the North Slope may affect shorebird populations. We studied staging shorebird populations on the Slope using a two-level approach: (1) a site-specific, in-depth analysis of staging phenology, behavior, and physiology at six locations across the North Slope, and (2) a broad-scale aerial survey and telemetry effort to investigate pre-migratory shorebird abundance, distribution, and movement patterns across the entire North Slope coastline.

To date, we have found that staging shorebirds are patchily, rather than uniformly, distributed across the coast of the North Slope. Hotspots of shorebird abundance occurred in both 2005 and 2006 at Icy Cape, Peard Bay, Elson Lagoon, the east side of Dease Inlet, Pogik Bay, and Beaufort Lagoon/Icy Reef. High densities of phalaropes were also found on the inner shores of the barrier island systems where gravel beach habitat was protected from wave action. Dates of peak abundance differed significantly across our five main study species: Semipalmated Sandpipers showed the earliest peak staging date (2 August), while Dunlin showed the latest (21 August); Western Sandpipers and both phalarope species were intermediate in peak abundance date (13 August). Juvenile birds of all species except Dunlin were present at staging areas later than adult birds, reflecting the tendency of most shorebirds to exhibit age-segregated fall migration.

We estimated tenure time across all species to be 6.5 days (95% confidence interval: 3.4-9.6 days). Detection probability for all species (conditional upon survival) was 68% (95% CI: 58-78%). Species-specific differences in tenure time were supported by our second-best model, with Semipalmated Sandpipers exhibiting shortest tenure times, Dunlin the longest, and Western Sandpipers/phalaropes intermediate in tenure time length. The majority of our data on movement patterns between locations on the North Slope come from Semipalmated Sandpipers, which typically moved north along the Chukchi Sea and/or east along the Beaufort Sea to the Canning River Delta, with an average movement vector of 97° vector (circular std. dev = 31.4°). We did not obtain enough telemetry detections for remainder of the species to perform statistical analysis of the data. However, on average Dunlin moved west along the Beaufort coast to Point Barrow, then southwest along the Chukchi toward the Yukon Delta. Western Sandpipers tended to remain at a single staging area (camp) rather than moving between areas. Red and Red-necked Phalaropes did not show a distinct pattern or direction of movement, although our data for these species are sparse.

Our analysis of the relationships between fattening rates, stress hormone concentrations, and food availability for staging shorebirds across the North Slope are ongoing. In previous years, we found interspecific differences in fattening rates (assessed by plasma triglyceride concentrations) between Semipalmated Sandpipers, Western Sandpipers, and Dunlin. In 2006 we investigated whether we can reasonably compare fattening rates across species since Dunlin

are molting during staging whereas the sandpiper species are not. We found no effect of molt score on either baseline or maximal corticosterone levels in adult or juvenile Dunlin, and our repeated measures analysis indicated that individual birds did exhibit a distinct rise in corticosterone (the adrenocortical stress response) after 30 minutes of being held. In addition, there was a positive relationship between molt score and fat score, indicating that Dunlin are able to simultaneously molt and fatten in preparation for migration. Thus, we plan to continue our comparative analysis of physiological fattening rates and body condition of Dunlin, Semipalmated Sandpipers, and Western Sandpipers.

Introduction

Preliminary work conducted in the 1970's in Barrow, Alaska, indicated that arctic littoral habitats were of critical importance for most arctic-breeding shorebirds during the staging period (prior to southbound migration to wintering areas). However, little information exists to quantify pre-migratory shorebird use of Alaska's North Slope or what factors may influence site use. This information is critical given increased levels of human activity and development near littoral areas across the Arctic Coast. Pre-migratory shorebirds depend on resources found in coastal areas on the North Slope to acquire fat necessary for southward migration. Prior to fall migration, many species of Arctic-breeding shorebirds depart tundra breeding areas for littoral staging sites, where they concentrate in habitat types that allow rapid fat deposition. Connors et al. (1984) documented that the densities of post-breeding shorebirds using North Slope littoral zones were much higher than densities on adjacent tundra breeding areas. A more recent study of shorebirds staging at the Colville River Delta estimated that 41,000 individuals might use the delta prior to and during fall migration (Andres 1994). However, the survey information needed to estimate shorebird use of coastal staging areas exists for only a limited number of sites (e.g., Barrow: Connors et al. [1984], Canning River Delta: Martin and Moiteret [1981]), and biologists are currently unable to determine the degree to which habitat alterations and disturbance may affect shorebird populations staging in littoral zones along the Arctic coast (Brown et al. 2001). Increased energy and residential development along the North Slope has created the potential for disturbance, habitat modification, and oil spills to impact a large segment of a species' population. Shoreline oiling from offshore spills could directly affect staging shorebirds by oiling their plumages, or indirectly by contaminating or killing invertebrate food sources (Andres 1994). In addition, construction and maintenance of industrial development could negatively impact shorebirds by causing them to flee from noise or human presence, or may eliminate important staging habitats entirely. Studies in other areas of the country have identified shorebirds as one of the most susceptible taxa to human-induced disturbance (Burger 1981). Based on this evidence, it seems plausible that the effects of energy development and associated disturbance on staging shorebirds could be detrimental to populations that already appear to be in decline (Brown et al. 2001).

This project will help determine (1) how pre-migratory shorebirds are distributed across the Arctic Coastal Plain, (2) what sites are particularly valuable during this period, (3) how long birds stay at North Slope staging sites, and (4) the degree to which birds move between sites. It will also indicate how species composition and abundance at various staging sites may have changed between the 1970's and the present, and help us to understand the role physiology plays in staging site selection and length of use. This research will supply basic knowledge regarding staging requirements and habitat for several species of arctic-breeding shorebirds in order to facilitate an evaluation of the potential effects of development along the Arctic Coastal Plain.

Objectives and Predictions

The specific objectives and associated predictions for this research are to:

1. *Assess the abundance, distribution, and species composition of shorebirds staging along North Slope coastlines prior to the fall migration.* We predict that shorebirds should be distributed across the North Slope in a non-uniform fashion according to local resource availability (e.g., food abundance), and that abundance and species composition within a staging area will reflect the surrounding breeding community.
2. *Quantify phenological aspects of staging, such as timing of arrival after breeding for adult and hatch-year birds, overall and species-specific peaks in shorebird numbers, residency times at staging sites, and movement patterns of birds across the North Slope.* We predict that adult

birds will arrive at and depart from staging areas prior to hatch-year birds, following the typical shorebird pattern in which adults abandon young to prepare for migration. We also predict that the peak of staging shorebird abundance will be later as one moves from west to east across the North Slope, based on trends documented by Connors (1983) for Semipalmated (*Calidris pusilla*), and Western (*C. mauri*) Sandpipers between Cape Krusenstern, Barrow, and Prudhoe Bay. Finally, we predict that peak abundances and residency times will vary by species, due to differences in life history requirements. For example, Dunlin (*C. alpina*) may show the latest peak abundance dates and the longest residency times because they are undergoing a flight feather molt while acquiring fat for southbound migration. We also believe that birds will be more likely to stage close to where they bred (adults) or fledged (hatch-year birds) at the beginning of the staging period but will disperse farther from breeding or natal areas as the season progresses.

3. *Examine differences in measures of physiological condition (fattening rates and stress hormone concentrations) among species and staging sites*. We predict that shorebirds sampled at different staging sites along the North Slope will show quantifiable differences in these parameters and that these physiological measurements will correlate with food quality measurements taken at the same site. If this prediction holds true, knowledge gained from this study will allow an assessment of the relative importance of different staging areas in preparing shorebirds for migration south from Alaska.

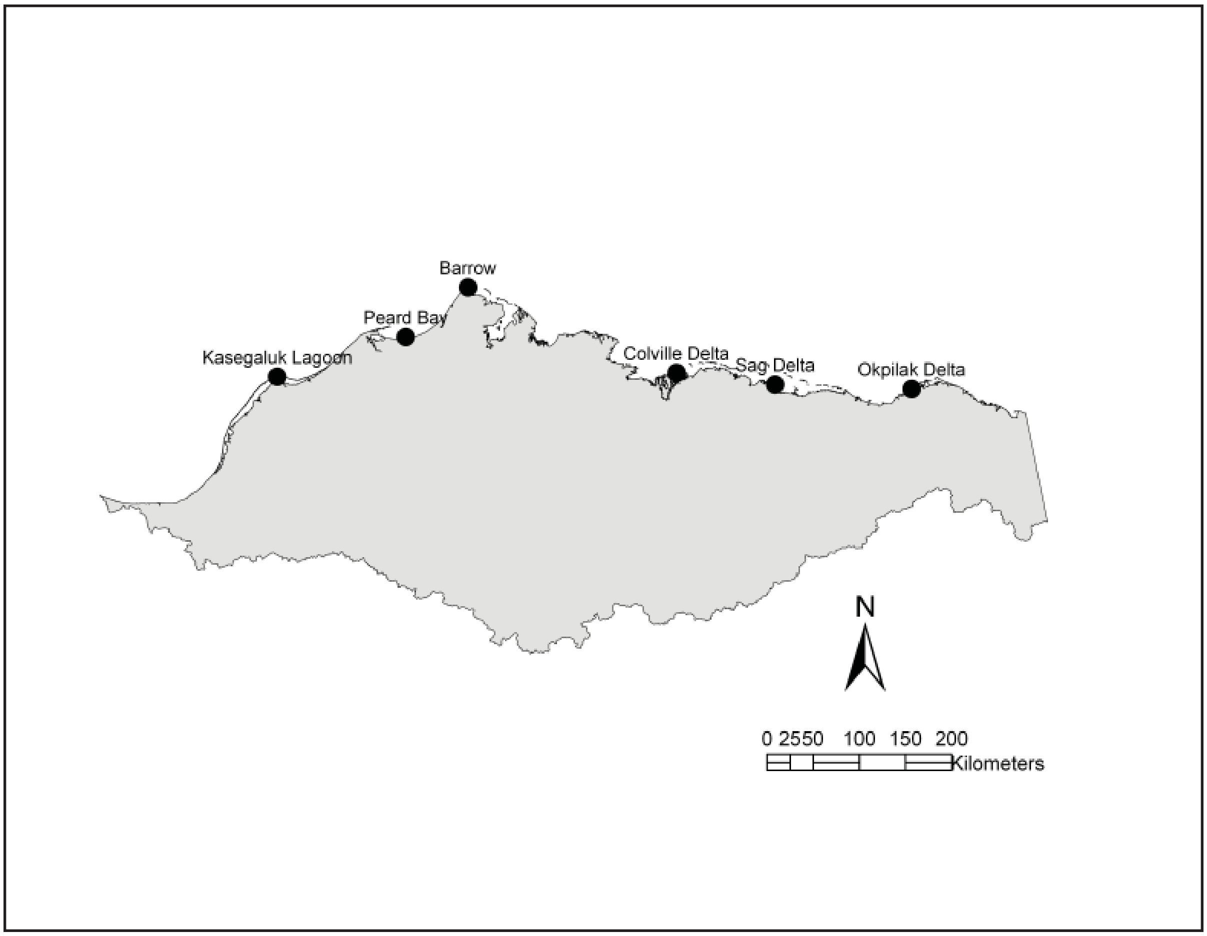


Figure 1. Shorebird field camp locations along the North Slope of Alaska, 2005-2006.

Study Area

From mid-July to early September 2005-2006, field camps were located at six sites across the North Slope (Figure 1): Barrow (71.290°N, 156.788°W), Peard Bay (70.812°N, 158.323°W), Kasegaluk Lagoon (70.301°N, 161.888°W), and the Colville (70.473°N, 150.564°W), Sagavanirktok (70.291°N, 148.202°W), and Okpilak (70.080°N, 144.011°W) river deltas. The study sites were selected using the following criteria: (a) presence of either a large lagoon system (Peard Bay, Barrow, Kasegaluk) and/or a large river delta (Colville, Sagavanirktok, Okpilak), both of which might support large numbers of staging shorebirds, and (b) the potential for logistical support from other collaborators for conducting work at the site. We also conducted aerial surveys of the coastline of the North Slope from the southern end of Kasegaluk Lagoon to Demarcation Point, the eastern border of Alaska and the Arctic National Wildlife Refuge.

Methods

Data collection by personnel at the field camps was designed to examine shorebird use of each area during the staging period at a narrow spatial but broad temporal scale, focusing on five study species: Dunlin, Semipalmated Sandpiper, Western Sandpiper, Red Phalarope (*Phalaropus fulicaria*), and Red-necked Phalarope (*P. lobatus*). The aerial telemetry and survey component of the study did the reverse by examining general shorebird distribution over a broad spatial scale but a narrow (although repeated) temporal scale. At each field camp, personnel delineated a 10-km diameter study area at a location where they observed appropriate shorebird foraging habitat. Subsequently, most field work was performed within this study area. From approximately mid-July to early September 2005 and 2006 (exact dates varied by camp and year for logistical reasons), field crews at each camp (1) conducted staging shorebird surveys, (2) captured birds for blood sample collection, banding, and radio transmitter deployment, (3) performed manual and automated telemetry for radio-tagged birds from their study area and from other breeding and staging sites, and (4) sampled used and unused foraging habitat for invertebrate abundance. Aerial surveys consisting of a belt transect 100-m wide were conducted via helicopter (2005) or fixed-wing aircraft (2006) along the coastline and nearshore barrier islands during the staging period. The helicopter survey in 2005 occurred from 7-16 August; the fixed-wing surveys, due to a lower cost for the aircraft, were conducted approximately four days each week from 22 July-26 August 2006. Specific methods for addressing each of the three objectives are described below.

Objective 1: Abundance, Distribution, and Species Composition

To assess the abundance, distribution, and species composition of shorebirds staging along North Slope coastlines prior to fall migration, we relied primarily on the aerial survey component of this project. In 2005, using a Robinson R-44 helicopter, we surveyed the coastline between Kasegaluk Lagoon and Demarcation Point (Canadian border) at an altitude of 15 m and a cruising speed of 95-115 km/hr (depending on wind speed). The front left biologist identified and counted birds within 200 meters to the left of the centerline of the plane, while the rear left biologist recorded data and watched for birds missed by the front surveyor. We recorded all shorebirds within belt transect sections designated by GPS locations recorded every two minutes. Twelve major river deltas (Meade, Ikpikpuk, Fish Creek, Nechelik, Colville, Kuparuk, Sagavanirktok, Staines/Canning, Hulahula/Okpilak, Jago, and Kongakut) were surveyed more intensively by conducting transects perpendicular to the coastline at 1-km intervals across the width of each delta. In 2006, using a Bellanca Scout aircraft, we surveyed the coastline between Kasegaluk Lagoon and Demarcation Point at an altitude of 15 m and a cruising speed of 130-170 km/hr (depending on wind speed). We flew transects perpendicular to the coastline at all major river deltas and in areas where suitable staging habitat was found more than 100 m inland from the coast. Data were recorded by a single observer from the rear seat of the plane on one side only. We utilized a voice-recorder program developed by the US Fish and Wildlife Service that records a GPS fix and audio file for each observation; these were later transcribed into an Excel spreadsheet of geo-referenced data points. Small shorebirds were generally not identifiable to species from the air, so we categorized individuals as "small peep" (probably Semipalmated, Western, and Baird's [*C. bairdii*] sandpipers), "medium peep" (probably Dunlin, Sanderling [*C. alba*], and Long-billed Dowitcher [*Limnodromus scolopaceus*]), "phalarope" (either Red or Red-necked), and "plover" (either American Golden-plover

[*Pluvialus dominica*] or Black-bellied Plover [*P. squatarola*]). Where possible we identified individuals to species.

Objective 2: Staging Phenology and Movements

To quantify phenological aspects of staging along the North Slope coast, we relied primarily on data collected at the six field camps. Repeated surveys of nine transect lines (1 km each) at each field camp were used to document the arrival and departure of post-breeding adults and hatch-year birds, and to assess the overall and species-specific peaks in shorebird numbers. Transects were surveyed every three days throughout the time personnel were in the field. Surveys were conducted by walking the transect line from start to finish, and recording the following for each bird or group of shorebirds present: number of birds in the group, species, age, perpendicular distance from the transect line, and habitat type. Data collected in this manner are being analyzed using Program DISTANCE (Thomas et al. 2004) to obtain density estimates for each habitat type during each survey period.

The field camp at Barrow was unique in that we have 1970's data with which to compare present-day densities of shorebirds using local coastal staging habitats. We reestablished eight of the original transects that Peter Connors and colleagues surveyed from 1975-1979 to determine the abundance of staging shorebirds in Barrow (Connors et al. 1979, 1984). We conducted surveys on these transects regularly between 2004-2006, and will compare density and species composition with Connors' density and species composition estimates to investigate whether staging shorebird densities have changed in the intervening 30 years.

To understand how long shorebirds remain at staging sites before either migrating south or moving to other areas on the North Slope (tenure time), personnel at the six field camps captured shorebirds with mist nets and walk-in traps, then marked them with individual color band combinations, enamel head paint, and/or radio transmitters. We subsequently searched for marked birds by revisiting banding sites and watching for marked birds during transect and other opportunistic surveys. Field crews also used hand-held yagi antennas and portable radio receivers to monitor radio-equipped birds. In addition, an automated remote telemetry station (ARTS) located within each study area was used to monitor radio-equipped birds at each camp 24 hours/day. Because the aircraft used for addressing Objective 1 was rigged for telemetry, we also listened for radio-equipped birds throughout the aerial surveys. All radio frequencies were monitored until the birds had not been heard within the study area for at least five days. Resightings of painted and color banded birds allowed us to determine the minimum time the bird remained within a field camp's study area. However, we could not account for the amount of time the bird was at the site prior to capture or how long it remained at the site post-capture without being seen. In contrast, detections of radio-tagged birds (Table 1) allowed us to estimate a more accurate residency time because exact departure time from the study area could be determined.

To determine tenure time for radio-marked shorebirds at each of the six field camps, we used mark-recapture methods implemented in Program MARK (White and Burnham 1999). The detection records for each radio-marked bird were transformed into encounter histories with a 1 denoting the bird being present at a particular camp (as detected either by manual telemetry or the ARTS station), and a 0 denoting that bird's absence. We used the Cormack-Jolly-Seber (CJS) open-population model framework to analyze these encounter histories. Model parameters included the encounter history for each bird, species, and a suite of covariates that turned the encounter history off if the camp was not doing telemetry on a particular date. AIC_c was used as a model selection criterion: the model with the lowest AIC_c was the one from which we drew inference (Burnham and Anderson 2002). We corrected for a high level of overdispersion in our telemetry data by adjusting the c-hat value in MARK to 10.0. CJS models estimate survival (Φ) for marked animals; we transformed the survival estimates from Program MARK into life expectancy according to the following formula:

$$\textit{life expectancy} = -1/\ln(\Phi)$$

and used this to represent tenure time (Kaiser 1995).

We also investigated movement patterns of radio-marked birds by following individuals from breeding locations to staging areas and from initial to subsequent staging sites. We used Oriana (Version 2.02c, Kovach Computing Services) to calculate mean movement vectors and standard deviations for this data.

Table 1. Number of radio transmitters placed on shorebirds at Arctic Coast field camps in 2005 and 2006. Species names are abbreviated: Dunlin (DUNL), Semipalmated Sandpiper (SESA), Red Phalarope (REPH), Red-necked Phalarope (RNPH), and Western Sandpiper (WESA).

Season	Location	Species	2005	2006
Breeding	Barrow	DUNL	8	5
		SESA	3	5
		REPH	5	5
	NPR-A	DUNL	6	10
		SESA	7	10
		REPH	10	10
	Prudhoe Bay	DUNL	0	5
		SESA	3	5
		RNPH	0	4
	Canning	DUNL	0	4
		SESA	3	5
		RNPH	4	4
	Arctic Refuge	SESA	0	8
		RNPH	0	8
	Total breeding		*49*	*88*
Post-breeding	Kasegaluk	DUNL	0	6
		SESA	0	5
		REPH	0	5
		RNPH	0	3
		WESA	0	3
	Peard Bay	DUNL	3	6
		SESA	5	5
		REPH	6	5
		RNPH	0	3
		WESA	0	3
	Barrow	DUNL	3	6
		SESA	5	5
		REPH	6	5
		RNPH	0	3
		WESA	6	3
	Colville	DUNL	4	6
		SESA	5	5
		REPH	3	3
		RNPH	3	3
	Sag	DUNL	0	6
		SESA	4	5
		RNPH	4	3
	Okpilak	DUNL	0	6
		SESA	7	5
		RNPH	5	0
		WESA	1	4
	Total post-breeding		*70*	*112*

Objective 3: Physiology

To examine differences in measures of physiological condition among species and staging sites, we collected small (200-300 µl) blood samples from shorebirds captured during the staging period at each of the six field camps (Table 2). The collected blood was subsequently centrifuged for 15 minutes and plasma was drawn off for fat metabolite (triglyceride) and stress hormone (corticosterone) analysis. Plasma samples were frozen immediately after separation. The bird handling and bleeding procedures were approved in our UAF Institutional Animal Care and Use Committee protocol (#04-31).

Triglycerides have been shown to be the best measure of fattening rate in captive Western Sandpipers (Guglielmo et al. 2002). As birds ingest dietary fats, these are converted to triglycerides and sent to adipose tissue via the bloodstream for storage. Additionally, many pre-migratory birds increase *de novo* lipogenesis rates in the liver; triglycerides from this process are also circulated in the bloodstream. Thus the level of triglyceride in an individual's plasma may be used as a relative measure of mass gain, or fattening rate prior to migration. The advantage of this method is that it allows determination of fattening rates from a single capture rather than relying on mass changes between two captures of the same bird (a rare event). The fat metabolite analyses were conducted under the guidance of Dr. Tony Williams at Simon Fraser University in two separate assay periods (December 2005 for 2005 samples and December 2006 for 2006 samples). Triglyceride content in duplicate 5-µl plasma samples was determined by enzymatic endpoint assay, using Sigma Trinder reagents A (240 µl) and B (60 µl) to first assess total glycerol content, then free glycerol content. Triglyceride is the difference between free and total glycerol levels. We analyzed differences between species and camps with an ANCOVA taking into account season-date, time between capture and bleeding, and the mass of each bird.

Pre-migratory increases in baseline corticosterone (cort) may result in increased foraging activity and lipogenesis, thus aiding in fat storage necessary for commencement of long-distance flight (reviewed by Holberton et al. 1996). On the other hand, maximal cort levels occur in response to a perceived acute or chronically stressful event, and may be detrimental to an individual's survival if sustained for long periods of time. Thus the combination of these measures gives us insight into a bird's condition at the time of capture: baseline cort levels indicate whether a bird is actively preparing for migration, and, when paired with that same bird's triglyceride levels, may indicate how successful that individual is at acquiring fat resources. Maximal cort levels (measured in response to our standardized stress protocol of capture and holding for 30 minutes) may indicate whether an individual is capable of mounting an additional stress response; this is an additional measure of physiological condition. Both baseline and maximal cort levels were determined by direct radioimmunoassay (Wingfield et al. 1992) in Sasha Kitaysky's lab at the University of Alaska Fairbanks. The radioimmunoassay procedure involves 1) the extraction of plasma steroids with dichloromethane and 2) competitive binding between corticosterone in the sample and radioactively-labeled synthetic corticosterone. A standard curve produced for each assay using synthetic, non-radioactive corticosterone is used to assess the amount of natural corticosterone in each plasma sample. We ran seven separate assays from 2006 plasma samples between November 2006 and March 2007. Data from these assays are being analyzed for species, camp, and time of season effects. In addition, we will investigate the

Camp	Dates in field 2005	Dates in field 2006	2005	2006
Kasegaluk	No camp in 2005	17 July - 3 September	N/A	100
Peard Bay	23 July - 23 August	13 July - 3 September	100	109
Barrow	20 July - 1 September	15 July - 9 September	139	188
Colville	25 July - 23 August	18 July - 3 September	62	125
Sagavanirktok	25 July - 21 August	18 July - 21 August	14	52
Okpilak	1 - 25 August	18 July - 5 September	22	127

Table 2. Number of birds captured and blood-sampled per field camp in 2005-2006.

previously unknown relationship between triglyceride and corticosterone levels in staging shorebirds; it is possible this may form the basis of an improved measure of body condition that could facilitate assessments of site or habitat quality across the North Slope.

Results and Discussion

Objective 1: Abundance, Distribution, and Species Composition

The analysis for overall abundance (from 2006 aerial survey data) is ongoing in Program Distance. However, visual analysis (using ArcGIS to georeference survey count data) of shorebird numbers and abundance hotspots indicated several similarities between 2005 and 2006: Icy Cape, Peard Bay, Elson Lagoon, the east side of Dease Inlet, Pogik Bay, and Beaufort Lagoon/Icy Reef (Figure 2). Shorebirds appeared to be patchily distributed across the coastline of the North Slope in accordance with our prediction of non-uniform distribution. Surprisingly, we found high abundances of shorebirds at several small creek deltas or coastal inlets (e.g., Pogik Bay) where the tundra habitat gave way to mud or silt barren, and lower abundances than expected at many of the larger river deltas. High densities of birds (mostly phalaropes) were also found on the inner shores of the barrier island systems where gravel beach habitat was protected from wave action.

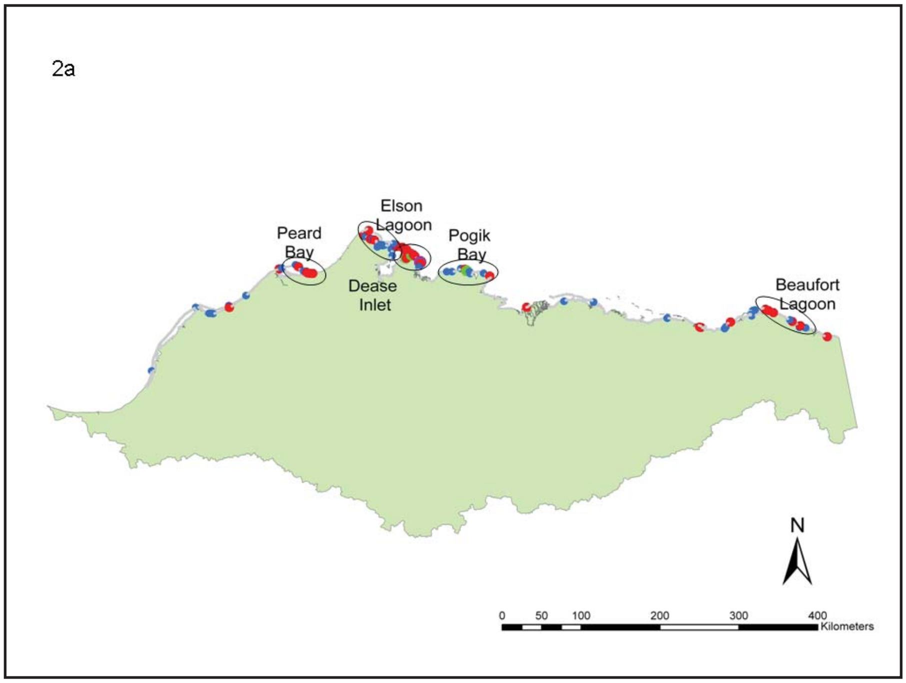
Objective 2: Phenology and Movements

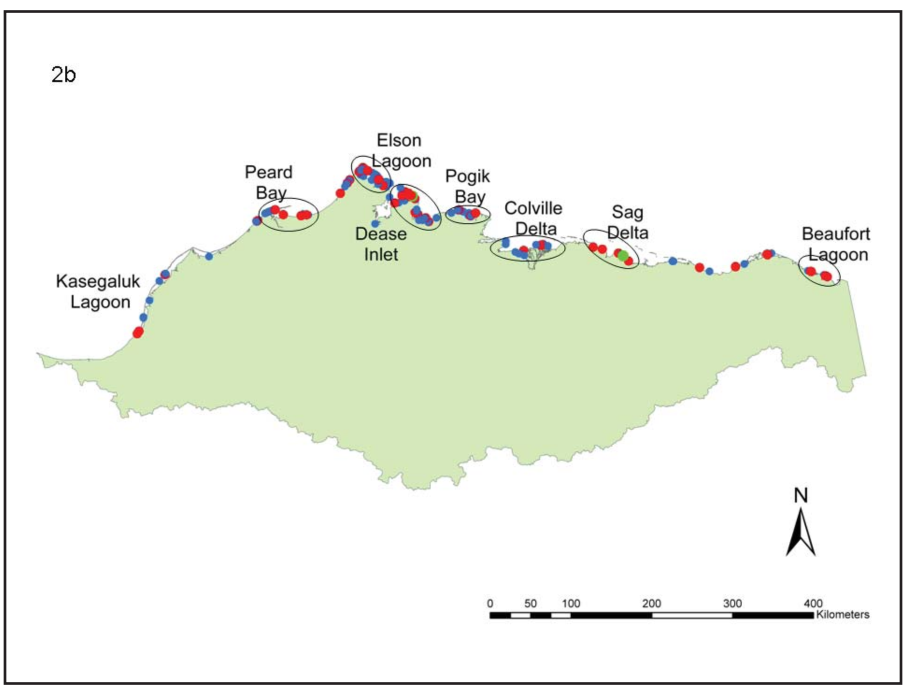
We used banding records obtained during the 2005 and 2006 field seasons to examine phenology of our five main study species (Dunlin, Semipalmated Sandpipers, Western Sandpipers, Red Phalaropes, and Red-necked Phalaropes). We captured few adult birds in mist nets or walk-in traps, but those we did trap were captured early in each species' staging period, indicating that adult birds do likely leave the North Slope prior to juvenile birds. An exception to this generality is Dunlin; this species was still present at coastal staging areas well into mid-September, and many adults were present (although juveniles were more numerous). We used average capture dates as a proxy for peak staging abundance, since it is easier to capture individuals of a given species when they are abundant. Capture probability may also be affected by wind and weather patterns and by inherent differences between species, but we were unable to collect sufficient data to examine these effects directly. As predicted, dates of peak abundance differed significantly across our five main study species (ANOVA, $F = 122.14$, $p < 0.0001$, $df = 4$; Figure 3). Semipalmated Sandpipers showed the earliest peak staging date (2 August), while Dunlin showed the latest (21 August); Western Sandpipers and both phalarope species were intermediate in peak abundance date (13 August). Previous studies have indicated that Semipalmated and Western Sandpipers exhibit later peaks in abundance as one moves west to east across the coast of the North Slope (Connors 1983). We aim to quantify the extent of this trend by analyzing density of each species at each camp through time.

Tenure times of radio-equipped individual birds at each camp were highly variable across locations and years. Thus, after adjusting for overdispersion in the telemetry data likely caused by such variability, our best model for tenure time was one of constant survival and detection probability across all five study species. Using this model, we estimated tenure time for all species to be 6.5 days (95% confidence interval: 3.4-9.6 days). Detection probability for all species (conditional upon survival) was 68% (95% CI: 58-78%). Although our power to detect a species effect on tenure time was low, we believe there is biological reality in our second best model, which indicated a species-specific effect on tenure time: Semipalmated Sandpiper and both phalarope species exhibit distinctly shorter tenure times (CJS estimate: 4.4 days) than Western Sandpipers (CJS estimate: 7.9 days), which in turn have distinctly shorter tenure times than Dunlin (CJS estimate: 12.9 days). However, after adjusting for overdispersion the 95% confidence intervals for these point estimates overlap each other, thus we are confident only in the overall (non-species-specific) tenure time estimate presented above.

We have movement data from 32 individual shorebirds in 2005 and 2006 that were detected at more than one ARTS station or at an ARTS station other than where they were radio-equipped. The majority of these ($n = 28$) were Semipalmated Sandpipers, which invariably moved north along the Chukchi Sea and/or east along the Beaufort Sea to the Canning River Delta. Accordingly, their average direction of movement was almost due east along a 97° vector (circular std. dev = 31.4°). Interestingly, no Semipalmated Sandpipers were detected at the most eastward ARTS station (located on the Okpilak River delta), and three individuals were detected at an ARTS sta-

Figure 2a-b. Overall distribution of staging shorebirds (all species) estimated from aerial surveys conducted in 2005 and 2006 from Kasegaluk Lagoon to the Alaskan Border. Fig. 2a = 2005 helicopter survey data; Fig 2b = 2006 fixed-wing survey data. Blue dots represent a concentration of 50-99 birds; red dots indicate a concentration of 100-499 birds; green dots represent a concentration of 500-999 birds, and purple dots are concentrations of 1000 or more birds. Hotspots were visually estimated and are circled in black.





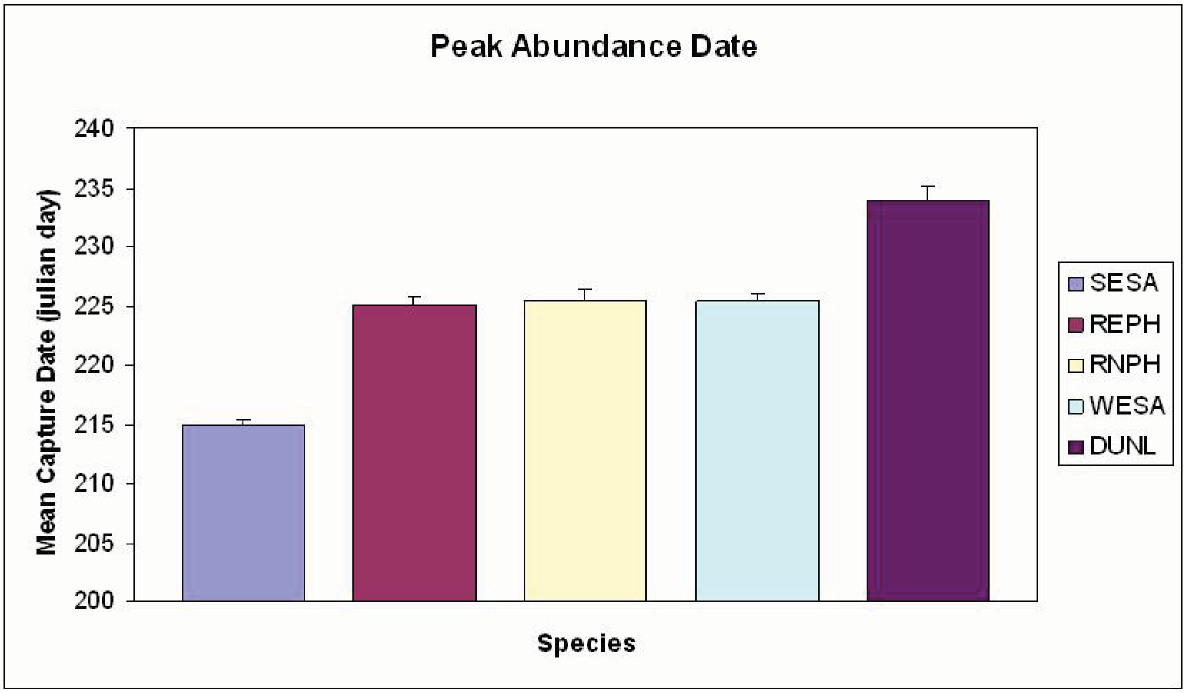


Figure 3. Average peak abundance dates for five study species found at North Slope coastal staging areas. Error bars represent one standard error of the mean. Abbreviations for species names are the same as for Table 1. Average capture dates were used as a proxy for peak staging abundance since individuals of a given species are most easily captured when that species is abundant.

tion located approximately 33 km south of the Beaufort coast along the Canning River. This suggests that migrating Semipalmated Sandpipers may use the Canning River as a migration corridor through the Brooks Range into interior Alaska. We did not obtain enough telemetry detections for remainder of the species to perform statistical analysis of the data. However, on average Dunlin moved west along the Beaufort coast to Point Barrow, then southwest along the Chukchi toward the Yukon Delta. Western Sandpipers tended to remain at a single staging area (camp) rather than moving between areas as did Dunlin and Semipalmated Sandpipers. Red and Red-necked Phalaropes did not show a distinct pattern or direction of movement; individuals of both these species moved both west and east along the Beaufort coast, and Red Phalaropes moved both north and south along the Chukchi coast.

Objective 3: Physiology

In 2005, we found distinct differences in fattening rates (as assessed by plasma triglyceride concentrations) between Semipalmated Sandpipers, Western Sandpipers, and Dunlin, all of which feed in mixed species flocks at coastal North Slope staging areas (see results section of 2005 Coastal Marine Institute Annual Report). To ascertain that we could reasonably compare fattening rates and stress hormone levels across these terrestrially-foraging shorebird species (we omitted the phalarope species because they feed in both terrestrial and nearshore marine habitats), we investigated whether Dunlin exhibit lowered baseline corticosterone and down regulated adrenocortical responses to stress during staging, since they are also undergoing prebasic molt, unlike either sandpiper species. Baseline corticosterone levels are lower than any other time during the year in passerines undergoing post-nuptial molt, and adrenocortical responses to stress are low or non-existent (Romero 2002). In passerines, lowered corticosterone during molt is likely a physiological mechanism to avoid interference with the additional protein deposition needed for feather growth (Romero et al. 2005). Yet, passerine birds are often granivorous, and thus may be protein limited throughout much of their life cycle, while invertebrate-feeding shorebird species are unlikely to be protein limited.

Molt scores for each of five body regions were averaged to arrive at a molt intensity score for each individual, with a 0 indicating no molt and a 5 indicating replacement of nearly all body feathers. We log-transformed both baseline and stress-induced corticosterone values to meet assumptions of normality. We used general linear models in SAS 9.1 (SAS Institute 2002-2003) to examine the relationship between molt score and baseline corticosterone level for adult and juvenile dunlin separately. We then performed a repeated measures analysis to investigate whether an individual's adrenocortical response to capture stress depended on molt score, also for adults and juveniles separately. Finally, we used linear regression to examine the relationship between molt score and fat score. We found no effect of molt score on either baseline or maximal corticosterone levels in adult or juvenile Dunlin, and our repeated measures analysis indicated that individual birds did exhibit a distinct rise in corticosterone (the adrenocortical stress response) after 30 minutes of being held. In addition, there was a positive relationship between molt score (indicating increased numbers of feathers being molted) and fat score (a subjective measure of the amount of fat a bird has upon capture), indicating that Dunlin are able to simultaneously molt and fatten in preparation for migration (Figure 4). Thus, we feel confident that we may make comparisons between physiological fattening rates and body condition of Dunlin, Semipalmated Sandpipers, and Western Sandpipers for future analysis.

Analysis of predicted patterns of fattening rates and corticosterone levels and their interrelationship is ongoing and will be contained in the final report to the Coastal Marine Institute.

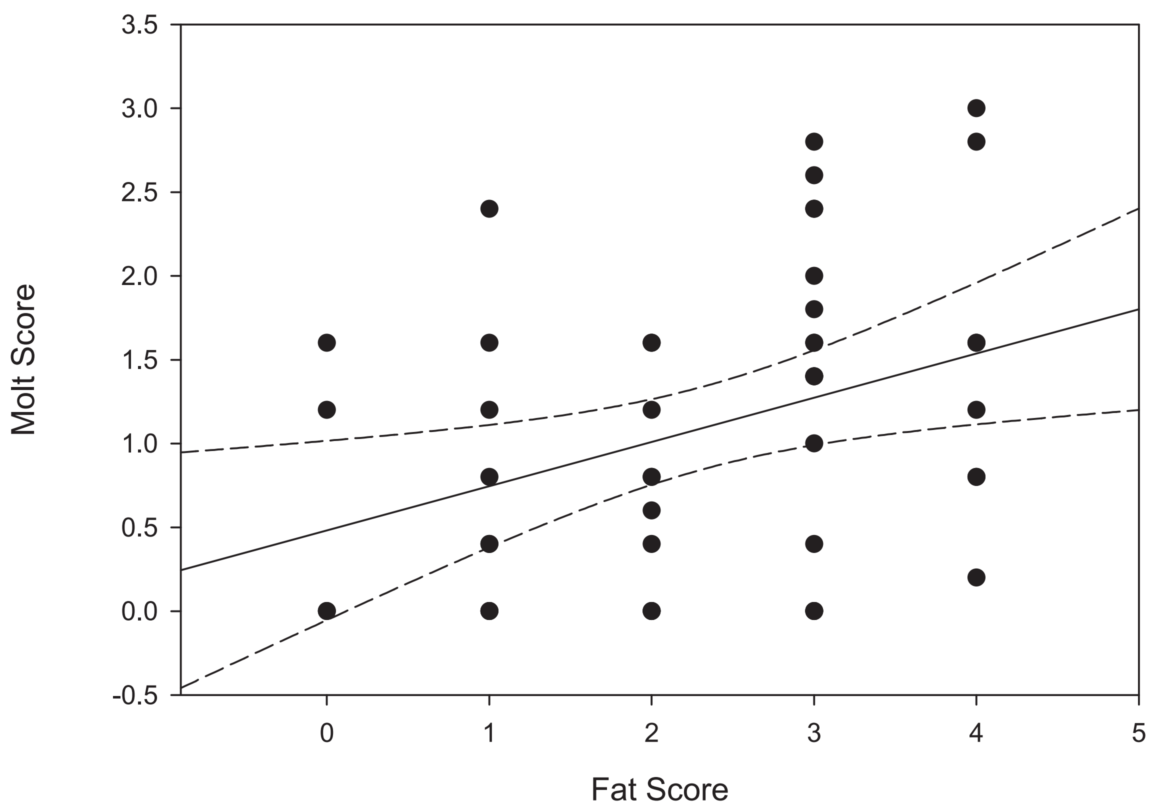


Figure 4. Relationship between molt score and fat score in Dunlin. Dotted lines represent 95% confidence limits of the regression line.

Future Plans

Each of the objectives for this project will form a chapter in A. Taylor's Ph.D. dissertation, with data analysis and subsequent reporting of results following committee recommendations. Data on abundance, distribution, and species composition (Objective 1) will be analyzed using spatial statistics and GIS to map presence/absence of shorebird species across the North Slope coast. We are in the process of using Program DISTANCE (Thomas et al. 2004) to estimate density of staging shorebirds across the entire study area for each of the four main aerial survey periods from 2006. The phenology, tenure time, and movement pattern data (Objective 2) is being analyzed using a combination of Program DISTANCE (phenology), Program MARK (tenure time), and spatial statistics (movement patterns) to characterize the spatial connectivity of the North Slope for staging shorebirds. Lastly, results from the plasma assays for triglyceride and corticosterone levels and the invertebrate samples collected at areas of high versus low foraging activity will be combined to assess what determines high quality habitat for staging shorebirds. The anticipated end date for this project is December 2008. The end products will be several peer-reviewed publications, A. Taylor's dissertation, and a final project report to CMI.

Summary

We have studied post-breeding (staging) shorebird populations on the North Slope of Alaska since 2004, building on a three-tiered assessment: 1) abundance, distribution, and species composition, 2) phenology, tenure time, and movement patterns, and 3) pre-migratory physiology and habitat quality. To date, we have found that shorebirds are patchily distributed across the North Slope coast, with some areas supporting larger concentrations of staging birds than other, comparable habitats. Several hot spots along the Chukchi and Beaufort coasts were identified as such in both 2005 and 2006. Semipalmated Sandpipers typically exhibit the earliest peak in abundance and exhibit the shortest tenure times on the North Slope. Western Sandpipers and both phalarope species exhibit intermediate tenure times and dates of peak abundance, while Dunlin exhibit a later peak abundance date and the longest tenure time of any species. These species-specific patterns in staging behavior may be important in predicting effects of development and climate change on staging shorebirds. Analysis of physiology data is ongoing, but thus far we feel we are justified in making comparisons between the three terrestrially-feeding species (Dunlin, Semipalmated Sandpipers, and Western Sandpipers) because they all exhibit positive pre-migratory fattening rates, similar adrenocortical function, and show a distinct response to stressful events.

Study Products (Academic year 2006-2007)

July 2007: Presentation: "Using radiotelemetry to determine tenure time and movement patterns of staging shorebirds on Alaska's North Slope," Association of Field Ornithologists' Annual Meeting, Orono, ME

March 2007: presentation at Alaska Cooperative Fish and Wildlife Research Unit's Annual Cooperators' Review, Fairbanks, AK

February 2007: presentation at Coastal Marine Institute Annual Review, Fairbanks, AK

December 2006: Presentation: "Corticosterone in Post-breeding Dunlin: regulating molt or pre-migratory fattening?" Tenth Western Sandpiper Group Meeting, Simon Fraser University, Vancouver, B.C.

December 2006: presentation to Alaska Shorebird Group, Anchorage, AK

September 2006: Annual Report for Coastal Marine Institute (written)

Acknowledgements

This project would not be possible without financial support from the Coastal Marine Institute and the Minerals Management Service. We would also like to thank the staff of the Barrow Arctic Science Consortium and the North Slope Borough Department of Wildlife Management (especially Robert Suydam) for support and advice in Barrow. Field camp support was provided by U.S. Fish and Wildlife Service (Barrow camp: Migratory Bird Management, Anchorage; Okpilak Delta camp: Arctic National Wildlife Refuge), Bureau of Land Management (Peard Bay camp and NPR-A helicopter support), ConocoPhillips Alaska, Inc. (Colville Delta camp), and BP Exploration (Alaska), Inc. (Sagavanirktok Delta camp). Data collection was accomplished with much help from the following technicians: Kelly and Josh Boadway, Fabrice LeBouard, Liliana Naves, Caleb Ashling, and Jen Selvidge (Barrow); Blake Trask, Cory Gregory, and Alexis Will (Kasegaluk Lagoon); Deb Nigro, Greg Norwood, and Terry Kowalzyk (Peard Bay); Jim Johnson, Brad Andres, Taylor McKinnon, Ayme Johnson, and Aaron Wells (Colville Delta); Meg Laws, Kevin Pietrzak, Laura Ganis, and Dan Fontaine (Sagavanirktok Delta); and Steve Kendall, Ryan Burner, Scott Freeman, Slade Sipora, Trevor Lloyd-Evans, Ben Fleurer, Cashell Villa, and Robin Hunnewell (Okpilak Delta). Julie Morse, Amy Leist, Kerri Frangioso, the Barrow avian influenza helicopter crew, the Arctic National Wildlife Refuge's Canning Delta breeding shorebird camp, and the Wildlife Conservation Society's Prudhoe Bay breeding shorebird/avian influenza crews were invaluable during deployment of breeding season radio transmitters. Larry Larrivee of Pollux Aviation and Sandy Hamilton/Chris Zimmer of Arctic Air Alaska were incredible pilots and companions while we counted and listened for very small birds across the North Slope. We also gratefully acknowledge A. Taylor's graduate advisory committee at UAF (Tony Williams, Sasha Kitaysky, and Falk Huettmann). Other generous individuals (too numerous to name) helped with various aspects of this project, and we are indebted to them for making the 2005-2006 field seasons successful.

Literature Cited

Andres, B.A. 1994. Coastal zone use by postbreeding shorebirds in northern Alaska. Journal of Wildlife Management 558(2):206-213.

Brown, S., C. Hickey, B. Harrington, and R. Gill, eds. 2001. The U.S. Shorebird Conservation Plan, 2nd edition. Manomet Center for the Conservation Sciences, Manomet, MA.

Burger, J. 1981. The effect of human activity on birds at a coastal bay. Biological Conservation 21:231-241.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd Edition. Springer-Verlag, New York, New York, USA. 488 pp.

Connors, P.G. 1983. Distribution and biology of Semipalmated Sandpipers and Western Sandpipers in Alaska; species account. RU-0172 report, 29 pp.

Connors, P., C.S. Connors, and K.G. Smith. 1984. Shorebird littoral zone ecology pf the Alaska Beaufort Coast. Outer Continental Shelf Environment Assessment Program. Final Report of Principal Investigators, National Oceanic and Atmospheric Administration, Boulder, CO. Vol 23, pp. 297-396.

Connors, P., J.P. Myers, and F.A. Pitelka. 1979. Seasonal habitat use by arctic Alaskan shorebirds. Studies in Avian Biology 2:101-111.

Guglielmo, C.G., P.D. O'Hara, and T.D. Williams. 2002. Extrinsic and intrinsic sources o variation in plasma lipid metabolites in free-living Western Sandpipers (Calidris mauri). Auk 119: 437-445.

Holberton, R.L., J.D. Parrish, and J.C. Wingfield. 1996. Modulation of the adrenocortical stress response in neotropical migrants during autumn migration. Auk 113:558-564.

Kaiser, A. 1995. Estimating turnover, movements, and capture parameters of resting passerines in standardized capture-recapture studies. Journal of Applied Statistics 22: 1039-1047.

Martin, P.D., and C.S. Moiteret. 1981. Bird populations and habitat use, Canning River Delta, Alaska: Fairbanks. Unpub. Report for U.S. Fish and Wildlife Service, Fairbanks, AK.

Romero, L.M. 2002. Seasonal changes in plasma glucocorticoid concentrations in free-living vertebrates. General and Comparative Endocrinology 128:1-24.

Romero, L.M., D. Strochlic, and J.C. Wingfield. 2005. Corticosterone inhibits feather growth: potential mechanism explaining seasonal down regulation of corticosterone during molt. Comparative Biochemistry and Physiology, Part A 142:65-73.

Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H. and Bishop, J.R.B. 2004. Distance 4.1. Release 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/ .

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 Supplement:120-138.

Wingfield, J.C., C.M. Vleck, and M.C. Moore. 1992. Seasonal changes in the adrenocortical responses to stress in birds of the Sonoran Desert. Journal of Experimental Zoology 264:419-428.

Sea Ice-Ocean-Oilspill Modeling System (SIOMS) for the Nearshore Beaufort and Chukchi Seas: Parameterization and Improvement (Phase II)

Jia Wang
jia.wang@noaa.gov
NOAA Great Lakes Environmental Research Laboratory
2205 Commonwealth Blvd.
Ann Arbor, MI 48105

Kohei Mizobata
kmizobato@iarc.uaf.edu
International Arctic Research Center
University of Alaska Fairbanks
P. O. Box 757335
Fairbanks, AK 99775-7335

Meibing Jin
mjin@iarc.uaf.edu
International Arctic Research Center
University of Alaska Fairbanks
P. O. Box 757335
Fairbanks, AK 99775-7335

Haoguo Hu
Haoguo.Hu@noaa.gov
NOAA Great Lakes Environmental Research Laboratory
2205 Commonwealth Blvd.
Ann Arbor, MI 48105

Task Order: 35407

Abstract

The 3.8-km CIOM (Coupled Ice-Ocean Model) successfully reproduces many observed phenomena in the region, including the Bering-inflow-originated coastal current that splits into three branches, the Beaufort Sea slope current, the Beaufort Gyre, the East Siberian Current, mesoscal eddies, seasonal landfast ice, and sea ice ridging, shear, and deformation. Many of these downscaling processes can only be captured by using such high-resolution CIOM, nested by a global climate model.

The seasonal cycles for sea ice concentration, thickness, velocity, and other variables are well reproduced with solid validation by satellite measurements. The seasonal cycles for upper ocean dynamics and thermodynamics are also well reproduced, which include the formation of the halocline layer due to the injection of salt during sea ice formation, the Beaufort slope current, and the subsurface upwelling that brings up warm, saline Atlantic Water along the shelfbreak and shelf along the Beaufort coast.

Introduction

The Beaufort and Chukchi seas (Fig. 1) are an important region where the North Pacific water via the Bering Strait encounters the Western Arctic water with seasonal ice in the Chukchi Sea, and both seasonal and perennial ice in the Beaufort Sea. The Chukchi Sea is mainly featured by the continental shelf, while the Beaufort Sea is characterized by relatively narrow continental shelf and deep basin with a narrow steep shelf slope. More importantly, the Beaufort Sea is also featured by continuous landfast ice along the Alaska Arctic coast, parallel to the 20-m isobath (Eicken et al. 2005), compared to the discontinuous landfast ice along the western Alaska coast in the Chukchi Sea. All these features have challenged both observationalists and modelers.

The ocean circulation system in the Beaufort and Chukchi seas is very complex (Fig. 1) and consists of the Bering inflow that separates into three branches, the anticyclonic Beaufort Gyre, the Beaufort slope current (Pickart 2004), and the East Siberian Current. The Beaufort Sea slope current has a spatial scale of about several dozen kilometers (Weingartner et al. 1998; Pickart 2004), and Barrow Canyon current has a similar spatial scale of about 30 km (Shimada et al. 2006). Another important feature in the Beaufort Sea is the small-scale mesoscale eddies of several dozens of kilometers in diameter (Manley and Hunkins 1985; Muench et al. 2000; Chao and Shaw 2002), with anticyclones outnumbering the cyclones. Again, these small-scale features challenge both observation and

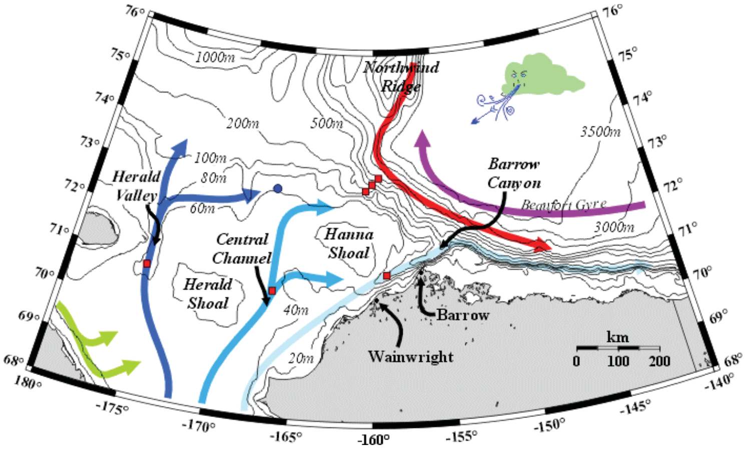


Figure 1. A schematic diagram for coastal circulation in the Chukchi-Beaufort Seas (light blue: Alaskan Coast Current with the origin of freshwater; Courtesy of Tom Weingartner).

modeling capability. Particularly, the coarse resolution observation arrays and model meshes cannot resolve these processes.

In the shallow Chukchi Sea, tidal current and its mixing should be important (Nihoul et al. 1993; Kowalik and Proshutinsky 1994). The wind-derived surface waves are also important mechanical sources to vertical mixing. These dynamical sources for the ocean should be seriously taken into account in both observational and modeling studies (Hu and Wang 2007).

The winter atmospheric wind pattern is mainly controlled by the anticyclonic (clockwise) Beaufort High, while the summer wind stress is relatively weak due to the weakened Beaufort High. The northward propagating summer storms occasionally move to the Chukchi Sea via the Bering Strait (Zhang et al. 2004), producing strong wind and mixing. The winter anticyclonic wind stress associated with the Beaufort High has many important effects, such as 1) surface Ekman drift that advects the Beaufort coastal freshwater into the Beaufort Gyre, 2) sub-surface upwelling that brings the warm, saline Arctic intermediate water (i.e., the Atlantic Water) into the Beaufort Sea shelf break, melting surface sea ice, and 3) formation of landfast ice (Mahoney et al. 2007a, b).

During 2004-2007, MMS/CMI continuously sponsored this project titled "Sea Ice-Ocean-Oilspill Modeling System (SIOMS) for the Nearshore Beaufort and Chukchi Seas: Parameterization and improvement (Phase II)." The goal of this project was to build a state-of-the-art, stand-alone coupled ice-ocean model to resolve many of these important small-scale dynamical and thermodynamical features of both the ocean circulation and sea ice. The end-product is to provide ocean and sea ice information to MMS to conduct hypothetical oilspill impact assessments on the environment in the Beaufort and Chukchi seas. This paper summarizes the major accomplishment of the past year.

Configuration of high-resolution CIOM and atmospheric forcing

The CIOM should refer to the studies of Yao et al., (2000), and Wang et al. (2002a, b; 2003a, b; 2004, 2005), and Wu et al. (2004). The ocean model used is the Princeton Ocean Model (POM) (Blumberg and Mellor 1987; Mellor, 1996), and the ice model used is a full thermodynamic and dynamics model (Hibler 1980) that prognostically simulates sea-ice thickness, sea ice concentration (SIC), ice edge, ice velocity, and heat and salt flux through sea ice into the ocean. The model has been successfully applied to the Bering Sea (Hu and Wang 2007; Wang et al. 2007a), the Beaufort Sea (Wang et al. 2003b), and in the northern China seas (Q. Liu, personal comm.).

Ocean Model:

- horizontal spherical grid with 3.8 km in longitude and latitude covering the Chukchi-Beaufort seas;

- 24 sigma levels in the vertical;
- open boundaries (velocity, T, and S) are embedded by a climate (atmosphere-ice-ocean-land) GCM from Japan with a resolution of about 25 km (Watanabe et al. 2006; Wang et al. 2007b) with volume transport conservation principle and radiation property (Wang et al. 2001a).
- river runoff is applied to the mouths of the Mackenzie River (Wang et al., 1999);
- inclusion of parameterization of wind-wave mechanic mixing;
- atmospheric forcing uses NCEP forecast products: heat flux, mass (moisture) flux, and six-hourly wind stress.

Ice Model:

- full thermodynamics with 1-layer ice and 1-layer snow;
- full dynamics with plastic-viscous rehology (Hibler 1979, 1980; Wang et al. 1994) under the NCEP forcing;
- multi-category ice model (Throndike et al. 1975; Yao et al., 2000) fully coupled to an ocean model (Mellor and Kantha 1989; Kantha and Clayson 1994);
- inclusion of lateral melting of sea ice;
- prognostic and diagnostic variables: Ice velocity, compactness, ice edge, thickness, heat budget, salt budget, ice stress, etc.

In this study, ten ice categories (0, 0.2, 0.5, 1, 1.5, 2, 3, 4, 5, and 6 m) are used, each having a percentage in a grid point. Thus, a thickness equation for each category is calculated. Then, the summation of each category thickness is the total thickness at each grid. Thus, sea ice concentration and thickness at each grid are calculated from the sum of the ten ice categories.

The model was spun up with temperature and salinity (PHC) of Steele et al. (2001), sea ice climatology, January concentration, and motionless sea ice and ocean for the first seven years under NCEP reanalysis monthly atmospheric forcing, which were derived from the period of 1958-97. At the bottom layer, both temperature and salinity are restored to the monthly climatology with the same time scale of 60 days. At the surface, salinity, with freshwater flux forcing from *P-E*, is restored to the observed monthly salinity fields at a time scale of 30 days for prescribing freshwater runoff into the Arctic Basin using the flux correction method of Wang et al. (2001a). After a four-year spinup, a dynamical and thermodynamical seasonal cycle is established. Then, we re-ran the model for another four years using the fourth year output as the restart or initial conditions. During the four-year run, all the monthly atmospheric forcings remain the same. Then, the last year variables are used for examining the seasonal cycle in this study.

Model simulations: Climatology with monthly forcing and with no lateral melting

The CIOM was driven by the NCEP/NCAR Reanalysis monthly atmospheric forcing (air temperature, humidity, sea surface wind, sea level pressure, satent heat flux, sensible heat flux, set shortwave radiation, set long wave radiation and precipitation rate). Those atmospheric datasets were derived from the NOAA/CDC/NCEP/NCAR website (http://www.cdc.noaa.gov/cdc/reanalysis/reanalysis.shtml).

General ocean circulation pattern vs. in situ observations

The high resolution CIOM reproduced very fine structure of the Alaska Coastal Current system (three branches) and the anticylonic large-scale Beaufort Gyre superimposed by mesoscale eddies with anticyclones outnumbering cyclones (Fig. 2). The first branch is the Alaska Coastal Water/Current (ACW/C) along the Alaska Arctic coast. This current flows mainly along the isobaths with relatively warm water. The second branch (middle) flows northward and turns to the right, joining ACW/C. The ACC flows eastward all the way to the Canadian Beaufort Sea, encountering the Mackenzie River outflow. The coastal current then turns sharply to the left and joins the Beaufort Gyre (westward) circulation. As a consequence, between the Beaufort Gyre and ACC there is a strong horizontal shear, resulting in a deep trough in sea surface height (SSH). This phenomenon is found for the first time using this high resolution CIOM, which needs field measurements to confirm. The third branch flows northwestward into the Chukchi Sea. In addition, the Eastern Siberian Sea is also reproduced.

The simulated Beaufort Gyre is well confirmed by the high SSH (red) with anticyclones dominating due to baroclinic instability (Wang and Ikeda 1997; Chao and Shaw 2002). It is not well known that the barotropic instability can produce

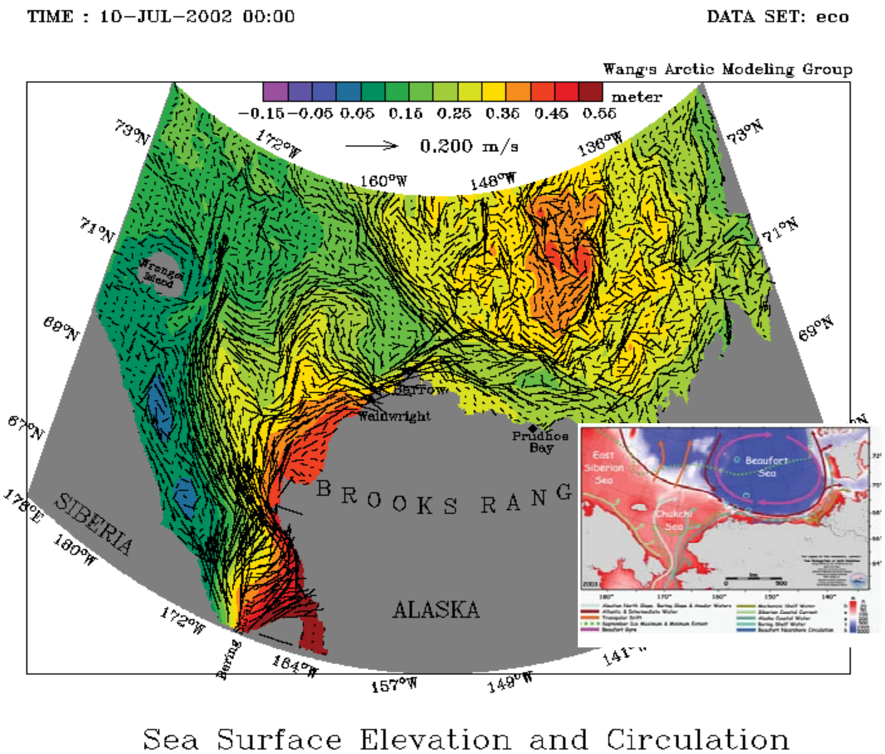


Figure 2. Model-simulated upper surface 50-m averaged ocean velocity on July 10 under the climatological forcing, compared with the schematic ocean circulation pattern (imbedded on the lower right corner; courtesy of Weingartner). In the left panel, the color bar indicates the sea level height (SSH) with red being high SSH, while in the right panel, the color bar denotes the bottom topography in meters with red being shallow water.

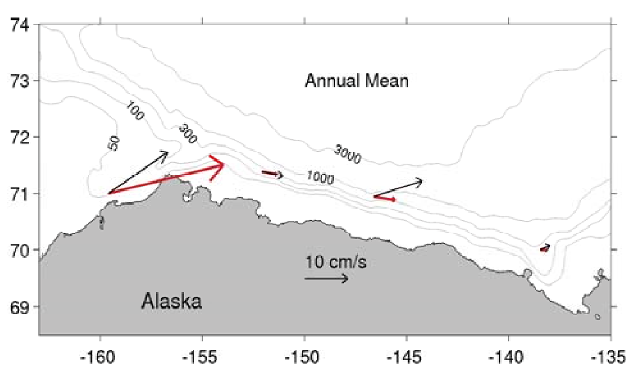
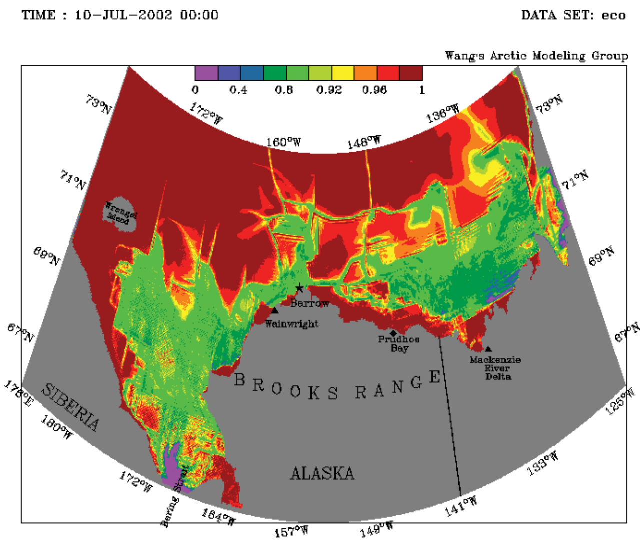
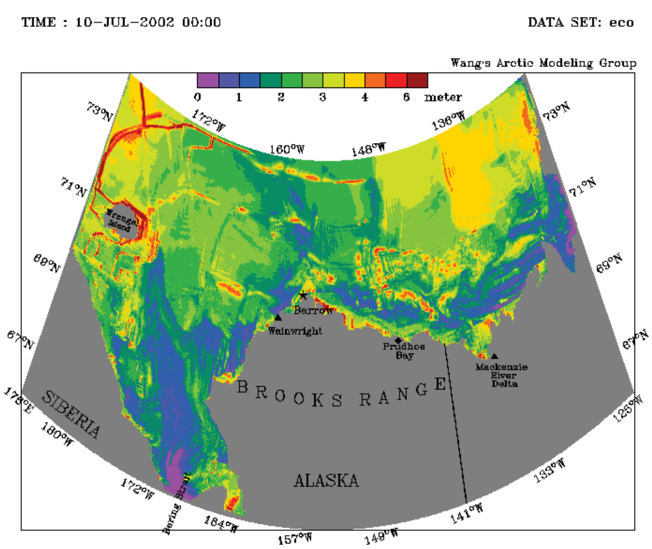


Figure 3. Climatological annual mean velocity reproduced by the model (black arrows) are compared to the JAMSTEC ADCP- measured velocity (red arrows) at the 70 m depth in the Beaufort and Chukchi seas.

Figure 4. The sea ice concentration (left; scale: from 0 to 1) and sea ice thickness (top panel) on July 10, as simulated by the high-resolution Coupled Ice-Ocean Model (CIOM; Wang et al. 2002a, 2005) that is nested to the Japan CCSR/NIES/FRCGC (Center for Climate System Research/National Institute of Environmental Studies/Frontier Research Center for Global Change) high-resolution global model. Sea ice breaks up offshore piece by piece; landfast ice remains untouched along the Beaufort Sea coast. Sea ice floes are irregular in shape and break away from pack ice. Sea ice ridging, rafting, and openings/leads can be well reproduced by sea ice thickness (bottom panel).



Sea Ice Concentration



Sea Ice Thickness

such mesoscale eddies, and it should be further investigated.

Both in-situ and satellite remote sensed data are used to validate the Beaufort Sea CIOM. Figure 5 shows the comparison between the model simulation velocity (black) and the ADCP mooring velocity (red) at a subsurface layer of 70 m. The ADCP data were taken from 1992 to 2001 by the Japan Agency for Marine-earth Science and TEChnology (JAMSTEC). The simulated velocities are, in general, consistent with the observed. Nevertheless, there are discrepancies in both velocity direction and magnitude, which may be due to the following facts: 1) the model topography/depth was smoothed, 2) the model vertical and horizontal resolution is still coarse, and 3) the model forcing is climatological monthly forcing, while the observations were taken from 1992 to 2001 by JAMSTEC.

We further validate the CIOM using historical transitional CTD measurements. There were several observational campaigns in the regions by JAMSTEC, NSF's SBI (Shelf-Basin Interactions in the Western Arctic) project (Pickart 2004), Canadian Beaufort Sea project (Melling 1993) , and MMS-sponsored Beaufort Sea oceanographic survey (Weingartner et al. 1998) and landfast ice survey (Eicken et al. 2005). The comparisons were conducted using available data in next section.

Sea ice ridging and landfast ice

Figure 4 shows sea ice concentration (SIC) and thickness on July 10 under the climatological monthly forcing. SIC map (Fig. 4, upper) indicates various shapes of ice floes during the melting season. During spring, sea ice melts offshore first, and the pack ice gradually melts piece by piece into various shapes. Even in July, the Beaufort coast landfast ice remains untouched, which usually melts completely in September.
Sea ice arching, leads, and cracks can be observed from the simulated seasonal SIC maps (not shown).

Sea ice thickness map (bottom panel of Fig. 4) on July 10 shows sea ice ridging and rafting due to sea ice dynamic interaction with oceanic circulation pattern, shear, convergence, and divergence. Landfast ice along the Beaufort Sea coast is clearly simulated. Mechanics of formation and maintenance of landfast ice may be attributed to the following factors: 1) a northeast wind due to the Beaufort Gyre, 2) the eastward Alaska arctic coastal current (or ACC) has a right-turning force due to Coriolis effect, 3) high resolution topography and geometry, and 4) internal sea ice stress. However, how to identify and quantify these major factors remains open. Sensitivity experiments are in progress to test these mechanisms.

Comparison of model simulation with satellite measurements

The seasonal cycle of the Beaufort and Chukchi sea ice is well reproduced in comparison to the satellite-measured sea ice area as shown in Fig. 5. Mizobata et al. (2007) not only collected and analyzed sea ice extent, SST, but they also collected chlorophyll *a* and the derived primary productivity data. Figure 5 indicates the model does not capture the summer minimum sea ice area, although the overall seasonal cycle is well reproduced. Note that the SSM/I does not identify ice ponds (i.e., melting

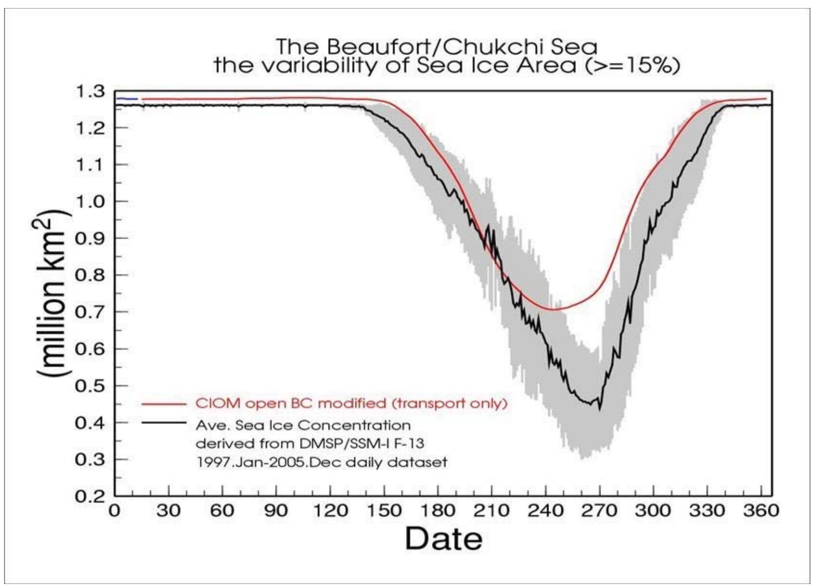
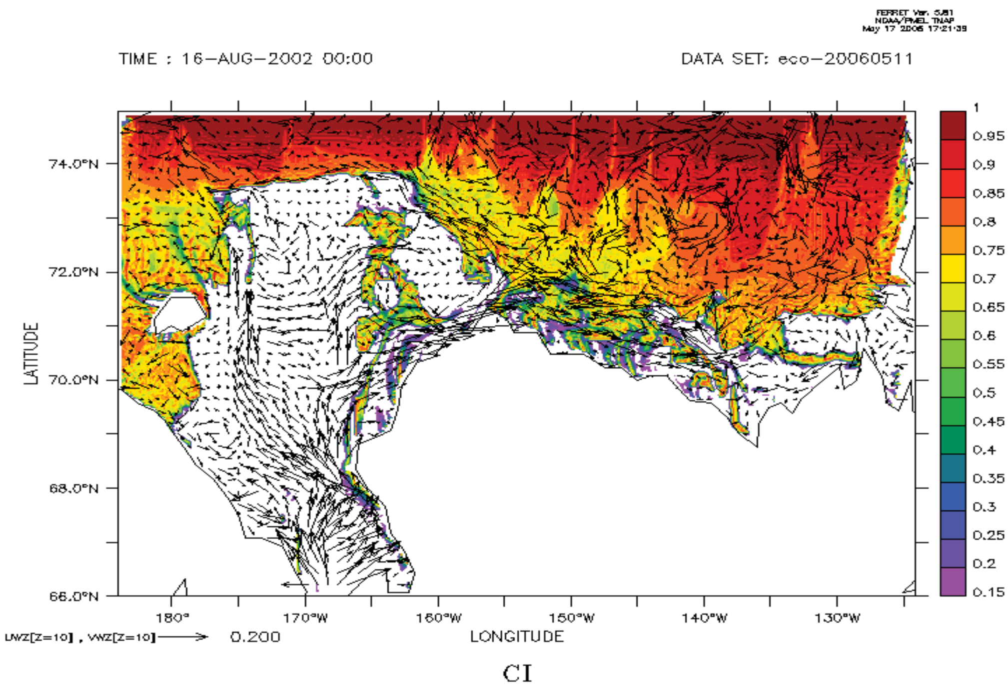
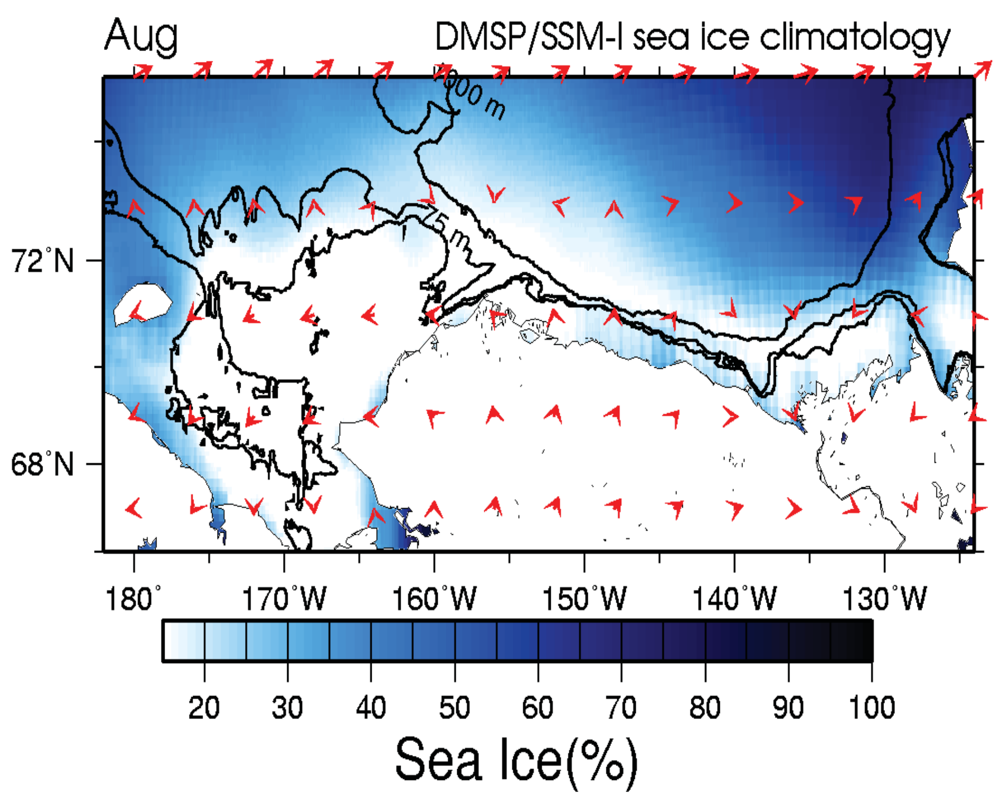


Figure 5. Model-data comparison: Satellite-measured (black) and model-simulated (red) sea ice cover; For more details of the satellite products prepared for validation of CIOM, please go to: http://www.frontier.iarc.uaf.edu/~jwang/SatelliteProducts.

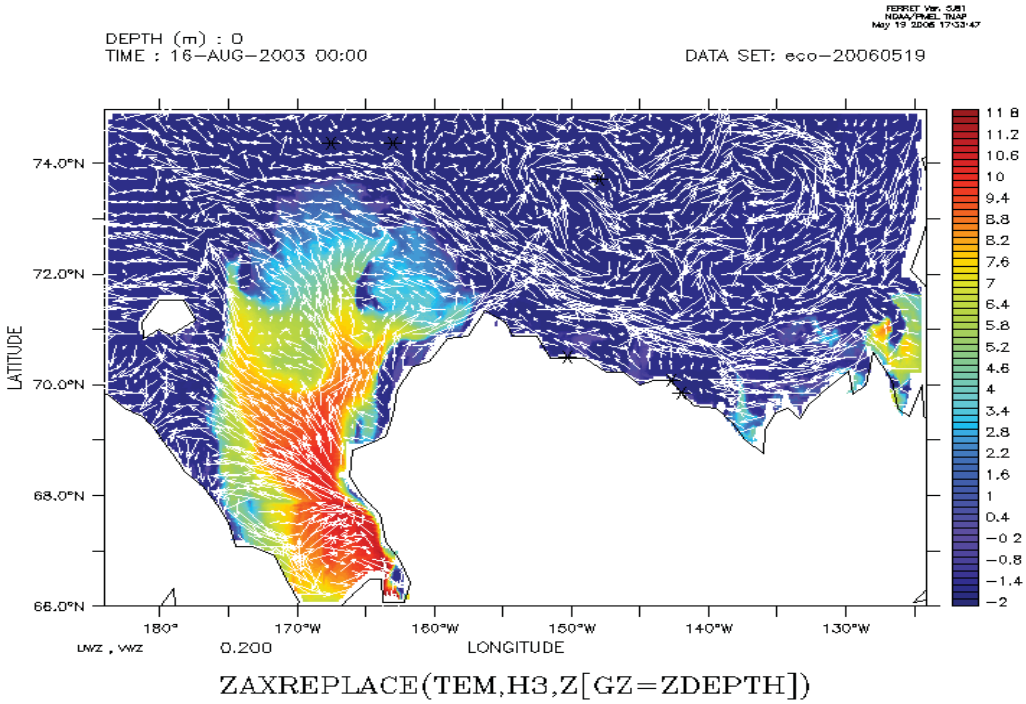
Panel 1



Panel 2



Panel 3



Panel 4

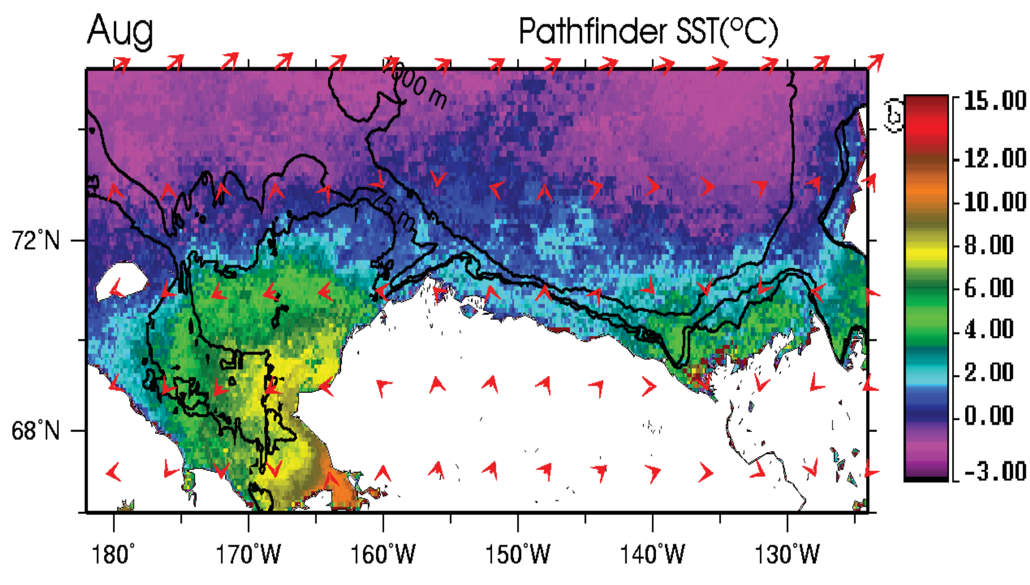
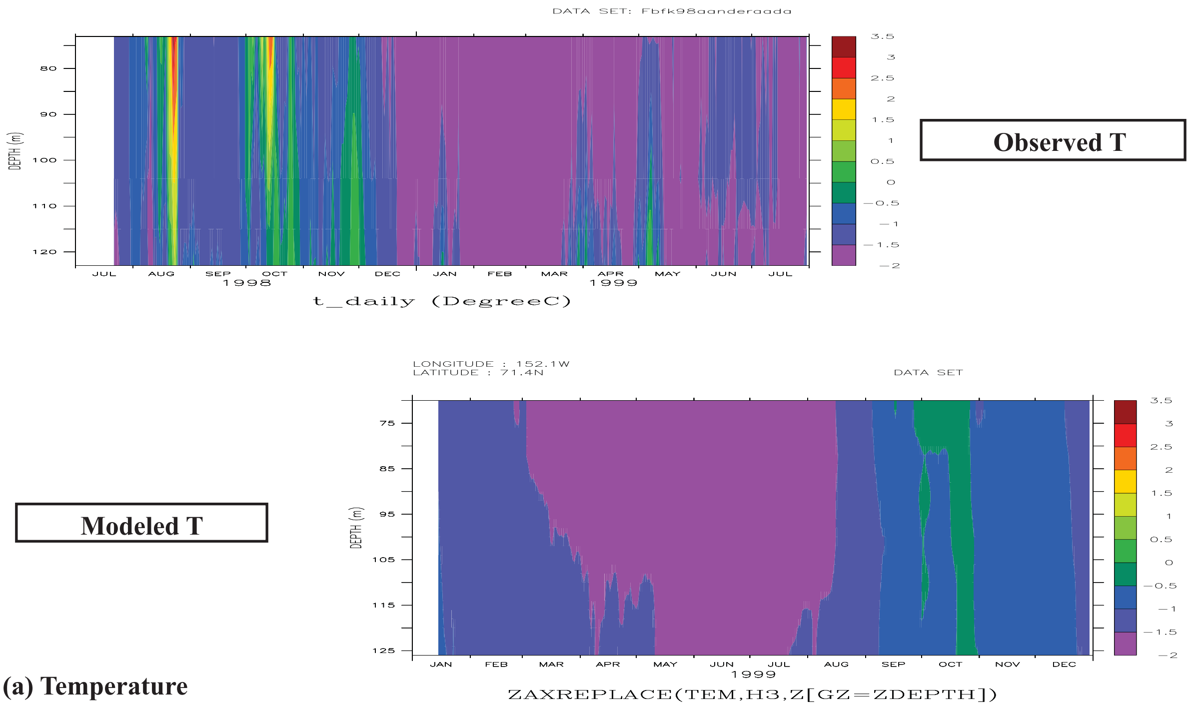
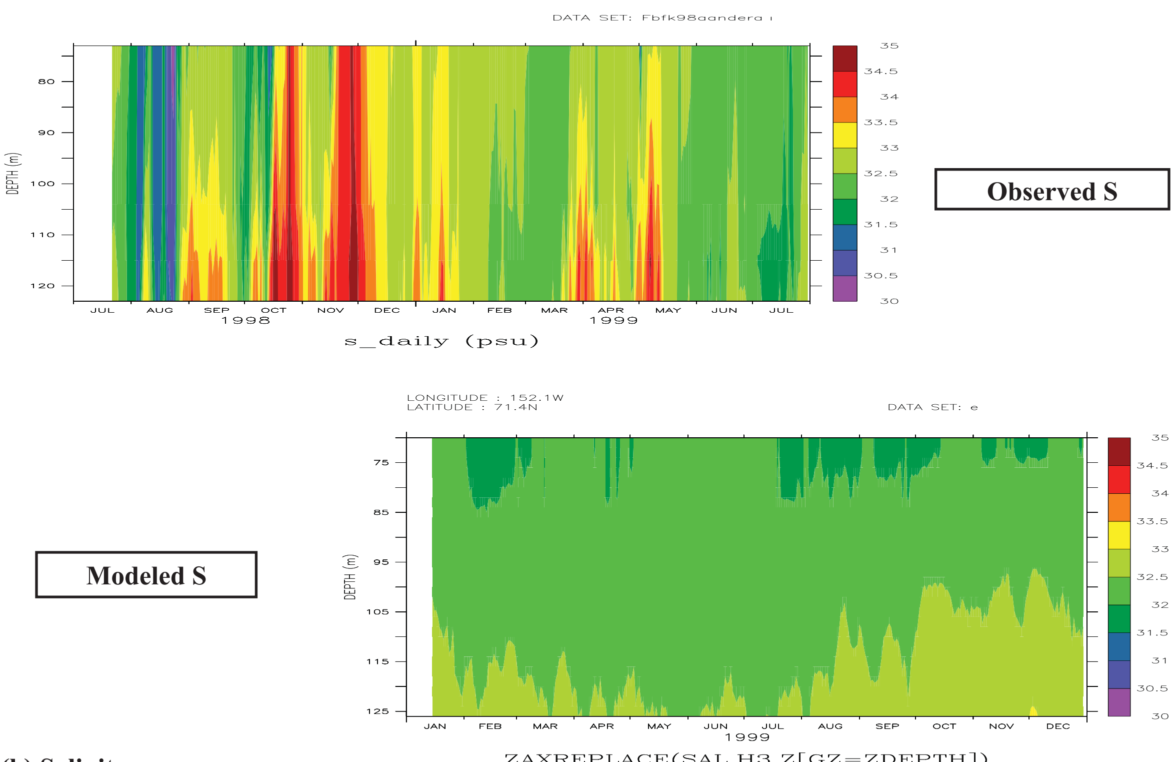


Figure 6. The comparison between the CIOM-simulated SIC (1st panel) and SST (3rd panel) and satellite-measured SIC (2nd) and SST (4th panel). Superimposed into the modeled SIC and SST maps are the surface ocean currents (1st and 3rd panels), while superimposed into the remote sensed SIC and SST maps are the NCEP wind vectors (2nd and 4th panels).

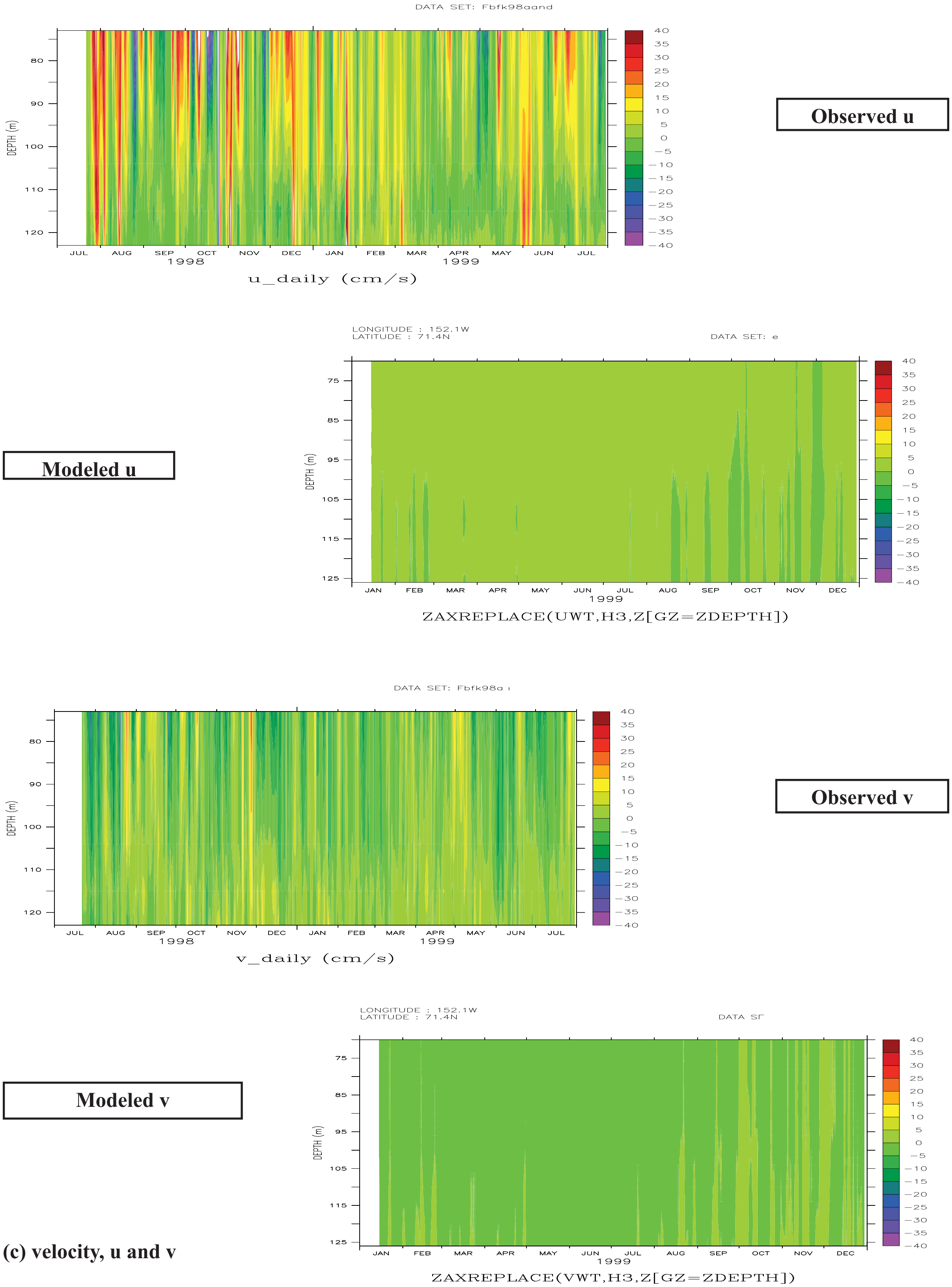
Figure 7. Time-depth comparison of observed (upper) and modeled (lower) temperature (a), salinity (b), and velocity, u and v (c) at BFK98 (station 10). The model captures the mean state, with less variability for all the variables.



(a) Temperature



(b) Salinity



(c) velocity, u and v

water ponds on the sea ice) from sea water (R. Kwok, personal comm., 8/2006); thus, the satellite observed sea ice area minimum (black line) may underestimate the summer sea ice area (i.e., overestimate the open water). Nevertheless, CIOM still needs to be improved.

The model-simulated spatial patterns of sea ice extent and SST are compared to satellite measurements for July (not shown), August (Fig. 6), and September (not shown). The August map indicates that the CIOM in general reproduces a reasonable spatial pattern of SIC and SST, except that the SST along the Beaufort Sea coast is underestimated. This results in the overestimate of sea ice along the Beaufort coast, particularly the landfast ice. There may be several reasons for the underestimate of SST: 1) the Bering Sea warm inflow is not well represented, 2) lateral melting is not included, 3) tidal mixing is not included, and 4) monthly forcing rather than daily forcing is used. These problems will be addressed in the next section.

Model simulations with daily forcing and lateral melting

After the spin-up integration, we ran the CIOM under the NCEP/NCAR Reanalysis daily atmospheric forcing. Those daily datasets also originate from the NOAA/CDC/NCEP/NCAR website.

Validation of CIOM using in-situ observations

The JAMSTEC measurements were used to validate the model results under the daily atmospheric forcing in a specific year, such as during 1998-99 measurements at Station 10 (BFK98, located west of Barrow Canyon). We conducted a point-to-point comparison that has long challenged all ocean models (except for tide models), including CIOM. Nevertheless, the comparison between the averaged parameters is expected to be more reasonable.

Figure 7 shows the depth-time temperature comparison at BFK98 for the period of January-July 1999. A common problem for models is that CIOM produces less temperature variability (Fig. 7a) than in situ measurements. This problem exists for all variables: salinity (Fig. 7b) and velocity (Figs. 7c). The point-to-point comparisons of T, S, and velocity time series are shown in Fig. 8, indicating that a large discrepancy exists in all the predicted variables with no data assimilation. The model basically captures the mean values, which is correct and encouraging on the first-order approximation, nevertheless with less variability. This problem exists in all models from small-scale to large-scale circulation models, except for ocean tide simulation (Ford et al. 1989; Wang 1998).

Encouragingly, the comparison in the averaged variables such as velocity (Fig. 9) indicates CIOM captures the mean state of the ocean velocities and their vertical structures.

There are many factors responsible for less variability derived from CIOM and from other models as well: 1) the boundary conditions use a coarse-resolution (1/4x1/6 degrees) global GCM monthly output, which filters out the high frequency and small-scale variability with smaller magnitude, 2) smoothing of topography, 3) numerical filtering in the model, and 4) numerical diffusivity due to truncation errors, and many others. This problem can be improved, but may never be cured until high accuracy numerical schemes with natural (zero) numerical diffusivity are developed and applied to ocean models without smoothing topography.

Validation of CIOM using satellite measurements

Seasonal cycle of sea ice area

To evaluate outputs of the CIOM, we compared simulated results with satellite measurements. Figure 10 shows the time series of the averaged sea ice area derived from SSM-I measurements between 1997 and 2005 (black line), sea ice area in 2002 (blue line), and sea ice area in 2002 simulated by the CIOM (red line). In Fig. 10, we plotted a 3-day averaged sea ice area estimated from the CIOM output, so that short-term variability, which is shown by the SSM-I measurements, is hard to be detected. However, the CIOM accurately reproduces the seasonal cycle of sea ice in the Chukchi/Beaufort Sea, while simulated sea ice was suddenly melted in late July due to the imposed lateral melting parameterization. The maximum sea ice area and the timing of ice melting/freezing are consistent with SSM-I measurements. Also, sea ice freezing during winter (October-December) was accurately reproduced. During August, the open water area was larger in the simulation than what was measured by the SSM-I. The melting rate of sea ice from May to August and maximum sea ice retreat still need to be improved. Obviously ice melting rate is slow during June and fast during late July and August, compared with SSM-I measurements.

Simulated sea ice distributions and motions during ice freezing season (January - April)

Figure 11 shows sea ice concentration and sea surface temperature in the Chukchi/Beaufort Sea on January 15th to April 27th. Red (black) arrows represent ice (10-m ocean) velocity. Generally, ice velocity in the Chukchi/Beaufort Sea in January (Fig.11a) and February (Fig.11b) is greater than that in March (Fig.11c) or April (Fig.11d) due to strong sea surface wind, while ice movement is also affected by surface ocean current. Relatively strong ice velocities along the Alaska coast on April 27th indicate ice advection by the Alaska Coastal Current (Fig.11d). Those coastal currents flow in the narrow Beaufort coastal area and continue to the estuary of the Mackenzie River. On the other hand, cyclonic circulation, which has been observed (e.g., Pickart et al., 2002), was captured in the Beaufort Sea basin area during winter.

Simulated sea ice distributions and ocean circulation during ice melting season (June – September)

The CIOM also simulated sea ice melting starting from June 2002. Figure 12 shows sea ice concentration greater than 30% (gray area), ice velocity (red arrows), sea surface temperature, and water velocity at 10 m water depth (black arrows) on June 20th (Fig. 12a), July 20th (Fig. 12b), August 10th (Fig. 12c), and September 18th (Fig. 12d). Ice

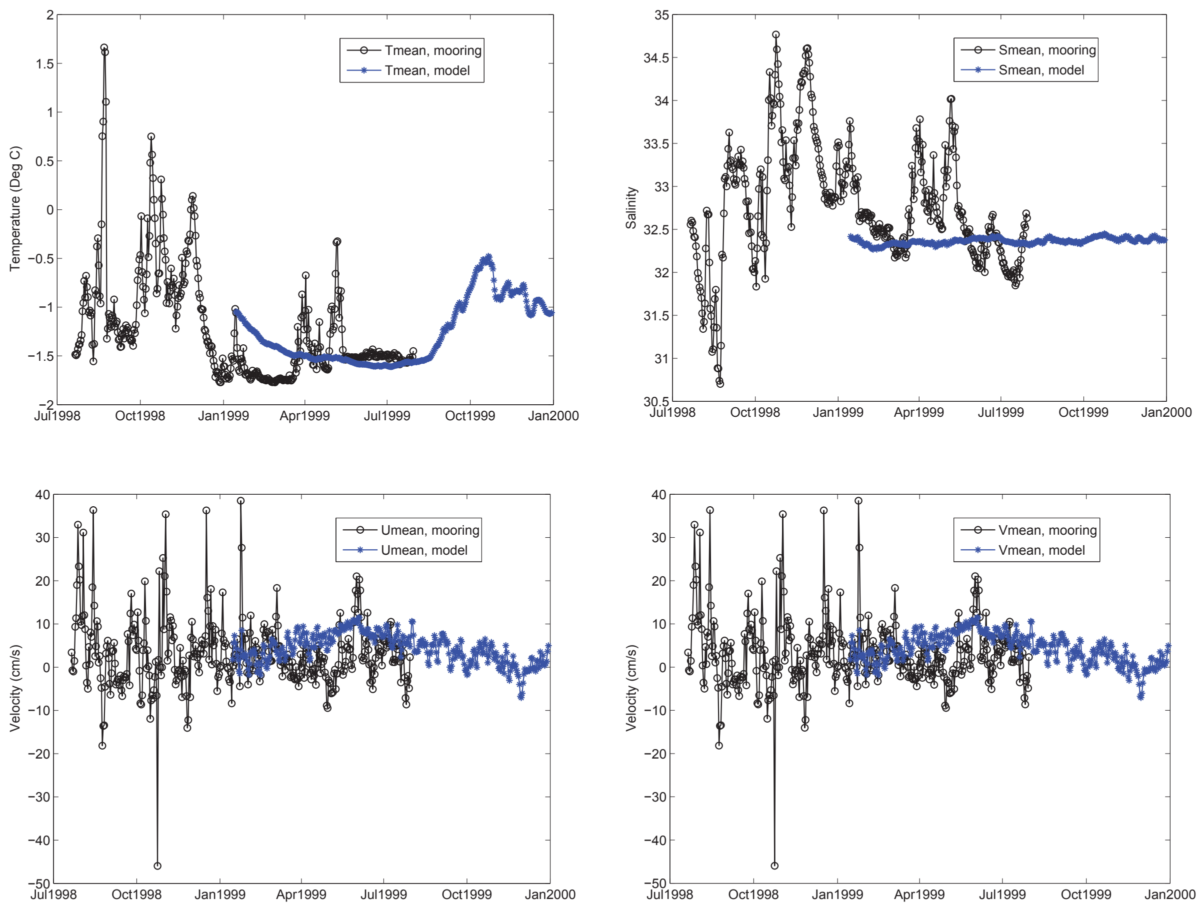


Figure 8. The point-to-point comparisons of the time series of temperature (upper left), salinity (upper right), velocity u (lower left), and velocity v (lower right) at BFK98 (station 10). Black curves are observation, while blue lines are modeled time series.

Figure 9. Time-averaged vertical profiles of observed velocity, u and v (black) and modeled velocity, u and v (blue) at BFK98 (station 10).

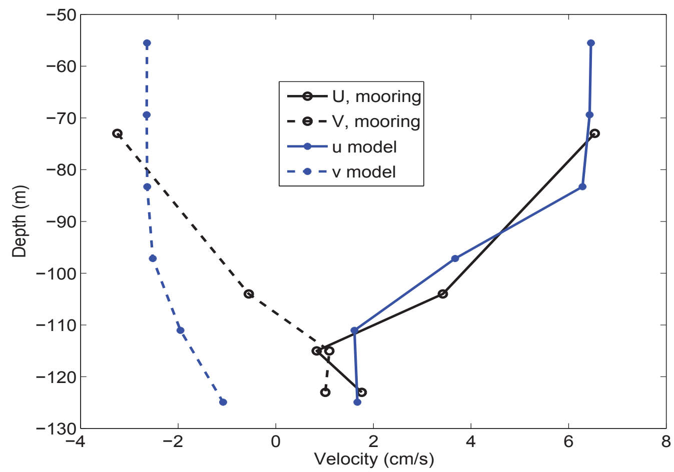
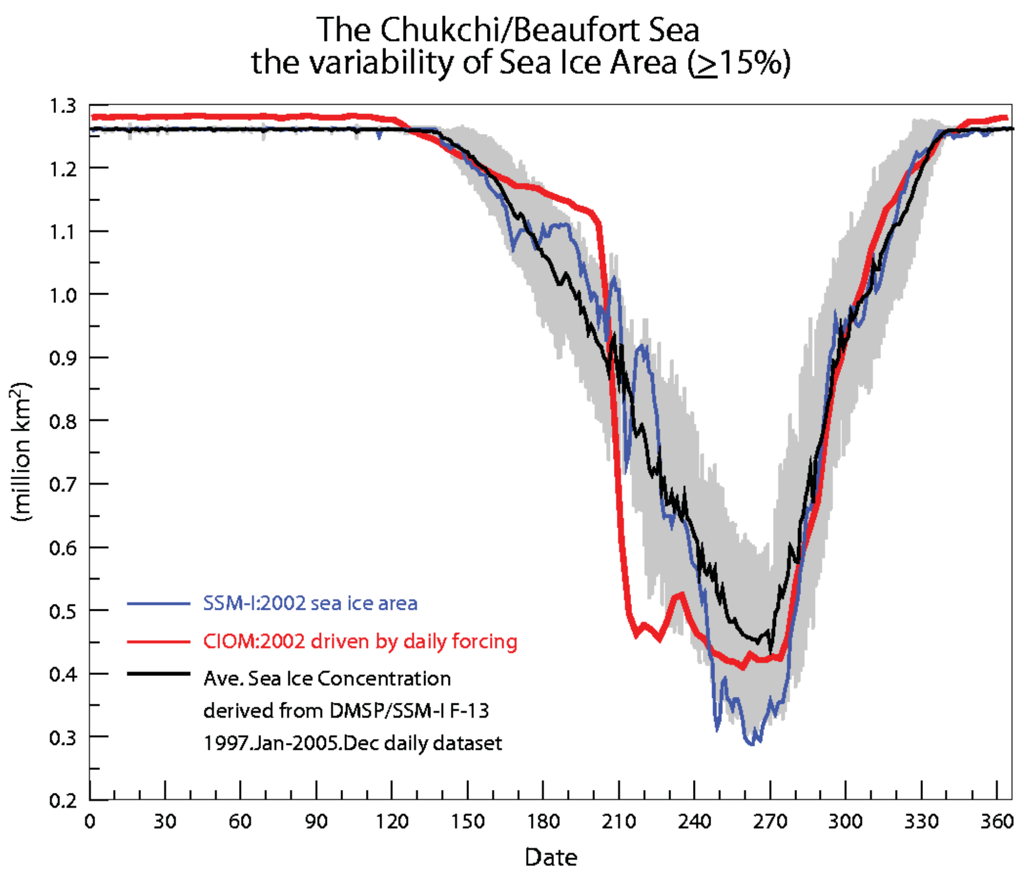


Figure 10. Seasonal cycle of sea ice area in the Chukchi/Beaufort Sea derived from the SSM-I measurements (black line, daily) and simulated by the CIOM (red line, 3-day averaged). Sea ice concentration less than 15 % was ignored to avoid the error of SSM-I measurement. Gray area represents the variance of the averaged sea ice cover from 1997 to 2005.



velocity was weaker than that during winter. Open water started to form at the southern Chukchi Sea shelf in May or June (Fig. 12a) and at the estuary of the Mackenzie River in July (Fig. 12b). In August, wide open water occurred at the northern Chukchi Sea shelf and basin area (Fig. 12c). Also wide lead-like feature and landfast ice can be seen at the northern Alaska coast in the Beaufort Sea. Detail of landfast ice will be discussed later. In September, sea ice cover is diminished resulting in wide open water in the Beaufort Sea (Fig. 12d). Mesoscale features can be found at the ice edge in the Beaufort Sea. In August and September, high water temperature more than 8^{o}C was found in the Chukchi Sea. The distributions of warm waters and ocean circulation represent the pathway of the Pacific Summer Water through the Bering Strait (Fig. 12c, white arrows). Relatively high temperature in the Beaufort Sea is due to both river discharge of the Mackenzie River and the Alaska Coastal Current flowing along the Alaska coast. The plume near the estuary of the Mackenzie River was well simulated. Those features are consistent with previous ship surveys.

Figure 13 shows remote-sensed SST and SIC in the Chukchi/Beaufort Sea. Satellite measurements indicate that open water started at the southern Chukchi Sea and at the estuary of the Mackenzie River (Fig. 13a), and covered the Chukchi Sea shelf in July (Fig. 13b). The relatively warm Alaska Coastal Current can be seen in the Chukchi Sea shelf in August (Fig. 13c, white arrow) and near the northern Alaska coast from Point Barrow to the Mackenzie River in September (Fig. 13d, white arrows). Those features are similar to the simulated results (Fig. 12). On the other hand, open water derived from satellite images is wider than that simulated by the CIOM

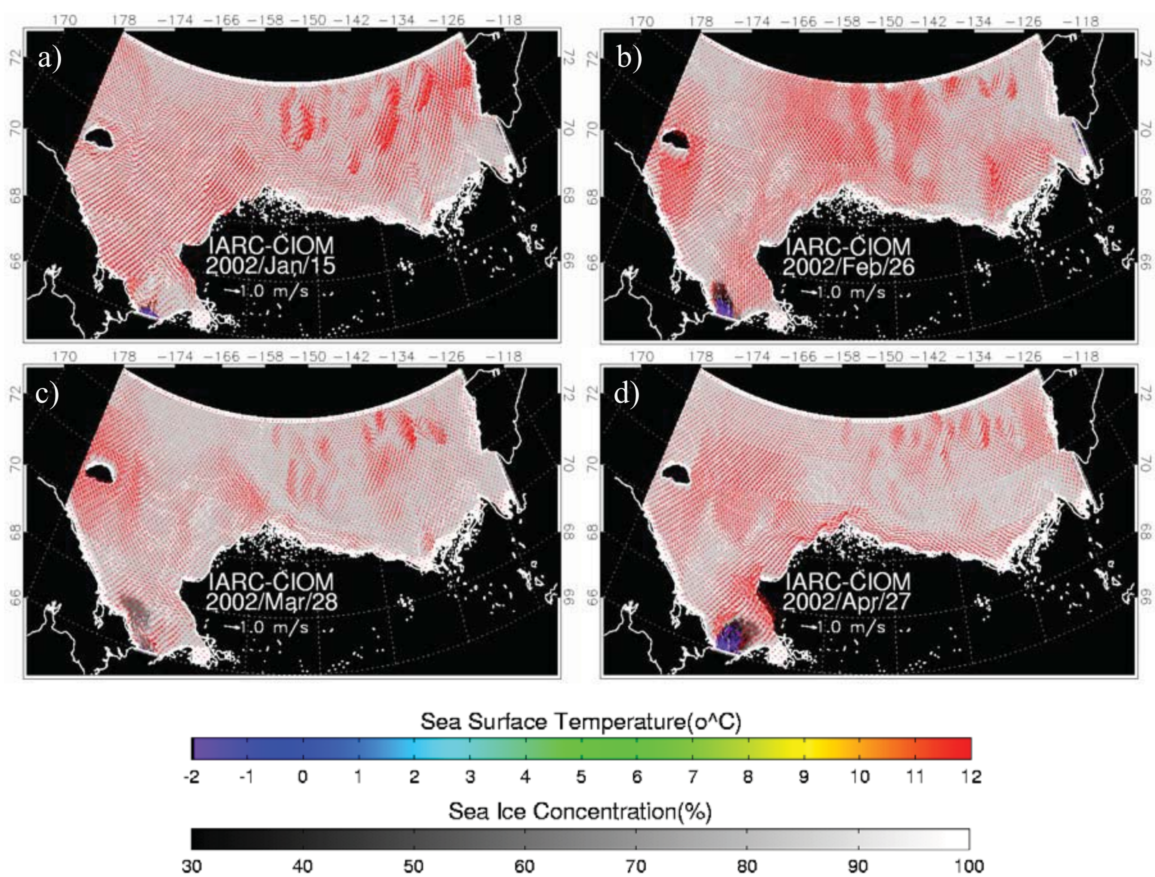


Figure 11. Sea ice cover and motion in the Chukchi/Beaufort Sea on a) January 15th , b) Feb 26th , c) March 28th, and d) April 27th in 2002 simulated by the CIOM. Red (black) arrows indicate ice (10-m ocean) velocity. Sea surface temperature is shown near the Bering Strait.

during August and September in the Chukchi Sea. The difference between SSM-I measurements and CIOM simulation results is due to the open boundary condition, ice-melting scheme, or errors in satellite measurements.

Ocean circulation in the Chukchi Sea Shelf

In the Chukchi Sea shelf, warm Pacific water intrudes through the Bering Strait. Heat input through the Bering Strait could be a trigger of rapid sea ice reduction (Shimada et al. 2006). Figure 14 shows AVHRR daily sea surface temperature images on July 21st (Fig. 14a), August 1st (Fig. 14c) and September 22nd (Fig. 14e) and ice-ocean circulation (Figs. 14b, d, and f) simulated by the CIOM (same as Fig. 12) in the Chukchi Sea. SST patterns are similar to the ocean temperature simulated by the CIOM. Both AVHRR SST and ocean temperature derived from the CIOM show warm water covering the Chukchi Sea in July (Figs. 14a and b) and extending to the Herald Canyon, western Hanna Shoal, and southeastern Siberian coast in August (Figs. 14c and d). The warm water pattern greater than 8^{o}C captured by the AVHRR indicates the ACC and its branches (Fig. 14c, white arrows). Those features were well simulated by the CIOM, except for magnitude of temperature (Fig. 14d, white arrows). The AVHRR SST indicates the warm Alaska Coastal Current flowing along the Alaska coast. Warm water reached the Icy Cape in August (Fig. 14c) and at the Barrow Canyon in September (Fig. 14e). The CIOM results are consistent with satellite measurements and previous ship surveys. Thus, the distribution of the warm Pacific Water and ocean circulation in the Chukchi Sea were well simulated. The difference between AVHRR images and CIOM results is the high water temperature core at the Siberian coast (Figs. 14a

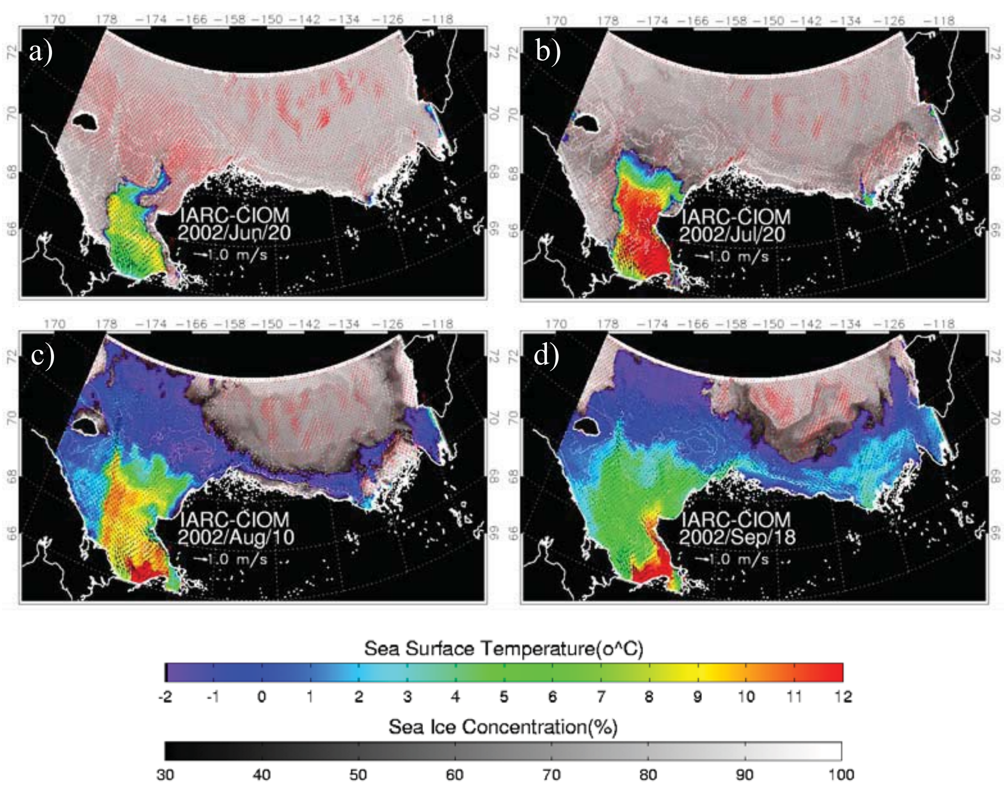


Figure 12. Sea ice cover and motion in the Chukchi/Beaufort Sea on a) June 20th, b) July 20th, c) August 10th, and d) September 18th in 2002 simulated by the CIOM. Gray area means sea ice concentration between 30% and 100%. Red arrows and black arrows indicate ice velocity and 1-m ocean velocity, respectively.

and c). Currently, this high water temperature core is not simulated. A similar warm core was found in July 2004. Therefore, this warm core will not be due to error; however, it is hard to determine the origin. No scientific reports or papers exist showing this kind of feature. The investigation for this warm core is ongoing. If this warm core is a real phenomenon, it will affect the timing and pattern of sea ice freezing. The cold band at the Siberian coast in September is due to errors resulting from cloud or fog.

Landfast ice, ice cover and ocean circulation in the Beaufort Sea coastal area

The ice-ocean circulation is very complex in the Beaufort Sea coastal area. There are sea ice, the ACC, small-scale eddies, river discharge, and the Beaufort gyre. Figure 15 shows the CIOM results from August to November. Water velocity is plotted at every grid point (black arrows) because the scale of eddies is small (10-20 km) and because the Rossby radius of deformation is about 5 km. In August, open water was formed and warm Pacific water came from the Barrow canyon (Figs. 15 a, b, and c). There was another source of heat, the Mackenzie River. Sea ice in the basin was melted, but the Landfast ice still remained at the Alaska coast between 156°W and 144°W (Figs. 15 a, b, and c). SSM-I measurements also indicate the landfast ice along the Alaska coast in August (Fig. 16). During September, wide open water and meandering of the boundary current resulting from eddies were simulated. Small-scale eddies in the Beaufort Sea will be discussed later. In October, boundary current was close to the Alaska coast (Oct. 06, Fig. 15g) and sea ice freezing started.

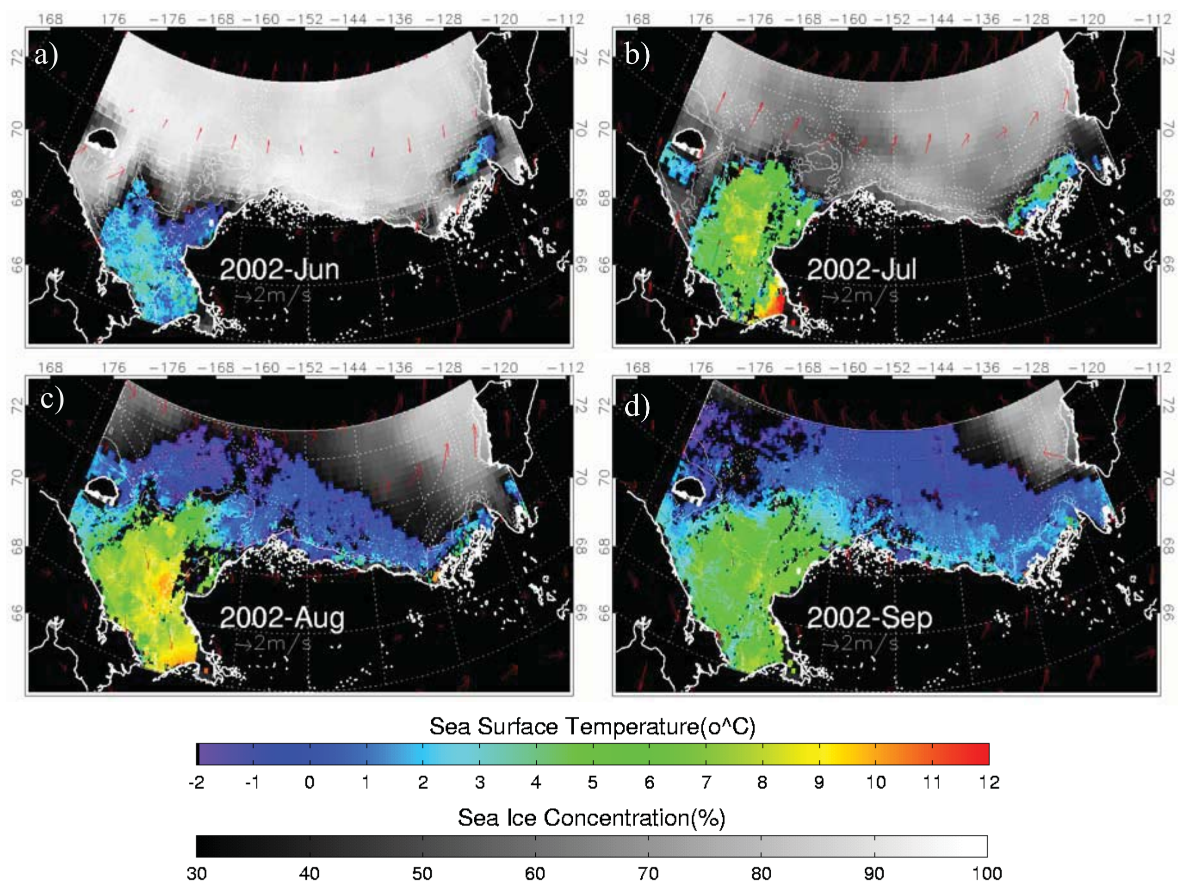


Figure 13. Monthly sea ice cover and sea surface temperature in the Chukchi/Beaufort Sea between June and September 2002 derived from satellite measurements. Red arrows show NCEP/NCAR sea surface wind velocity..

In November, the CIOM simulated sea ice freezing and polynia in the Beaufort basin (Figs. 15 h-i). According to Fig. 15, sea ice cover resulted from ice production at the coast (landfast ice) and in the basin, and ice advection from the basin to the Alaska coast. Ice was produced at the Alaska coast is due to the shallow water depth, resulting in rapid freezing.

On the other hand, SSM-I measurements show that sea ice cover is due to ice production in the basin area or advection from north or east (Fig. 17). Wide landfast ice was not seen in October from SSM-I measurements. SSM-I measurements possibly have errors because it is difficult to measure melt pond during the melting season. We still need to validate

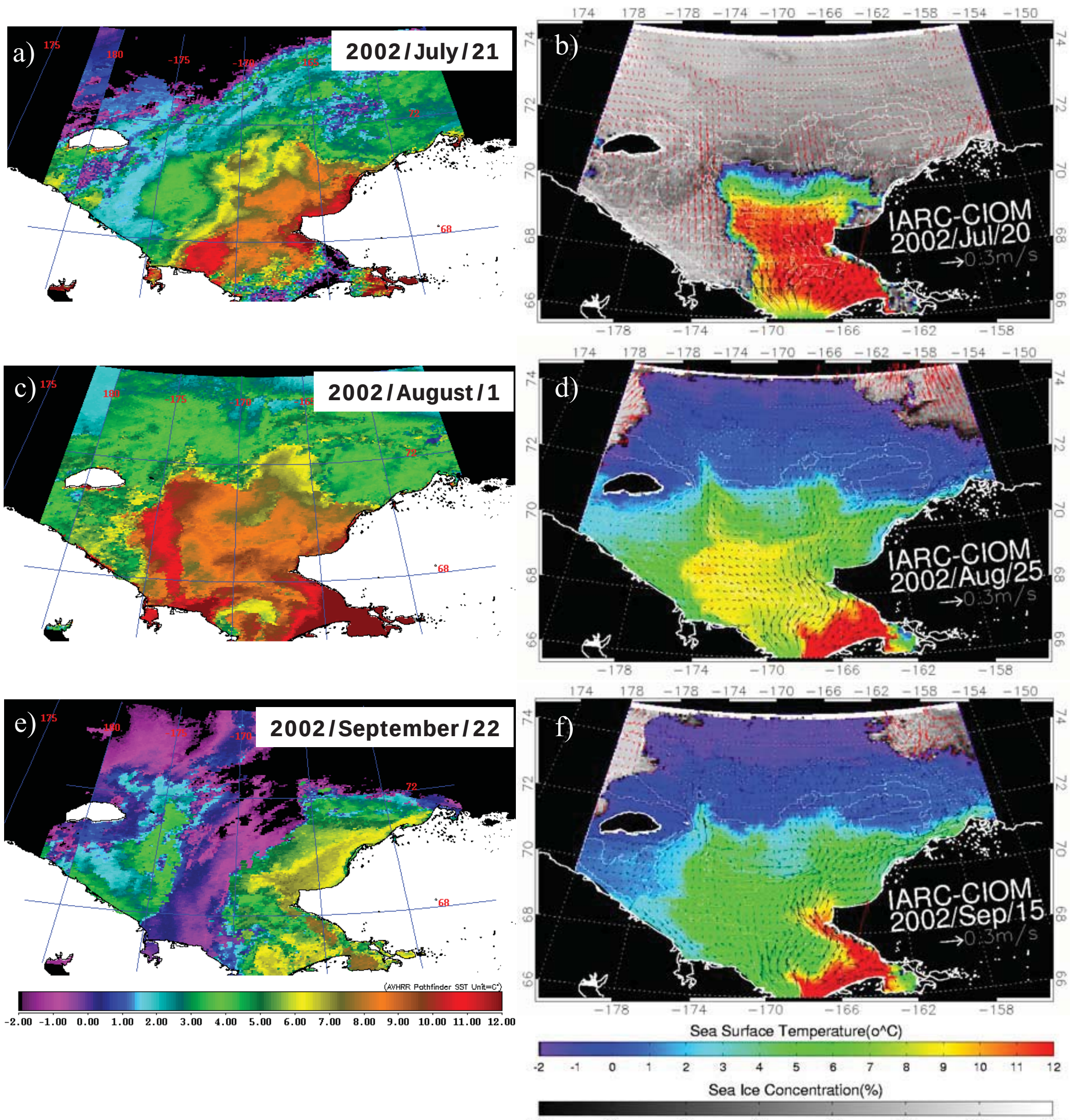


Figure 14. AVHRR-derived daily sea surface temperature images on a) July 21st, c) August 1st, and e) September 22nd (left) and simulated ice-ocean circulations (b, d, and f) same as Fig. 12 but only for the Chukchi Sea.

landfast ice production. The difference in the pattern of ice production between the CIOM and SSM-I measurements is under investigation.

Figure 18 shows the 10-year (1994-2004) climatology (mean) of minimum, mean, and maximum landfast ice extents in the Beaufort Sea, measured by SAR and SSM-I (Eicken et al. 2005). During the period, the Arctic Oscillation (AO) was weakened (Wang and Ikeda 2000, 2001) and the Arctic Dipole Anomaly (DA; Wu et al. 2006; Watanabe et al. 2006) was intensified. The positive DA-derived anomalous meridional wind stress along the Trans-polar Drift Stream (TDS) toward the eastern Arctic produced anomalous open water in the Alaska Beaufort Sea, and thus the anomalously less landfast ice along the coast. This is why there was little landfast ice in October (freezing season) and July (melting season). In other words, during the positive (negative) phase of DA, there is less (more) landfast ice extent due to the offshore (onshore) wind

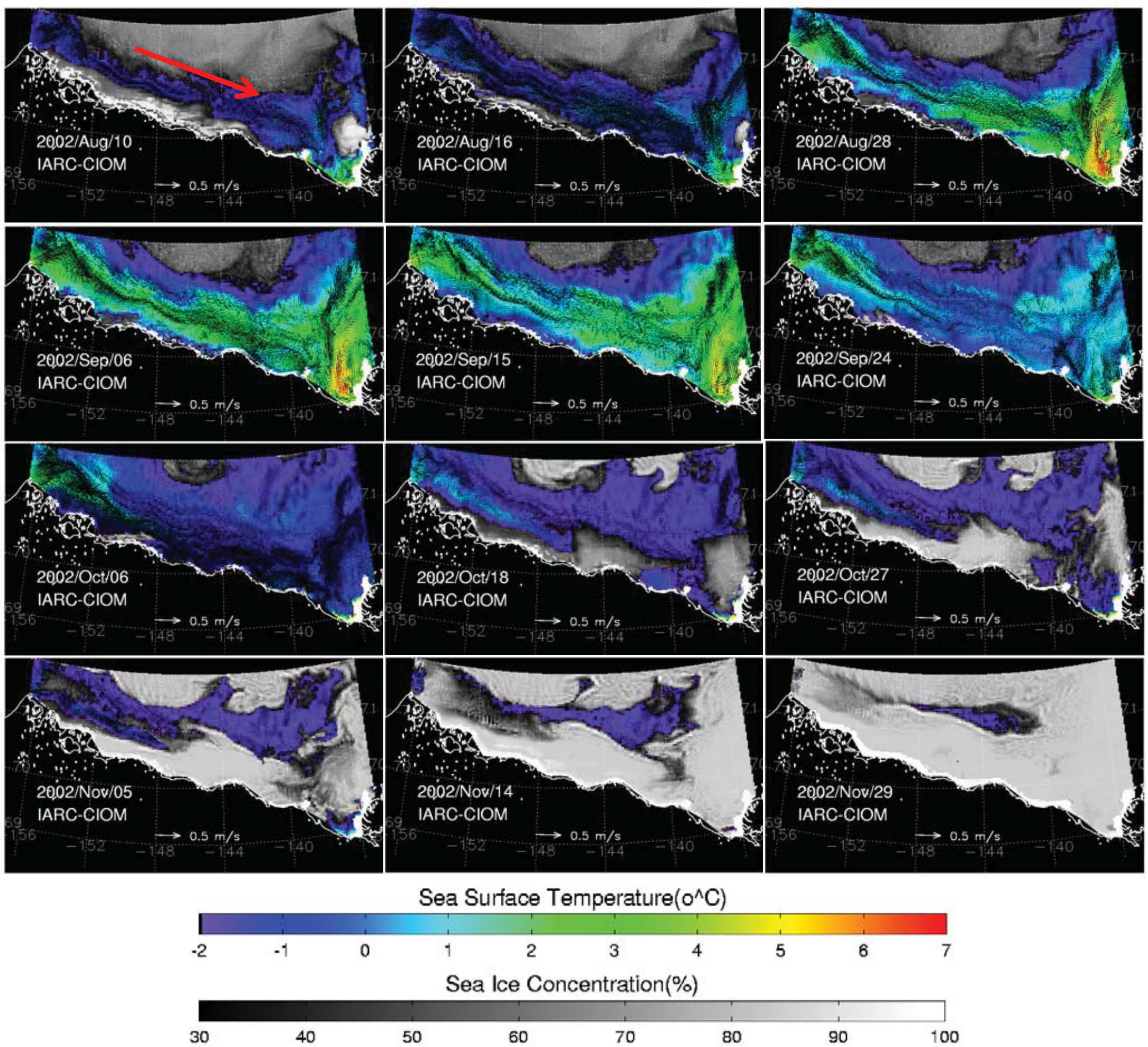


Figure 15. Sea ice cover and ocean circulation in the Beaufort Sea coastal area on a) August 10th, b) August 16th, c) August 28th, d) September 6th, e) September 15th, f) September 24th, g) October 6th, h) October 18th, i) October 27th, j) November 5th, k) November 14th, and l) November 29th in 2002 simulated by the CIOM. Gray area means sea ice concentration between 30% and 100%. Black arrows indicate water velocity (10 m water depth) at every grid point.

anomalies.

During the open water period, small-scale eddies have been observed in the Beaufort Sea basin area (e.g., Muench et al., 2000). Figure 19 shows the simulated result on September 24th. Red boxes indicate the eddy field. There are two main streams of the warm Pacific water having a north-south component of water velocity, implying a small-scale eddy field. Eddies also can be found near ice-edge. The CIOM has potential capability as a tool to study of the eddy field in the Beaufort Sea. Nevertheless, higher resolution model (e.g., 1-km resolution) will be better than current 3.8-km CIOM. We will implement the nesting approach in the future.

Conclusions and Future Efforts

Through the Arctic Modeling Group's team efforts and also through lessons learned from Phase I, we have successfully improved the CIOM and conducted a realistic simulation. Simulation results were compared to available ship surveys and satellite measurements.

The major improvements and parameterizations are as follows:

i) modify boundary conditions by combining global GCM outputs with modification using historical data and satellite measurements to conserve transport with radiation property along the open boundaries.

ii) in addition to previous ice-bottom melting processes, a lateral melting parameterization, which is twice as larger than the bottom melting, was implemented into this new version of CIOM during the melting season.

iii) Wind-wave mixing parameterization was added to the surface ocean.

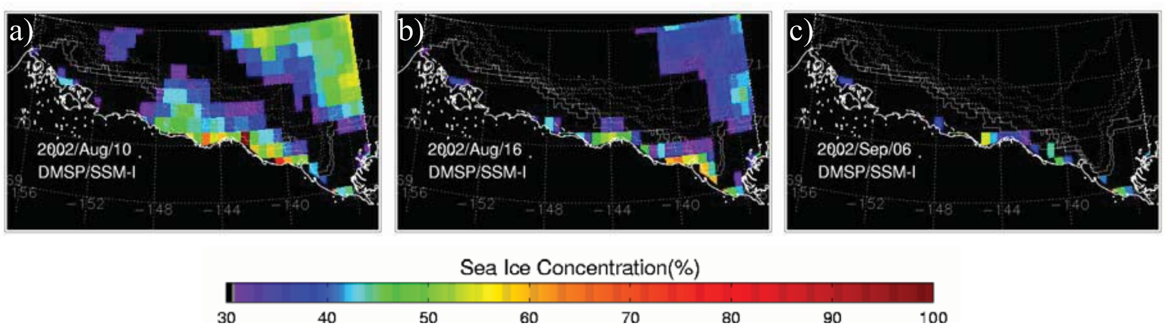


Figure 16. SSM-I sea ice concentration images in the Beaufort basin area on a) August 10th, b) August 16th, and c) September 6th. Note that the resolution is 25 km.

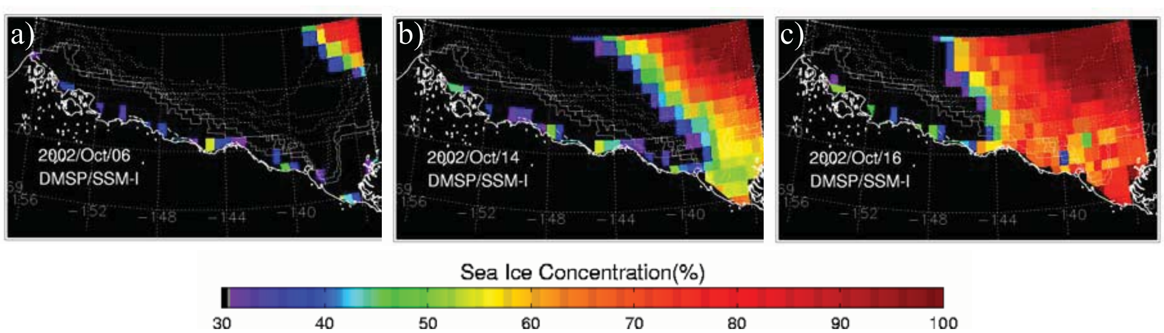


Figure 17. SSM-I sea ice concentration images in the Beaufort basin area on a) October 6th, b) October 14th, and c) October 16th.

Based on the above investigations including the sensitivity studies, the following major conclusions can be drawn:

1) The Chukchi-Beaufort seas coastal current was well reproduced: ACC and the two other branches via the Central Channel and Herald Valley. The Eastern Siberian Coastal Current was also captured with a cold and fresh water mass.

2) The ocean circulation, such as the Beaufort Gyre, and the imbedded mesoscale eddies with anticyclones outnumbering cyclones

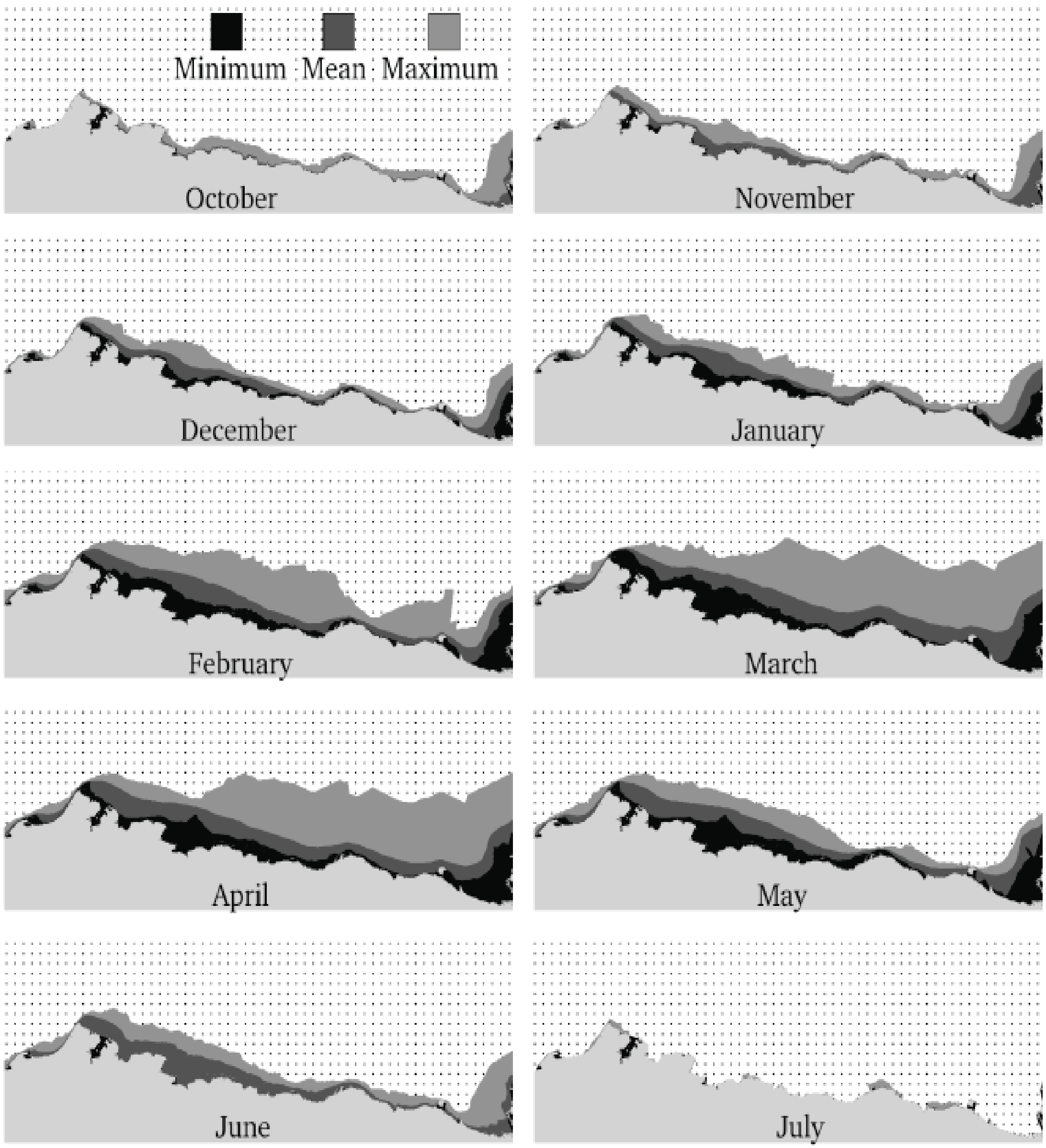


Figure 18. Minimum, mean, and maximum monthly mean landfast sea ice extents showing the change in landfast ice distribution in the study area through the annual cycle. The dotted area indicates where landfast ice was never observed. (Courtesy of Eicken et al. 2005).

along with the seasonal cycle were very well simulated.

3) The seasonal cycle of sea ice was well reproduced with some discrepancy from the satellite measurements. Without lateral melting, the CIOM produces more sea ice along the Beaufort coast in summer, leading to an excess of sea ice; while with the lateral melting, the sea ice seasonal cycle with sea ice-free conditions in September along the Beaufort coast was well reproduced.

4) Surprisingly, the landfast ice, for the first time, was reproduced under both monthly and daily atmospheric forcing. Sensitivity experiments suggest the most important factors affecting landfast ice are wind, Bering inflow, land the ateral melting process. Tides are also important in modifying landfast ice distribution.

5) Sea ice ridging, cracks, arching, and other downscaling characteristics were captured.

Literature Cited

Blumberg, A.F. and G.L. Mellor. 1987. A description of 3-D coastal ocean circulation model. In Heaps, N.S. (Ed.), Coastal and Esturine Sciences 4: 3-D Coastal Ocean Models. American Geophysical Union, Washington DC, pp 1-16.

Chao, S.-Y. and P.-T. Shaw. 2002. A numerical investigation of slanted convection and subsurface anticyclone generation in an Arctic baroclinic current system, *J. Geophys. Res.*,107(C3), 3019, doi:10.1029/2001JC000786.

Eicken, H., L.H. Shapiro, A.G. Gaylord, A.

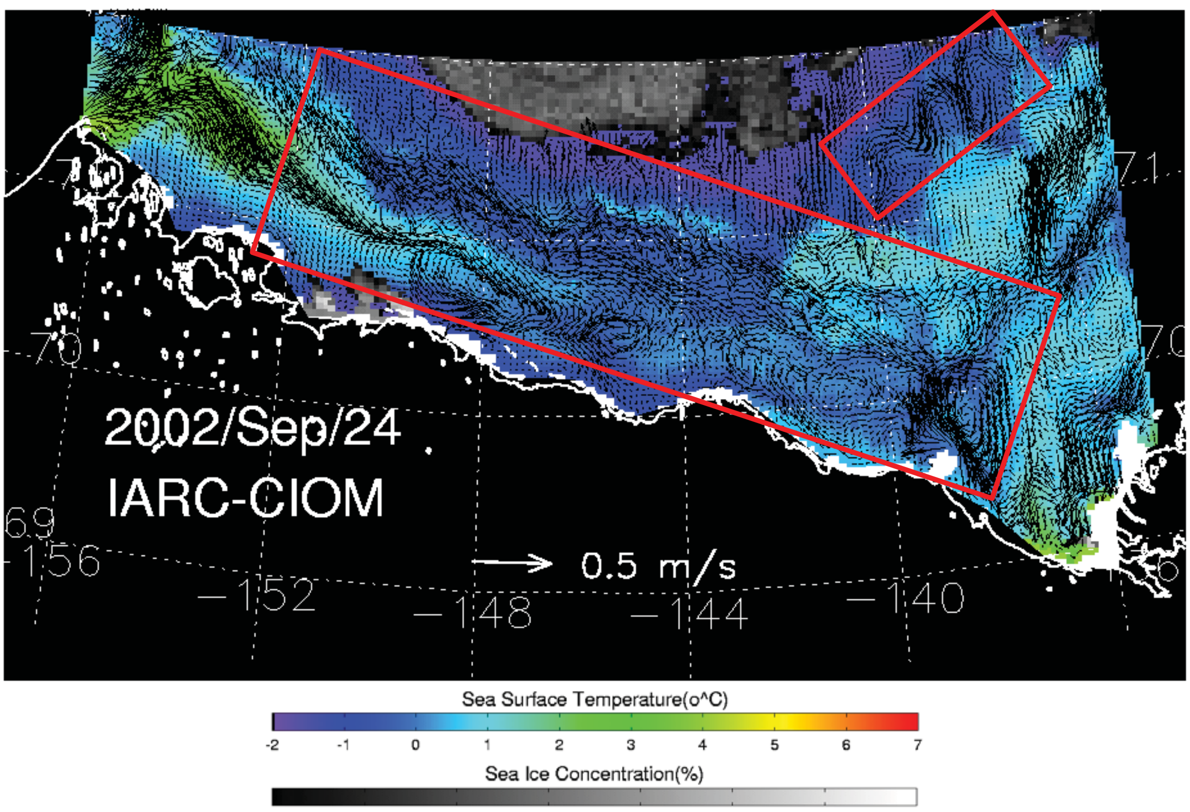


Figure 19. A snapshot of the CIOM simulation in the Beaufort Sea (September 24, 2002). Black arrows represent water velocity at 10 m water depth at each grid cell.

Mahoney, P.W. Cotter. 2005. Mapping and characterization of recurring spring leads and landfast ice in the Beaufort and Chukchi seas. U.S., Department of Interior, Minerals Management Service (MMS), Alaska Outer Continental Shelf Region, 2005-068, 180 pp. Anchorage, Alaska.

Ford, J.M., J. Wang, and R.T. Cheng. 1990. Predicting the vertical structure of tidal current and salinity in San Francisco Bay, California, *Water Resources Res*., 26 (5), 1,027-1,045.

Hibler, W.D. III. 1979. A dynamic and thermodynamic sea ice model. *J. Phys. Oceanogr*., 9, 15,959-15,969.

Hibler, W.D. III. 1980. Modeling a variable thickness sea ice cover. *Mon. Wea Rev., 108,* 1943-1973.

Hu, H. and J. Wang. 2007. Modeling the ocean circulation in the Bering Sea. (Submitted to *J.Geophys. Res*.).

Kantha, L.H. and G.L. Mellor. 1989. Application of a two-dimensional coupled ocean-ice model to the Bering Sea marginal ice zone. *J. Geophys. Res., 94*, 10,921-10,936.

Kantha, L.H. and C.A. Clayson. 1994. An improved mixed layer model for geophysical applications. J. Geophys. Res., 99(C12), 25,235-25,266.

Kowalik, Z. and A. Proshutinsky. 1994. The Arctic Ocean Tides, In: The Polar Oceans and Their Role in Shaping the Global Environment: Nansen Centennial Volume, Geoph. Monograph 85, AGU, 137--158.

Manhoney, A., H. Eicken. A.G. Gaylord, and L. Shapiro, 2007a. Alaska landfast sea ice: Links with bathymetry and atmospheric circulation, J. Geophys. Res., 112, C02001, doi:10.1029/2006JC003559.

Manhoney, A., H. Eicken, and L. Shapiro. 2007b. How fast is landfast ice? A study of the attachment and detachment of nearshore ice at Barrow, Alaska. Cold Regions Science and Technology, 47, 233-255.

Manley, T.O., and K. Hunkins. 1985. Mesoscale eddies of the Arctic Ocean. J. Geophys. Res. 90, 4911–4930.

Melling, H. 1993. The formation of a haline shelf front in wintertime in an ice-covered sea. Con. Shelf. Res., 13, 1123-1147

Mellor, G.L. 1996. Users guide for a 3-D, primitive equation, numerical ocean model. Atmospheric and Oceanic Sciences Program, Princeton Univ. (Princeton, NJ 08540), 39 pp.

Mellor, G.L. and L. Kantha. 1989. An ice-ocean coupled model. *J. Geophys. Res., 94*, 10,937-10,954.

Mizobata, K. J. Wang and H. Hu. 2007. Summer Oceanic Desert triggered by the warm Pacific Water in the Chukchi Sea. (in prep).

Muench RD, J.T. Gunn, T.E. Whitledge, P. Schlosser and W. Smethie. 2002. An Arctic Ocean cold core eddy. *J. Geophys. Res.*, 105 (C10): 23,997-24,006.

Nihoul, J.C.J, P. Adam, P. Brasseur, E. Deleersnijder, S. Djenidi, and J. Haus. 1993. Three-dimensional general circulation model of the northern Bering Sea's summer ecohydrodynamics. *Continen. Shelf Res.,13*, 509-542.

Pickart, R.S. 2004. Shelfbreak circulation in the Alaska Beaufort Sea: Mean structure and variability. *J. Geophys. Res.,* 109, C04024 doi: 10.1029/2003JC001912.

Pickart,RS, TJ Weingartner, LJ Pratt, S. Zimmermann, and DJ Torres. 2005. Flow of winter-transformed Pacific water into the Western Arctic, DEEP-SEA RESEARCH PART II-TOPICAL STUDIES IN OCEANOGRAPHY 52 (24-26), 3175-3198 2005

Shimada, K., T. Kamoshida, M. Itoh, S. Nishino, E. Carmack, F. MacLaughlin, S. Zimmermann, and A. Proshutinsky. 2006. Pacific Ocean inflow: Influence on catastrophic reduction of sea ice cover in the Arctic Ocean, Geophys. Res. Lett., 33, L08605, doi:10.1029/2005GL025624.

Steele, M., R. Rebecca, and W. Ermold. 2001. PHC: A global ocean hydrography with a high-quality Arctic Ocean. *J. Climate, 14,* 2079-2087.

Throndike, A. S., D. A. Rothrock, G. A. Maykut and R. Colony. 1975. The thickness distribution of sea ice, *J. Geophys. Res*., 80, 4,501-4,513

Wang, J., L.A. Mysak, and R.G. Ingram. 1994. A numerical simulation of sea-ice cover in Hudson Bay, *J. Phys. Oceanogr., 24,* 2515-253.

Wang, J. 1998. A two-channel laterally averaged estuarine circulation model (LAECIM), *J. Geophys. Res***.**, 103, 18,381-18,391.

Wang, J. and M. Ikeda. 2000. Arctic Oscillation and Arctic Sea-Ice Oscillation. *Geophys. Res.*

Lett. 27, 1287-1290.
Wang, J. and M. Ikeda. 2001. Arctic Sea-Ice Oscillation: Regional and seasonal perspectives. *Annals of Glaciology*, *33*, 481-492.
Wang, J., M. Jin, V. Patrick, J. Allen, D. Eslinger, C. Mooers and T. Cooney. 2001a. Numerical simulation of the seasonal ocean circulation patterns and thermohaline structure of Prince William Sound, Alaska. *Fisheries Oceanogr., 10 (*Suppl. 1), 132-148.
Wang, J., Q. Liu, M. Jin. 2001b. A nested coupled ice-ocean model for the Beaufort Sea. Annual Report No. 8, University of Alaska, MMS/Alaska OCS Region, Anchorage, Dept. of the Interior, pp80-94.
Wang, J., Q. Liu and M. Jin. 2002a. A User's Guide for a Coupled Ice-Ocean Model (*CIOM*) in the Pan-Arctic and North Atlantic Oceans. International Arctic Research Center-Frontier Research System for Global Change, Tech. Rep. 02-01, 65 pp.
Wang, J., Q. Liu, and M. Jin. 2002b. A nested coupled ice-ocean model for the Beaufort Sea. Annual Report No. 8, University of Alaska, MMS/Alaska OCS Region, Anchorage, Dept. of the Interior, pp 80-94.
Wang, J., M. Jin, M. Ikeda, K. Shimada, and J. Takahashi. 2003a. Validation of a nested coupled ice-ocean model in the Beaufort Sea. Annual Report No. 9, University of Alaska, MMS/Alaska OCS Region, Anchorage, Dept. of the Interior, pp 19-31.
Wang, J., R. Kwok, F.J. Saucier, J. Hutchings, M. Ikeda, W. Hibler III, J. Haapala, M.D. Coon, H.E.M. Meier, H. Eicken, N. Tanaka, R. Prentki, and W. Johnson. 2003b. Working towards improved small-scale sea ice and ocean modeling in the Arctic seas. *EOS*, AGU, Vol . 84 (34), 325, 329-330.
Wang, J., B. Wu, C. Tang, J.E. Walsh, and M. Ikeda. 2004. Seesaw structure of subsurface temperature anomalies between the Barents Sea and the Labrador Sea. *Geophys. Res. Lett. 31*, L19301, doi: 10.1029/2004GL019981.
Wang, J., Q. Liu, M. Jin, M. Ikeda and F.J. Saucier. 2005. A coupled ice-ocean model in the pan-Arctic and the northern North Atlantic Ocean: Simulation of seasonal cycles. *J. Oceanogr*., 61, 213-233.
Wang, J., H. Hu, and K. Mizobata. 2007a. Simulating sea ice and ocean circulation in the Beaufort/Chukchi Sea. (in prep.)
Wang, J., M. Jin, J. Takahashi, T. Suzuki, J.E. Walsh, H. Hasumi and I.V. Polyakov. 2007b. Modeling Arctic Ocean warming episodes in the 20th century caused by the intruding Atlantic Water. (submitted to *Geophys. Res. Lett*.)
Watanabe, E., J. Wang, T. Sumi, and H. Hasumi. 2006. Arctic Dipole and its contribution to sea ice export from the Arctic in the last 20th century. *Geophys. Res. Lett*., 33, L23703, doi:10.1029/2006GL028112.
Weingartner, T.J., D.J. Cavalieri, K. Aagaard, and Y. Sasaki. 1998. Circulation, dense water formation, and outflow on northeast Chukchi shelf. *Geophys. Res. Lett*. 103,7647-7661.
Wu, B., J. Wang, and R. Zhang. 2004. Effects of intraseasonal variations of the Arctic Oscillation on the Barents Sea. *Polar Meteorolo. Glaciol*., 18, 82-95.
Wu, B., J. Wang, and J.E. Walsh. 2006. Dipole anomaly in the winter Arctic atmosphere and its association with Arctic sea ice motion. *J. Climate, 19(2), 210-225. DOI: 10.1175/JCLI3619.1*
Yao, T., C.L. Tang, and I.K. Peterson. 2000. Modeling the seasonal variation of sea ice in the Labrador Sea with a coupled multi-category ice model and the Princeton Ocean Model. *J. Geophys. Res*., 105 (C1), 1153-1165.
Zhang, X., J. E. Walsh, J. Zhang, U. S. Bhatt, and M. Ikeda. 2004. Climatology and interannual variability of Arctic cyclone activity, 1948-2002. *J. Climate* 17, 2300-2317.

Evaluating a Potential Relict Arctic Invertebrate and Algal Community on the West Side of Cook Inlet

Nora R. Foster

fyaqua@uaf.edu
Marine Invertebrate Collection
University of Alaska
Museum of the North
907 Yukon Drive
Fairbanks, AK 99557

Susan Saupe

Saupe@circac.org
Cook Inlet RCAC
910 Highland Avenue
Kenia, Alaska 99611

Dennis Lees

dennislees@earthlink.net
Littoral Ecological
& Environmental Services
1075 Urania Avenue
Leucadia, CA 92024

Task Order: 37357

Introduction

Archived samples and specimens collected during intertidal and subtidal surveys in Cook Inlet over several decades are being used to re-evaluate identifications and to review their geographic distribution, especially to look for similarities between species collected in western Cook Inlet and the parent stocks of Arctic-Boreal species. The study is based on previous work conducted on the west side of lower Cook Inlet when it was observed that epifaunal invertebrates collected in the 1970s in lease block clearance and Outer Continental Shelf Environmental Assessment Program (OCSEAP) studies bore a striking resemblance to species reported for the Alaskan Arctic (Lees 1976; Lees and Driskell 1980; Lees et al. 1980). Additional information provided by other historical invertebrate collections in the area indicate that these west side species and assemblages more closely matched Arctic species and assemblages than those observed in Cook Inlet's southeastern corner (e.g., Kachemak Bay) or in other areas of the Gulf of Alaska (Rosenthal and Lees 1976; Lees and Rosenthal 1977).

Objectives

1. Conduct a museum survey of archived specimens that develops a more complete and accurate comprehension of the species composition of intertidal and subtidal benthic assemblages on the west side of Cook Inlet.
2. Evaluate the degree of geographic isolation for each potential relict Arctic species by reviewing species lists from previous studies conducted on the east side of Cook Inlet, the Alaska Peninsula, Kodiak, and in Shelikof Strait and the Bering Sea.
3. Determine the taxonomic status of the species observed on the west side of Cook Inlet by conducting detailed taxonomic evaluations on a wide variety of algae and invertebrates. These will include previous collections that have been preserved and archived.

Study Area

The study considers fauna from the west side of Cook Inlet, Alaska, from Kamishak Bay to Kalgin Island. It is based largely on specimens collected by Dennis Lees in (Lees 1976; Lees and Driskell 1980; Lees et al. 1980) from and on University of Alaska Museum collections resulting from a variety of investigations and collecting trips.

Preliminary Results

Contributions to the project by specialists helped refine and expand the original species tables presented in our original proposal. Bryozoa were re-examined by Andrei Grischenko, Perm State University, Perm, Russia. Forty-six specimens of bryozoan colonies or rocks and shells with encrusting colonies of Bryozoa were considered. Fifty-four species(4 Cyclostomata, 7 Ctenostomata, and 43 Cheilostomata) were identified from these samples (Table 1). The biogeographic affiliations include Boreal-Arctic and Pacific Boreal, with 34 Boreal-Arctic species and 19 species with a lower-latitude Pacific Boreal distribution (Table 2). Of the original 21 species of Bryozoa identified by Lees and Driskell

Table 1. Bryozoa from Cook Inlet

Order Cyclostomata
*Diplosolen arctica (*Waters, 1904)

Entalophoroecia vancouverensis O'Donoghue and O'Donoghue, 1923

Heteropora alaskensis (Borg, 1933)

Heteropora pelliculata Waters, 1879

Order Ctenostomata

Alcyonidium gelatinosum (Linnaeus, 1767)

Alcyonidium mamillatum Alder, 1857

Alcyonidium mytili Dalyell, 1847

Alcyonidium pedunculatum Robertson, 1902

Flustrellidra cervicornis (Robertson, 1900)

Flustrellidra corniculata (Smitt, 1872)

Flustrellidra gigantea Silen, 1947

Order Cheilostomata

Electra arctica (Borg, 1931)

Eucratea loricata (Linnaeus, 1758)

Bidenkapia spitzbergensis (Bidenkap, 1897)

Callopora lineata (Linnaeus, 1767)

Callopora sp.

Tegella aquilirostris (O'Donoghue and O'Donoghue, 1923)

Tegella arctica (d'Orbigny, 1951)

Tegella armifera (Hincks, 1880)

Tegella armiferoides Kluge, 1955

Antropora commandorica Tilbrook and Grischenko, 2004

Carbasea carbasea (Ellis and Solander, 1786)

Flustra foliacea (Linnaeus, 1758)

Bugula pacifica Robertson, 1905

Corynoporella tenuis Hincks, 1888

Dendrobeania exilis (Hincks, 1882)

Dendrobeania murrayana (Johnston, 1847)

Beania columbiana O'Donoghue and O'Donoghue, 1923

Caberea ellisi (Fleming, 1818)

Tricellaria gracilis (Van Beneden, 1848)

Tricellaria inermis (Kluge, 1962)

*Tricellaria ternata (*Ellis and Solander, 1786)

Celleporella hyalina (Linnaeus, 1767) species complex

Celleporella reflexa Dick and Ross, 1988

Cystisella beringia (Kluge, 1929)

Porella acutirostris Smitt, 1867 species complex

*Porella belli (*Dawson, 1859)

Porella compressa (Sowerby, 1806)

Smittina majuscula (Smitt, 1868)

Pachyegis princeps (Norman, 1903)

Myriapora coarctata (M. Sars, 1863)

Myriozoella plana (Dawson, 1859)

Cryptosula zavjalovensis Kubanin, 1976

Lagenicella neosocialis Dick and Ross, 1988

Microporella californica (Busk, 1856)

Microporella neocribroides Dick and Ross, 1988

Celleporina aspera Dick and Ross, 1988

Celleporina surcularis (Packard, 1863)

Table 2. Biogeographical affinities of Bryozoa from Cook Inlet

Affinity	Species	Original Determination
Boreal-Arctic circumpolar		
	Diplosolen arctica (Waters, 1904)	
	Alcyonidium gelatinosum (Linnaeus, 1767)	
	Alcyonidium mammillatum Alder, 1857	
	Alcyonidium mytili Dalyell, 1847	
	Electra arctica (Borg, 1931)	*Carbasea carbasea*
	Eucratea loricata (Linnaeus, 1758)	
	Bidenkapia spitzbergensis (Bidenkap, 1897)	
	Callopora lineata (Linnaeus, 1767)	*Costazia ventricosa*
	Tegella arctica (d'Orbigny, 1951)	
	Tegella armifera (Hincks, 1880)	
	Carbasea carbasea (Ellis and Solander, 1786)	
	Flustra foliacea (Linnaeus, 1758)	*Terminoflustra membraceo-truncata,* and *Flustra foliacea*
	Corynoporella tenuis Hincks, 1888	
	Dendrobeania murrayana (Johnston, 1847)	
	Tricellaria gracilis (Van Beneden, 1848)	
	Tricellaria ternata (Ellis and Solander, 1786)	
	*Celleporella hyalina (*Linnaeus, 1767) species complex	*Porella* sp. and *Hippothoa hyalina*
	Porella acutirostris Smitt, 1867 species complex	*Porella* sp.
	Porella belli (Dawson, 1859)	*Porella* sp.
	Porella compressa (Sowerby, 1806)	

	Arctonula arctica (M. Sars, 1851)	
	Raymondcia rigida Lorenz, 1886	*Pachyegis princeps*
	Myriapora coarctata (M. Sars, 1863)	*Myriozoum subgracile*
	Myriozoella plana (Dawson, 1859)	
	Celleporina surcularis (Packard, 1863)	*Costazia ventricosa*
Boreal-Arctic		
	Flustrellidra corniculata (Smitt, 1872)	*Flustrella corniculata*
High Boreal-Arctic circumpolar		
	Smittina majuscula (Smitt, 1868)	
High Boreal-Arctic		
	Tricellaria inermis (Kluge, 1962)	
	Pachyegis princeps (Norman, 1903)	
Boreal-Arctic Pacific		
	Heteropora pelliculata Waters, 1879	*Myriozoum* sp.
High Boreal-Arctic Pacific		
	Tegella armiferoides Kluge, 1955	
	Caberea ellisi (Fleming, 1818)	
	Cystisella beringia (Kluge, 1929)	
	Rhamphostomella costata Lorenz, 1886	
	Rhamphostomella spinigera Lorenz, 1886	
Pacific Boreal		
	Flustrellidra gigantea Silen, 1947	Flustrella gigantea
	Tegella aquilirostris (O'Donoghue and O'Donoghue, 1923)	*Tegella robertsoni*
	Bugula pacifica Robertson, 1905	*Caulibugula* sp.

	Beania columbiana O'Donoghue and O'Donoghue, 1923	
	Desmacystis sandalia (Robertson, 1900)	
	Parasmittina avicularissima (Gontar, 1982)	*Costazia ventricosa*
	Cryptosula zavjalovensis Kubanin, 1976	*Hippodiplosia pertusa*
Pacific High Boreal		
	Flustrellidra cervicornis (Robertson, 1900)	
Amphi-Pacific Boreal		
	Microporella neocribroides Dick and Ross, 1988	
Eastern Pacific Boreal		
	Entalophoroecia vancouverensis O'Donoghue and O'Donoghue, 1923	*Entalophora capitata*
	Heteropora alaskensis (Borg, 1933)	*Entalophora capitata*
	Alcyonidium pedunculatum Robertson, 1902	*Alcyonidium polyoum*
	Dendrobeania exilis (Hincks, 1882)	
	Lagenicella neosocialis Dick and Ross, 1988	
	Microporella californica (Busk, 1856)	*Costazia ventricosa*
Eastern Pacific High Boreal		
	Callopora sp.	
	Antropora commandorica Tilbrook and Grischenko, 2004	
	Celleporella reflexa Dick and Ross, 1988	
	Celleporina aspera Dick and Ross, 1988	*Costazia ventricosa*

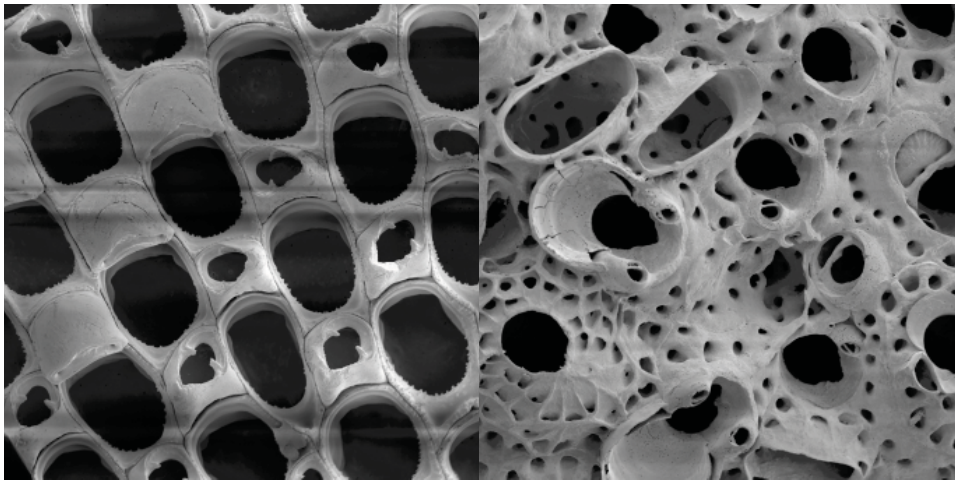


Figure 1. *Bidenkapia spitzbergenis* and *Celleporella surcularis*, two Cook Inlet Bryozoa with Arctic-Boreal distributions. SEM image.

(1980), twenty species were re-identified, and 33 additional species were added to the list.

As part of the examination of the Cook Inlet Bryozoa specimens, and to document the identifications, Scanning Electron Microscope pictures were made available for 19 taxa (Figures 1,2).

James McLean identified 13 species from the gastropod specimens that he examined. Identifications and names changes are based on his as-yet unpublished revisions of the east Pacific marine gastropods. *Buccinum glaciale*, an Arctic species was re-identified as *B. morchianum*, a boreal east Pacific species, *Beringius* cf. *B. beringi* was re-identified as *B. rotundus*, also a boreal east Pacific species. Two species of limited distribution, *Margarites baxteri,* and an undetermined *Lacuna* (identified as *L. crassior)* are poorly known. *Colus herendeeni* is known from samples from the southern Bering Sea and possibly represents an isolated population (McLean, personal communication).

Stegophiura nodosa was identified by Igor Smirnov based on specimens collected in a trawl in a shallow sandy habitat in outer Iniskin Bay in 2005.

Reliable information on distribution based on published literature, museum specimens, and project grey literature reports indicate that the distribution of 73 species includes the northern Chukchi/Beaufort Sea and Cook Inlet, and few or only isolated occurrences farther to the south or east. (Table 3). Isolated or disjunct species (Boreal-Arctic, High Boreal, and Circumpolar species) do not appear in species lists from adjacent waters, for example, the southern Bering Sea, Kodiak Island waters or the eastern Gulf of Alaska. These may indeed have broad distributions north of the Bering Sea and into much of the Arctic. The distributional range of Pacific Boreal species includes the Beaufort and Chukchi Seas, as well as the Bering Sea and extending south. The fauna of western Cook Inlet affiliated with the Arctic includes a large number of west Pacific and circumboreal species.

We continue to look for opportunities to consider other taxa, especially infauna and algae. While our knowledge of epibiotal forms is still limited, we have an even less detailed picture of infauna, especially polychaetous annelids and small crustaceans such as cumaceans and amphipods. The considerable abundance on beaches in western Cook Inlet of the large isopod *Saduria entomon*, so characteristic of the Beaufort Sea, suggests that the infauna probably includes numerous other Arctic or boreal species. Lindstrom has pointed out that algae known from high-latitude localities, especially species such as Palmariaceae and Bangiaceae (notably *Porphyra*) that favor disturbed areas, occur as well in "warmer" areas of Alaska (e.g., *Rhodomela tenuissima, Phycodrys riggii, Odonthalia dentata*).

We need to evaluate further the geographical extent of the fauna and flora. We recognize that the available species lists reflect the nature and emphasis of the limited sampling effort, and that species, either on the east side or west side, may have been overlooked. Dennis Lees has observed an absence of filter feeders such as *Mya* spp. during intertidal reconnaissance surveys north of Kalgin Island.

Figure 2. Encrusting Bryozoa colonies on *Fusitriton oregonensis* from Cook Inlet.

Detrital or deposit feeders *Macoma* spp. (especially *M. balthica*) dominate the intertidal infauna (Lees et al. 2002).

Our final report should consider the Pleistocene/Holocene geological history of western Cook Inlet. The term “relict fauna” may imply that this part of Cook Inlet may have been a refugium – possibly unglaciated during the glacial maximum of. So far a brief survey of geological reports indicates an ambiguous answer. Questions regarding the origin of this arctic-affiliated fauna remain.

We will also examine the physical oceanographic factors – the present-day understanding of the current regime of the west side - in an attempt to understand how currents contribute to the comparative isolation of the western Cook Inlet fauna. Associated with understanding this isolation, we will examine, to the degree possible, the reproductive strategies of as many species as possible. It appears that several species are brooders and it seems reasonable to suspect that many others use this strategy or have very short planktonic life histories. This strategy is a common characteristic of polar species.

Future Plans

We are interested in proposing further long-term monitoring now that we have established that the fauna on the west side of Cook Inlet is unique and strongly allied with the Arctic.

Now that we can focus on some clearly isolated species, advanced techniques such as DNA analysis could reveal just how long the fauna on the west side of inlet has been isolated.

Presentations

Evaluating a Potential Relict Arctic Invertebrate and Algal Community on the West Side of Cook Inlet. CMI Research Review. Fairbanks, Alaska February, 2007.

Biodiversity and Biogeography of Bryozoa in Cook Inlet, Alaska. AAAS Arctic Science Conference. Anchorage, Alaska, September 2007.

Table 3. Species with Arctic Affinities

Genus/Species	Isolated	Widespread
MOLLUSCA - 22 Total Taxa		
Polyplacophora		
Amicula vestita	x	
Stenosemus albus		x
Gastropoda		
Beringius rotundus	x	
Boreotrophon clathratus		x
Buccinum morchianum		x
Colus herendeeni	x	
Cryptonatica affinis		x
Epitonium groenlandica		x
Tectura testudinalis		x
Lacuna crassior	x	
Margarites baxteri	x	
Moelleria costulata	x	
Piliscus commodus	x	
Tectura testudinalis		x
Volutopsius castaneus	x	
Bivalvia		
Cyrtodaria kurriana	x	
Hiatella arctica		x
Macoma balthica		x
Modiolus modiolus		x
Musculus discors		x
Mya pseudaorenaria		x
Mya truncata		x
TOTALS	9	13
BRYOZOA - 35 Total Taxa		
Alcyonidium gelatinosum		x
Alcyonidium mamillatum		x
Alcyonidium mytili		x
Arctonula arctica		x
Bidenkapia spitzbergensis		x
Caberea ellisi	x	

Callopora lineata		x
Carbasea carbasea		x
Celleporella hyalina species complex		x
Celleporina surcularis	x	
Corynoporella tenuis		x
Cystisella beringia	x	
Dendrobeania murrayana		x
Electra arctica		x
Eucratea loricata		x
Flustra foliacea		x
Flustrellidra corniculata	x	
Heteropora pelliculata		x
Myriapora coarctata		x
Myriozoella plana		x
Pachyegis princeps	x	
Porella acutirostris species complex		x
Porella belli		x
Porella compressa		x
Raymondcia rigida		x
Rhamphostomella costata	x	
Rhamphostomella spinigera	x	
Smittina majuscula	x	
Tegella arctica		x
Tegella armifera		x
Tegella armiferoides	x	
Tricellaria gracilis		x
Tricellaria inermis	x	
Tricellaria ternata		x
TOTALS	10	24
TUNICATA - 4 Total Taxa		
Boltenia echinata	x	
Dendrodoa pulchella	x	
Halocynthia aurantia	x	
Pelonaia corrugata	x	
TOTALS	4	0
CRUSTACEA - 1 Total Taxa		

Saduria entomon	x	
TOTALS	1	0
BRACHIOPODA - 2 Total Taxa		
Hemithyrus psittacea	x	
Diestothyris spitsbergensis	x	
TOTALS	2	0
ECHIURA - 1 Total Taxa		
Echiurus echiurus alaskanus		x
TOTAL	0	1
ECHINODERMATA - 8 Total Taxa		
Crossaster papposus	x	
Henricia sanguinolenta		x
Leptasterias polaris acervata	x	
Solaster endeca		x
Asterias amurensis	x	
Strongylocentrotus droebachiensis		x
Stegophiura nodosa	x	
Echinarachnius parma	x	x
TOTALS	5	4
TOTALS - 73 Total Taxa	31	42

Literature Cited

Lees, D. C. 1976. The epifaunal assemblage in the Phillips Petroleum lease site off Spring Point, Chinitna Bay, Alaska. Homer, AK. Prepared for Phillips Petroleum Company by Dames & Moore. 32 pp + 3 appendices.

Lees, D. C., and W. B. Driskell. 1980. Investigations on shallow subtidal habitats and assemblages in lower Cook Inlet. Homer, AK. Prepared for Inst. of Mar. Sci., Univ. of Alaska, Fairbanks, by Dames & Moore. 115 + Appendices A - P.

Lees, D. C., W. B. Driskell, J. R. Payne, and M. O. Hayes. 2002. Intertidal reconnaissance survey in middle and upper Cook Inlet. Draft report. Cook Inlet Regional Citizens Advisory Council. November 2001. 299 pp + Appendices.

Lees, D. C., J. P. Houghton, D. E. Erikson, W. B. Driskell, and D. E. Boettcher. 1980. Ecological studies of intertidal and shallow subtidal habitats in lower Cook Inlet, Alaska. U. S. Dept. of Commerce, NOAA: OCSEAP. Final Reports 44(1986):437-646.

Lees, D. C., and R. J. Rosenthal. 1977. An ecological assessment of the littoral zone along the outer coast of the Kenai Peninsula for State of Alaska, Department of Fish and Game. Anchorage, AK, Prepared for Alaska Dept. of Fish and Game by Dames & Moore: 101.

MacGinitie, G. E. 1955. Distribution and ecology of the marine invertebrates of Point Barrow, Alaska. City of Washington, Smithsonian Institution.

Seasonality of Boundary Conditions for Cook Inlet, Alaska

Steve Okkonen

okkonen@alaska.net
Institute of Marine Science
University of Alaska Fairbanks
PO Box 757220
Fairbanks, AK 99775

Scott Pegau

wspegau@pwssc.gen.ak.us
Kachemak Bay Research Reserve
95 Sterling Hwy. Suite 2
Homer, AK 99603

Susan Saupe

saupe@circac.org
Cook Inlet Regional Citizens Advisory Council
910 Highland Avenue
Kenai, Alaska 99611

Task Order: 37628

Abstract

High spatial resolution hydrographic surveys were conducted in 2004 and 2005 along a series of transect lines in central and lower Cook Inlet to define the size and position of the major buoyancy driven currents within the study area. Analyses of those survey data suggested that significant modification/mixing of these buoyancy currents occurs between the transect lines in the lower inlet. In order to investigate modification/mixing within the lower inlet, two additional transect lines were added: a transect between Cape Douglas and Cape Adams and a transect between Magnet Rock and Augustine Island. The sampling schedule was adjusted to focus on the period of maximum freshwater inputs (August through September 2006) and to examine tidal influences by sampling during the spring and neap tides. Additionally, to improve our temporal resolution of freshwater signals in central and lower Cook Inlet, we moored C-T (conductivity-temperature) sensors near the Forelands and near Kennedy Entrance. Observations show significant differences between tides, seasons and years. Freshwater stratification is observed along all lines, including at the Forelands. The freshwater fluxes are important in determining the seasonal fluctuations in currents in this area.

Introduction

This work builds upon that of Burbank (1977) and Muench et al. (1978). These latter studies provide sometime contradictory views of circulation in Cook Inlet and were restricted to summer observations. This work is designed to improve our understanding of Cook Inlet's coastal marine environment and our ability to model specific components in this region with potential for impact by offshore oil and gas activities in lower Cook Inlet. The hydrographic survey component and moored-instrument component expands an existing CMI project that is providing detailed seasonal measurements during the spring, summer, and fall. The existing project was based on earlier hydrographic work in Cook Inlet funded by MMS (Okkonen and Howell, 2003a; Okkonen, 2003b) and other agencies (Willette and Pegau, 2003; Pegau, 2003) by providing information on the seasonal variability of these properties.

These descriptions of oceanic properties are not only intrinsically valuable, but they will also provide boundary measurements for validation of numerical circulation models currently existing (*e.g.* CIRCAC and NOAA HAZMAT) and under development (*i.e.* CMI-funded, Mark Johnson, PI). Net circulation in Cook Inlet is influenced by freshwater inputs from major river systems within Cook Inlet and by the flow of the Alaska Coastal Current (ACC). The influences of these freshwater sources and the rates of exchange between the Gulf of Alaska and Cook Inlet, and between Cook Inlet and Shelikof Strait need to be quantified to further our understanding of the spatial and temporal patterns of observed changes within Cook Inlet.

These research components will not only directly address CMI Framework Issues, but will also address several research recommendations arising from the February 2005 Cook Inlet Physical Oceanography Workshop sponsored by the Alaska Ocean Observing System, the Cook Inlet RCAC, and the Kachemak Bay Research Reserve to improve our ability to model Cook Inlet circulation in both state and federal OCS waters. In addition, the workshop identified the need to coordinate research efforts, and through our existing CMI study, we have worked closely with NOAA to conduct hydrographic measurements that overlap in space and time with NOAA's deployments of Acoustic Doppler Current Profilers in Cook Inlet.

Objectives

Our broad objectives of the study have been to improve our understanding of the temporal and spatial variations in the hydrography of central and lower Cook Inlet and to investigate the mechanism(s) influencing these variations. This past year focused on defining the freshwater influences in late summer and early fall as well as examining the role of the tides. Specifically, the goals of the proposed research were to:

1) use local fishing/charter vessels as platforms to acquire hydrographic measurements of temperature and salinity from which the seasonal cycle of density-driven, geostrophic circulation within the inlet can be derived, with a focus on the late summer/fall time period (July – September). Transects were occupied monthly bi-monthly as weather allowed between July and September (spring and neap tide).

2) continuously monitor freshwater signals in central and lower Cook Inlet by deploying moored C-T sensors to acquire time series measurements of temperature and salinity near the Forelands (central Cook Inlet) and near Kennedy Entrance in lower Cook Inlet. These point measurements will be compared to the hydrographic data to ascertain their utility as proxies for freshwater originating in northern Cook Inlet and associated with the Alaska Coastal Current.

This study provides an observational record of seasonal hydrographic (T, S, density) fields in lower Cook Inlet from which mixing/modification of freshwater inputs are investigated. Existing numerical models use prescribed seasonal signals of these physical fields at their boundaries. By better identifying the fluxes of water into and out of Cook Inlet we can better understand the residence time of water within Cook Inlet and the relative contributions of Cook Inlet and ACC-derived waters within Shelikof Strait.

Study Area

The study has been conducted in the central and lower portions of Cook Inlet. Transect lines (Figure 1) cross:

1) Kennedy and Stevenson Entrances from Port Chatham to Shuyak Island (80 km);

2) Shelikof Strait from Shuyak Island to Cape Douglas (65 km);

3) Cook Inlet from Johnson River to Anchor Point (55 km);

4) Kachemak Bay from Barabara Point to Bluff Point (19 km);

5) between the Forelands (16 km);

6) Lower Cook Inlet between Cape Douglas and Cape Adams (85 km); and

7) Lower Cook Inlet between Magnet Rock and Augustine Island (83 km).

The SeaBird SBE-37 microcat C-T logger moored in southern Cook Inlet was retrieved at the end of October 2006. The Forelands C-T was retrieved in mid-August 2006 due to a problem with the mounting bracket. The moored loggers in lower Cook Inlet and near the Forelands were reinstalled in 2007. The Foreland sensor is mounted on an oil platform. The southern Cook Inlet sensor is placed within the surface layer on bottom-mounted moorings near the Kenai Peninsula end of Line 1. Data is being recorded at each location at quarter hour intervals. The data from these sensors will be complemented with the existing monitoring sites in Kachemak Bay that KBRR maintains in Kachemak Bay.

Methods

Each transect consisted of surface-to-bottom vertical casts using a caged array of instruments

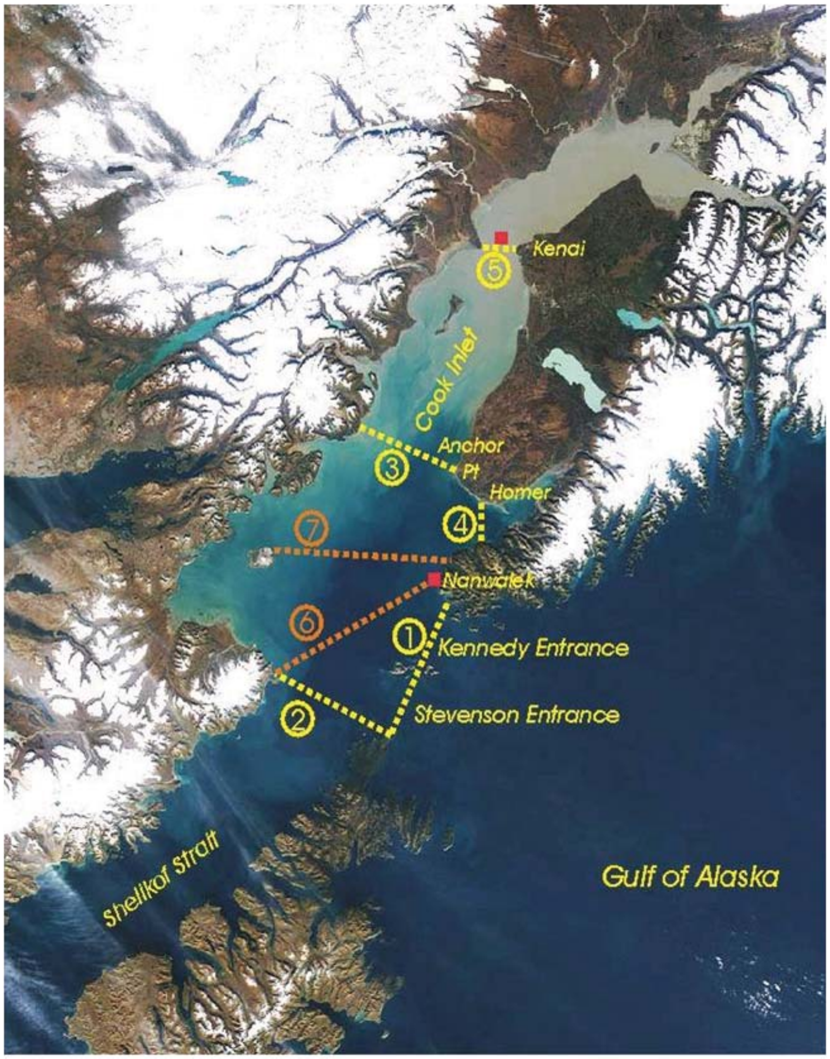


Figure 1. Map of previous (yellow) and new in 2006 (orange) hydrographic transects in the Cook Inlet study area. Red squares indicate the proposed locations of moored C-T sensors. The moorings were shifted slightly based in recommendations by local fishermen and the availability of the oil platform.

to profile temperature and salinity (19plus CTD), oxygen, chlorophyll fluorescence, and light transmission. Casts were made every 2 km within 10 km of shore and 4 km spacing away from shore along each transect. The CTDs recorded data at 4 Hz during the profile. A descent rate of less than 0.5 m/s was used during the profile. The CTDs used in this study were calibrated yearly at the beginning of the year.

Data was processed using SeaBirds processing algorithms (Datcnv, filter, alignctd, loopedit, derive, and binavg). Datcnv applies calibration coefficients to the raw data collected on the CTD. Filter applies low-pass filters to make sensor response to be similar and reduce the high-frequency variability associated with chlorophyll fluorescence measurements. Filter coefficients are based on recommendations from SeaBird. The alignctd program accounts for time lags between instrumentation. Coefficients used in alignctd are determined by minimizing salinity spiking and aligning up and down cast information on slow profiles. The loopedit program removes oscillations in depth caused by ship heave during the cast. Derive is used to calculate salinity, density, and oxygen parameters. The data is then averaged into one meter depth bins.

Work Completed

- Both CTD instruments and associated additional sensors were shipped to SeaBird for calibration and maintenance in preparation for sampling this summer.

- Analysis of annual differences and seasonal cycles has been completed..

- Additional data was collected as part of the ADF&G offshore test fishery program. This program runs daily in July along line 3 with six stations occupied each day. This work has been included in the match provided to CMI.

- We sampled at the confluence of Kachemak Bay and Cook Inlet to examine the role of tidally driven mixing on hydrographic properties.

- We have obtained and deployed the Microcats sensors. The sensor on the oil platform was installed at no cost by Scott Griffith and XTO energy.

- The PIs have met several times with staff from the Alaska Ocean Observing System to discuss integration into a Cook Inlet Region Ocean Observing System. These meetings resulted in a DRAFT Cook Inlet implementation plan, the hydrographic survey transects and the proposed C-T instruments were included in the plan as important for maintaining. As well, the transect lines will provide target locations for additional instrument deployments that have been proposed by Cook Inlet RCAC to other funding organizations (e.g. deployment of bottom mounted ADCPs that overlap coverage with the Kennedy/Stevenson and Shelikof hydrographic surveys).

Discussion

We begin by reviewing the distinct seasonal changes in temperature and salinity evident in lower Cook Inlet. Temperatures along Lines 1 and 2 (Kennedy and Stevenson Entrances, and Shelikof Strait) in April are nearly uniform. A colder, lower-salinity water mass can be seen at the northern end of the Shelikof line (Figure 2). This water is freshwater flowing out along the western side of Cook Inlet. By May, temperature stratification is evident along both lines. Temperature also increases at depth, particularly in Kennedy Entrance, in which the warming occurs nearly to the bottom. The freshwater flowing from Cook Inlet does not have a distinct temperature signature at this time. As warming continues into June and July the surface waters warm rapidly, but the deep waters also continue to warm. The exception to this warming trend is the deep water in Shelikof Strait, which remains cold and in 2004 became more saline starting in July. By July, the water flowing from Cook Inlet has become much warmer than the surrounding seawater. Also the lower salinity signal of the Alaska Coastal Current becomes evident along the eastern coast of Kennedy Entrance. The Alaska Coastal Current actually begins to become evident in May, but the signal is very weak. In May, June, and July there is evidence of upwelling along the shore of Shuyak Island at the southwestern end of the transect crossing Stevenson Entrance.

High spatial resolution sampling along original transect Lines 1-4 conducted in 2004 and 2005 helped to define the size and position of the major buoyancy driven currents within the study area. Those observations suggested that significant modification/mixing of the buoyancy currents occurred between those lines. In order to investigate this modification/mixing phenomenon, we added two additional transect lines within our study area in 2006: a transect between Cape Douglas and Cape Adams and a transect between Magnet Rock and Augustine Island. We adjusted the sampling schedule to focus on the period of maximum freshwater inputs (July through September) and to examine tidal influences by sampling during the spring and neap tides in each of the sampling months.

Line 6 was located directly across the mouth of Cook Inlet between Cape Adams in the east and Cape Douglas in the west. The warm, fresh signature of the ACC was most prominent along the eastern side of the line during neap conditions (Figure 3). Along the western side of Line 6 there was a general decrease in the amount of water with salinity <30PSU between 27 July and 13 August, but an increase in water with salinities between 30 and 31 PSU. Along the bottom of the western side there is an increasing presence of a colder, saltier water mass throughout the measurement sequence.

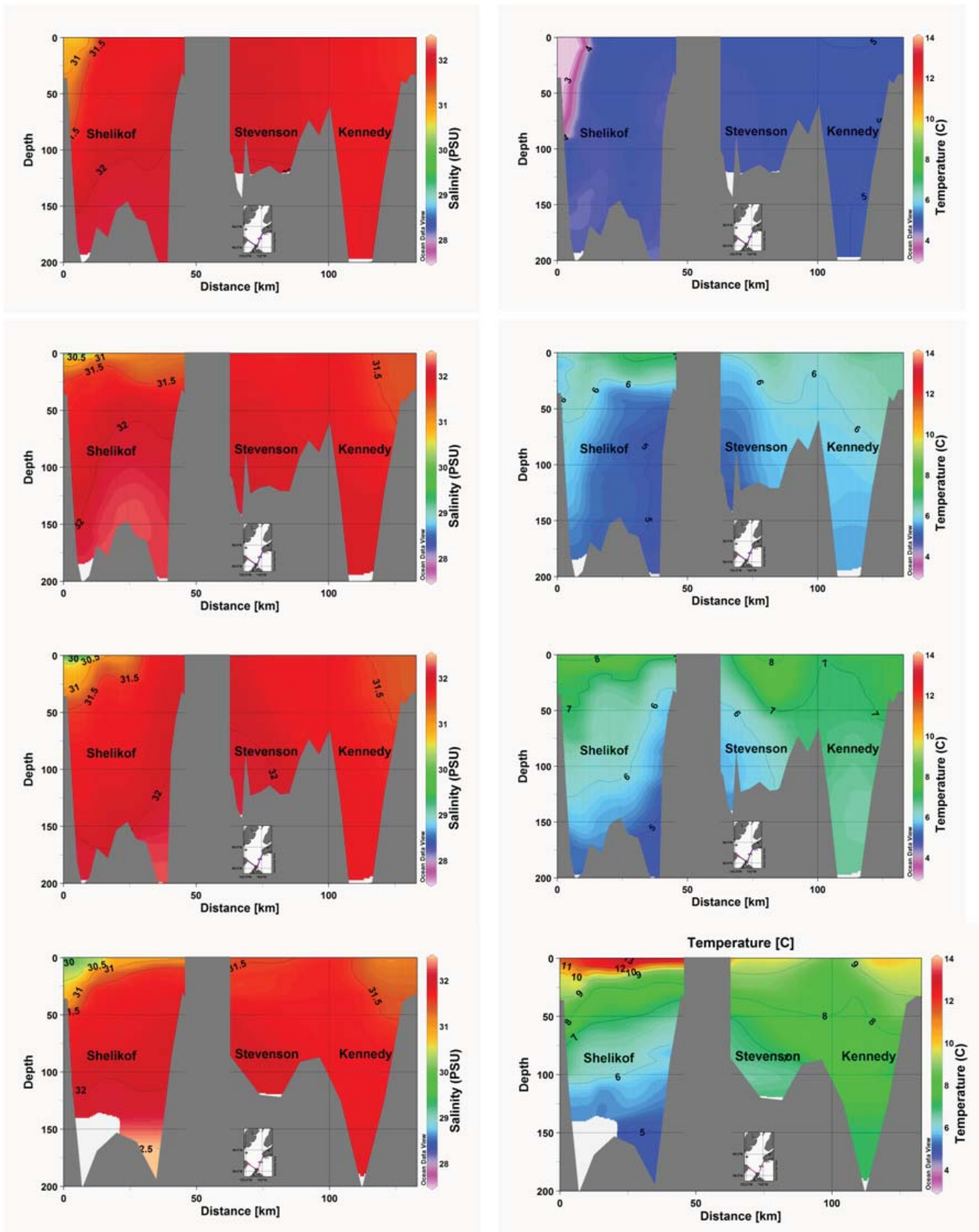


Figure 2. Salinity contours along lines 1 and 2 are displayed in the left panel and temperature in the right. The data in the panels are from April, May, June, and July 2004 as viewed from top to bottom.

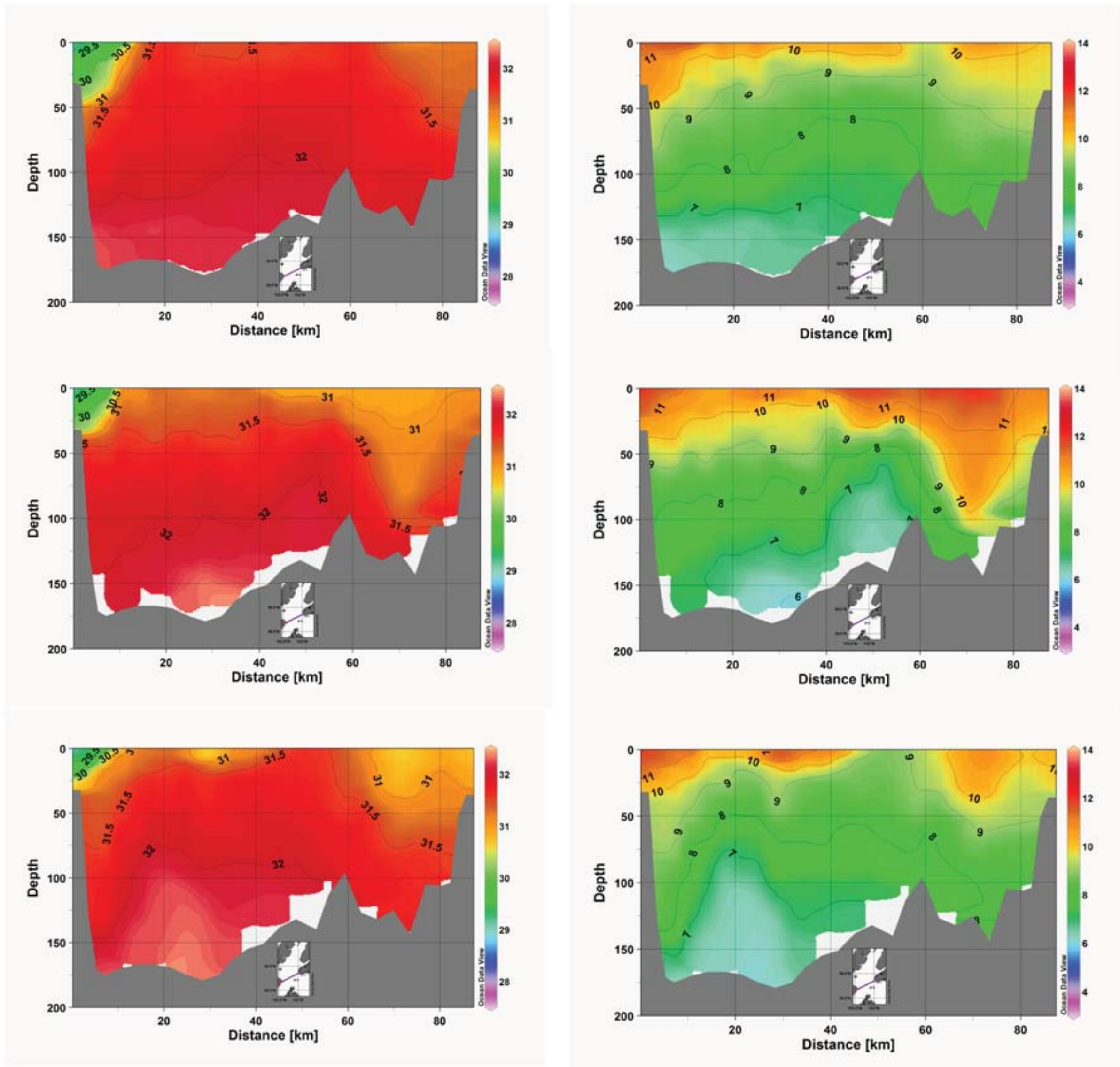


Figure 3. Salinity contours along line 6 (Cape Adams to Cape Douglas) are displayed in the left panel and temperature in the right. The data in the panels are from July 27 (spring), August 6 (neap), and August 13 (spring), 2006 as viewed from top to bottom.

Line 7 ran from Magnet Rock in the east to Mt. Augustine in the west (Figure 4). The average water depth along this line (~ 75 meters) is seen to be much shallower than across Line 6.

A freshening of the surface waters is observed along both the western and eastern boundaries. The dramatic difference between the spring and neap tides occurs in the center of the transect and along the bottom. On a spring tide there are two colder, more saline parcels of water along the bottom separated by a warmer, fresher water mass in the center. During the neap tide the cold-salty water extends from the bottom to nearly the surface in the center of the transect. The formation of the high salinity water mass near the entrance of Kachemak Bay is likely formed by the strong tidal mixing

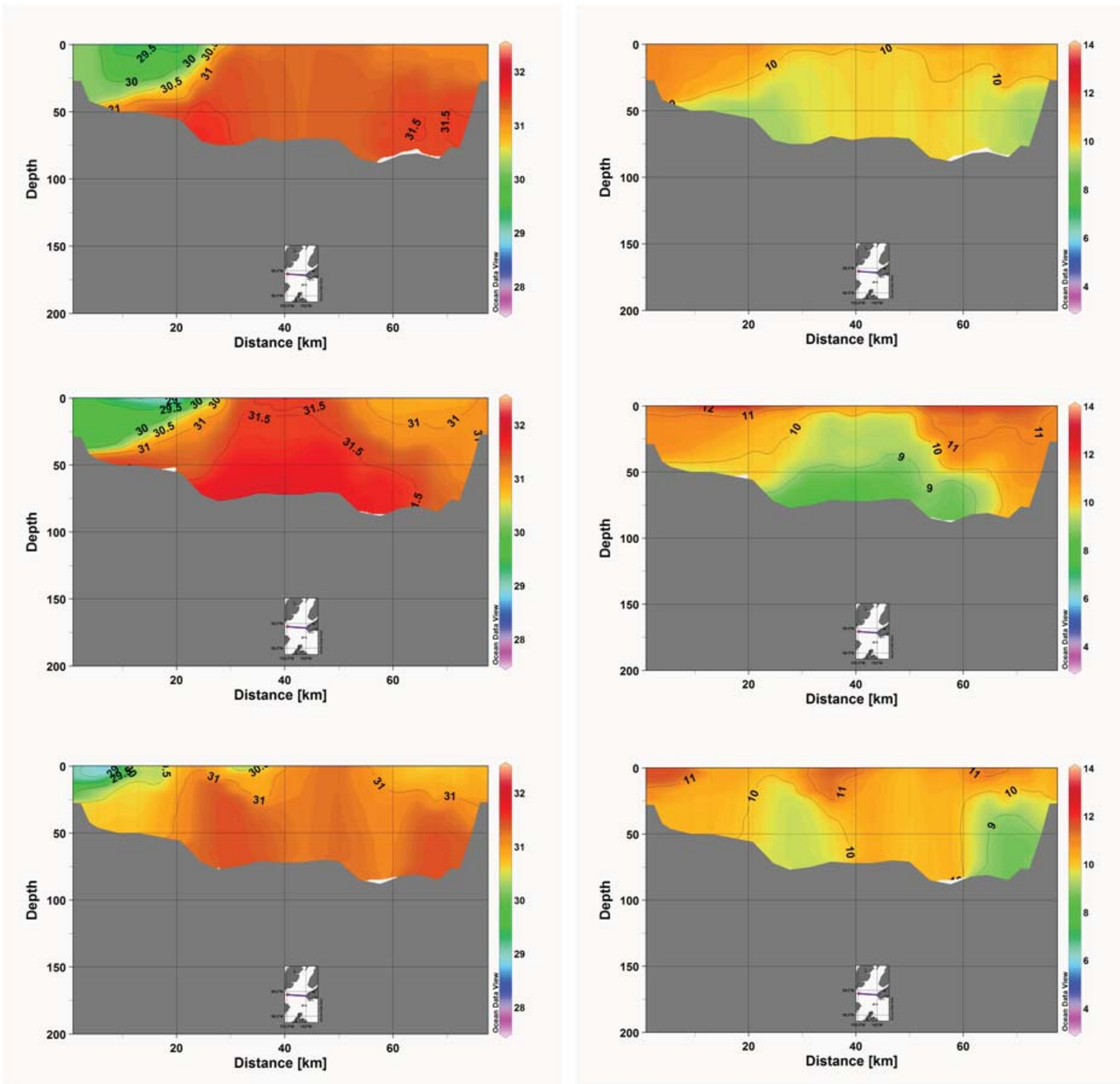
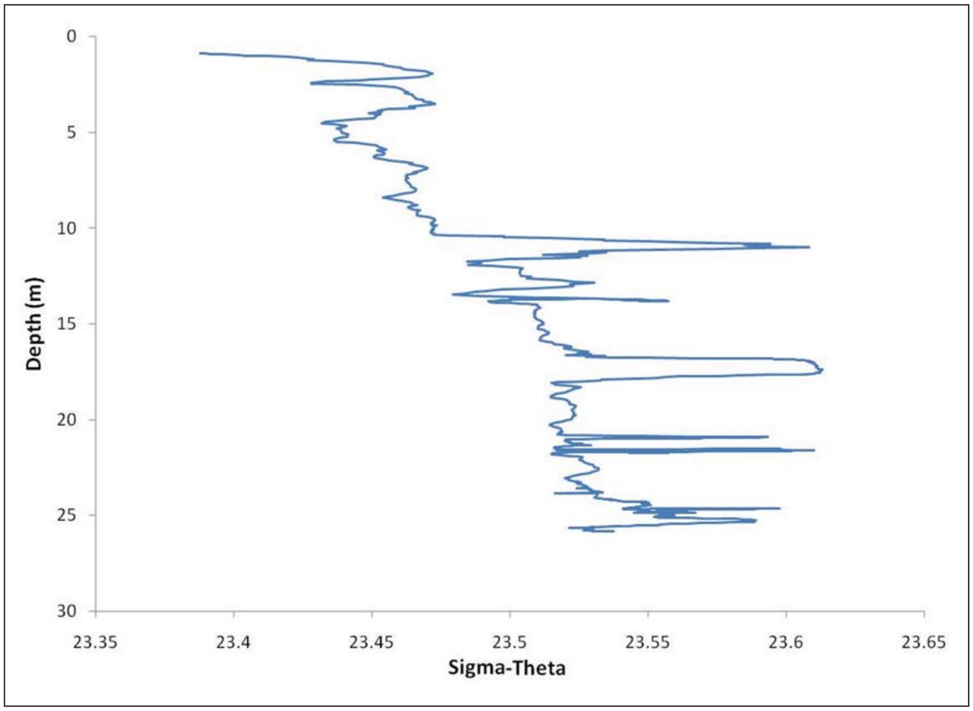


Figure 4. Salinity contours along Line 7 (Magnet Rock to Mt. Augustine) are displayed in the left panel and temperature in the right. The data in the panels are from July 27 (spring), August 6 (neap) and August 13 (spring), 2006 as viewed from top to bottom.

that occurs at the confluence between the tides of Kachemak Bay and Cook Inlet (Figure 5).

Interannual variability of oceanographic conditions in the vicinity of the lower inlet study area is illustrated by temperature data from tide stations at Kodiak and Seldovia (Figure 6). Kodiak is located south of our study region and Seldovia is inside the study area near the southern end of Line 4. During the three years of sampling, 2004 and 2006 were most similar in temperatures. The summer of 2005 was the warmest on record at the Seldovia tide station and the third warmest in Kodiak. In the last ten years the monthly averaged low temperature in Seldovia ranged from 1.1 to 4.7 degrees, and the summer high temperatures from 9.9 to 12.1 degrees. Kodiak experienced a slightly wider range of temperatures.

Figure 5. Plotted is a density profile collected at the confluence of Kachemak Bay and Cook Inlet. The fluctuations in density are an indication of the vigorous mixing that occurs in this region.



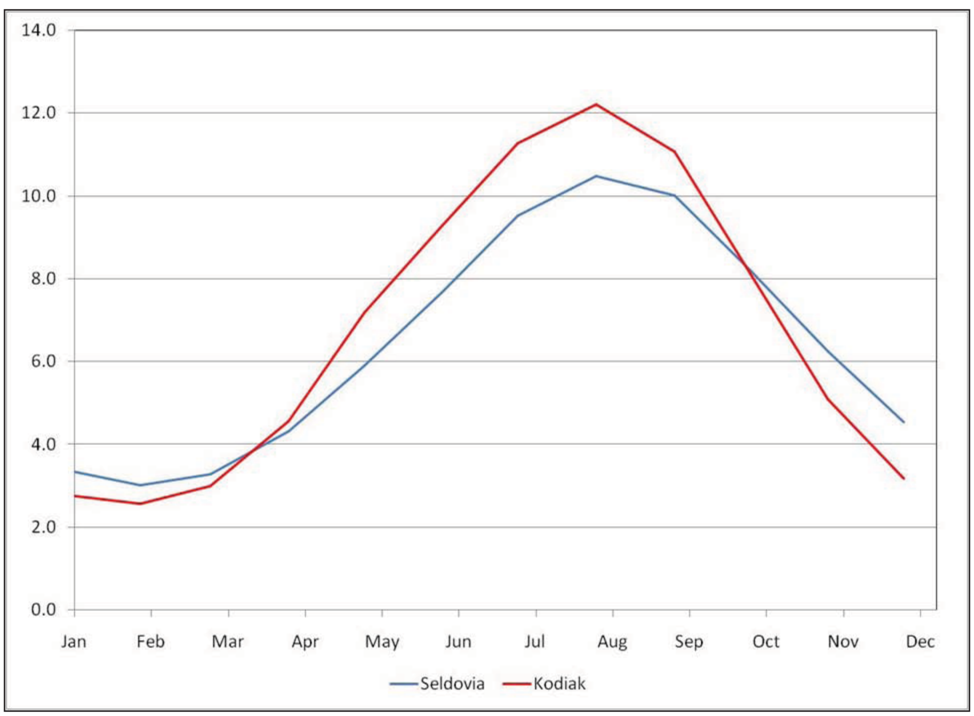


Figure 6. Water temperature measured at the tide stations in Seldovia (blue) and Kodiak (red).

At both stations the maximum temperature occurs in August and the minimum temperature in February. The winter cold period lasts from December until March. Beginning at the end of March the temperature increases steadily through June. July through September are the warmest months. Fall storms begin to bring down the temperature in October. The temperature drop in the fall is dependent on storm activity so it tends to drop rapidly during these events, unlike the steady increase in temperature through the spring.

Presentations

Pegau, W. S., S. Okkonen and S. Saupe (S. Pegau presenter). 2006. Seasonality of boundary conditions for Cook Inlet, Alaska. Presentation to CMI Annual Research Review, February 2007, Fairbanks, AK.

Literature Cited

Burbank, D.C. 1977. Circulation studies in Kachemak Bay and Lower Cook Inlet, in Environmental Studies of Kachemak Bay and Lower Cook Inlet, Trasky, LL., L.B. Flagg, and D.C. Burbank eds. vol III, 207 pp.

Johnson, M.A. and S.R. Okkonen (eds.). 2000. Proceedings Cook Inlet Oceanography Workshop, OCS Study MMS 2000-043, Coastal Marine Institute and Oil Spill Recovery Institute, 9 Nov 1999, Kenai, Alaska.

Muench, R.D., H.O. Mofjeld, and R.L. Charnell. 1978. Oceanographic conditions in Lower Cook Inlet: Spring and Summer 1973, *J. Geophys. Res.*, **83**, 5090-5098.

Okkonen, S.R. and S.S. Howell. 2003a. Measurements of Temperature, Salinity, and Circulation in Cook Inlet, Alaska. Final Report. OCS Study MMS 2003-036, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 28 p.

Okkonen, S.R. 2003b. Observations of hydrography in central Cook Inlet, Alaska during diurnal and semidiurnal tidal cycles. Ongoing CMI project.

Pegau, W. S. 2003. Visible remote sensing of the Gulf of Alaska, Ongoing EVOS-GEM project G-030685.

Willette, M. and W. S. Pegau. 2003. Monitoring dynamics of the Alaska coastal current and development of applications for management of Cook Inlet salmon – a pilot study, Ongoing EVOS-GEM project G-030670.

Radio Frequency Identification Tags for Grizzly and Polar Bear Research

Lori Quakenbush
Lori.Quakenbush@alaska.gov
Alaska Department
of Fish and Game
1300 College Road
Fairbanks, AK 99701

Richard Shideler
Dick.Shideler@alaska.gov
Alaska Department
of Fish and Game
1300 College Road
Fairbanks, AK 99701

Geoff York
Geoff_York@usgs.gov
U.S. Geological Survey
Alaska Science Center
1011 East Tudor Road
Anchorage, AK 99503-6199

Task Order: 39266

Abstract

Grizzly bears (Ursus arctos) and polar bears (Ursus maritimus) are important species for subsistence communities along the Beaufort Sea coast for food, fur, and for their cultural importance. Both species are also important components of Arctic terrestrial, nearshore, and marine ecosystems. Much of our current knowledge about bear populations, habitat use, movements, and interactions with oil and gas activities on the North Slope has been the result of repeated observations of telemetrically collared bears (VHF and satellite). For polar bears in particular, much of the information comes from females and subadults because adult male bears have a low retention rate for collars due to their neck anatomy. Application of existing and emerging Radio Frequency Identification (RFID) technology, currently used for military and commerce, has the potential to significantly increase the sample size of marked bears by decreasing the cost and providing a way to mark male bears. The goal of this research and development project was to test the feasibility of the RFID system for grizzly and polar bear research and management by modifying the tags so they could be attached to bear ears and by modifying the reader and antenna system for use in aircraft and land vehicles. RFID tags were placed on 52 polar bears and 22 grizzly bears in 2006 and 20 polar bears in 2007. Signals from tags were received from ~400 m at ground level and up to 1.6 km from an aircraft at 1000 m elevation. Although RFID range exceeded our expectations, tag retention, especially for females with dependent young, was a major limitation.

Introduction

Grizzly bears (*Ursus arctos*) and polar bears (*U. maritimus*) are important species for subsistence communities along the Beaufort Sea coast for food, fur, and for their cultural importance (Amstrup et al. 1986, Shideler and Hechtel 2000, Treseder and Carpenter 1989). These bears are also important components of Arctic terrestrial, nearshore, and marine ecosystems. Both species use the oilfields and will be affected, directly or indirectly, by future oil and gas development in terrestrial, nearshore, and offshore areas. Much of our current knowledge about bear populations, habitat use, movements, and interactions with oil and gas activities on the North Slope has been the result of repeated observations of radio-collared or satellite-collared bears (Amstrup et al. 2000, Shideler and Hechtel 2000). Unfortunately, adult male bears have a low retention rate for collars due to their neck anatomy. Although adult male grizzly bears shed collars less frequently than polar bears, 59% of those in the Oilfield Grizzly Bear Project have lost their collar at least once. Thus, much of what we know about interactions between grizzly or polar bears and oil development is based on relocations of female and subadult bears.

In our studies, we often recapture polar bears only to release them once their identity is confirmed from lip tattoos. Currently, other than adult females wearing active VHF collars, the only way we can confirm individual identity is through capture and handling. The time, effort, risk, and cost it takes to recapture a bear that does not add to the results of the study limits the overall number of bears that can be marked. The ability to identify individual bears of either sex without having to recapture them would provide more efficient information on bear habitat use and interactions with oil and gas exploration and production activities. Radio Frequency Identification (RFID) technology is currently used in military and commercial applications. It has the potential to significantly increase the sample size of marked bears by decreasing the cost and by providing a method to mark male bears.

Additional uses for the tags include marking bears near oil and gas facilities in order to determine the number of bears using the area, their movements, and their den sites. Bears wearing RFID tags could be monitored as they move past RFID readers mounted on poles, buildings, or other existing structures in the oil field or near seasonal aggregations. The presence and movements of RFID tagged bears could be monitored without the need for continual human presence, and without the potential disruptions that presence may cause. This type of information can aid in planning temporary and permanent facilities and in developing effective mitigation measures.

In recent years, concurrent with an apparent increase in polar bear numbers as well as changes in summer ice dynamics, increases in numbers of polar bears on terrestrial and nearshore habitats have been recorded. At least some of this increased nearshore use appears to be attributed to climate change. Documentation of polar bear numbers and movements onshore could assist in assessing the effects of climate change on polar bears (Stirling and Derocher 1993, Stirling et al. 1999). Although the oilfields have attracted bears for the last 15 years (Shideler 1993) there has been an increase in polar bear use of habitats in and around North Slope oilfield facilities and have congregated near villages where the remains of bowhead whales are available. Questions to be answered about these recent concentrations include: a) are bears becoming food-conditioned to these sites, b) are the same bears using sites repeatedly, c) what component of the population is involved in these concentrations, d) are bears moving among these locations, or are they faithful to one area, and e) are more bears attracted to onshore and nearshore oil and gas development as a result of obtaining food at these sites?

Grizzly bears are also attracted to bowhead whale carcasses frequented by polar bears near Kaktovik (R. Shideler, pers. obs.) and at West Dock in the Prudhoe Bay oilfield (Shideler and Hechtel 2000). The same questions about polar bear use of these carcasses apply to grizzly bears, and, in addition, the interactions of the two species are of interest. For example, some observations indicate that grizzly bears have prevented polar bears from feeding on the carcass.

An RFID system contains two major components: tags and readers. Our objectives include modifying the tag to be applied to grizzly and polar bears as an ear tag and testing the technology in Arctic conditions using readers attached to trucks, fixed-wing aircraft, and helicopters.

Objectives

Our specific objectives include:

*Objective 1***:** Develop and build 50 RFID ear tags suitable for attachment to wild, free-ranging grizzly and polar bears. Tags will be programmed so that they report the individual ID number of the bear to which they are attached.

*Objective 2***:** Develop four RFID tag-readers and antenna systems capable of identifying hundreds of individually coded RFID tags at a horizontal and vertical distance of greater than or equal to 100 m. The reader must be compact, light-weight, and durable enough to allow easy operation in the cabin of a Bell 206 helicopter and Cessna 185 or similar fixed-wing aircraft. Receiving antennae must be designed to fit the helicopter or fixed-wing aircraft, durable enough to withstand severe arctic conditions, and sensitive enough to identify the tags at the required distance in fog, rain, and snow. The reader-antenna configurations also must be portable enough that they can be used in a pickup truck or mounted on fixed poles or industrial antennae.

Objective 3: Test and evaluate the RFID system on 40 grizzly bears on the North Slope over two summers. Grizzly bears can be captured and monitored more easily and inexpensively than polar bears, and the Oilfield Grizzly Project currently maintains a radio-marked sample of approximately 50 bears annually. RFID deployment would occur during capture operations for that project. The first summer would be deployment of tags and monitoring their fate. The following summer would be monitoring the fate of the tags after denning and especially after the breeding season when our experience indicates that radio-collars and ear tags are most likely to be lost during bear-bear interactions.

Objective 4: Test and evaluate the RFID system on 10 polar bears captured on or near shore in the fall of Year 1. Monitor the tags through the following winter and summer.

Methods

Polar bears were captured in the Beaufort Sea of northern Alaska and northwestern Canada by injecting Telazol® (tiletamine hydrochloride plus zolazepam hydrochloride) with projectile syringes fired from helicopters (Larsen 1971), Schweinsburg et al. 1982, Sterling et al. 1989). RFID ear tags were placed on the right ear when possible. If the right ear was compromised in some way, tags were placed on the left ear.

Grizzly bears were captured on the North Slope of Alaska using the same techniques as for polar bears above. RFID ear tags were placed on either the left or right ear. Grizzly bears ears are marked with colored flagging so that individual bears can be identified from the air. In most cases, the white RFID tags were placed on ears that had either white or yellow flagging so as to minimize interference with the ear flag color and create mistaken identities from the air.

Bears that had been previously ear-tagged had useable holes in their ears. Bears without usable holes were fitted with RFID tags by making a hole with an ear punch. A mechanical C-clamp was modified to allow quick and easy installation of the plastic washer and lock ring that holds the RFID tag on. This allowed fine control of the tightness of the lock ring.

Results

Funding did not become available in time to have tags and readers developed, tested, and ready to use during the summer 2005 field season when grizzlies were being captured for collaring. In 2006, however, development and testing was completed and RFID tags were placed on polar bears in April and May and on grizzly bears in August and September. In 2007, tags were placed on polar bears and tags placed on polar bears and grizzlies in 2006 were evaluated.

RFID tags: Integral RFID, Inc. developed a semi-passive prototype tag and an active prototype tag for testing. The active tag showed much greater promise in lab tests and semi-passive tag development was abandoned. An active tag sends a signal every two seconds that transmits the tag ID and the batteries last for four years. The ear tag electronics are housed in high-density polyethylene (HDPT) chosen because it does not interfere with RF signals, is durable, waterproof, and does not become brittle at extremely cold temperatures. The first generation tags weighed 17.7 g but the post was found to be too short for deployment on larger grizzly bears which have thicker ear tissue. Only three of these tags were deployed on grizzly bears, however all 52 polar bears tagged in 2006 received first generation tags. The second generation of tags had thinner housings, were smaller overall, weighed less (16.1 g), and had longer posts for easier deployment. Nineteen of these tags were put on grizzlies in 2006 and 17 on polar bears in 2007.

Tag readers and antenna systems: Tag readers and antennas were developed to work with aircraft and ground transportation. One directional yagi antenna was mounted off the right wing of a Cessna 185, oriented 90° to the direction of flight and down at a 30° angle. This allowed us to circle grizzly bears from a consistent altitude and horizontal distance while evaluating the RFID reader's ability to receive the signal. Because the detection range from the fixed-wing aircraft exceeded our initial expectations, we developed a multi-antenna mounting and switching system that can be used to radio-locate RFID-tagged grizzly bears in a similar fashion to that used in conventional radio-tracking. After initial testing we abandoned that approach because the current system cannot selectively modify signal strength, a major requirement for radio-tracking. Development of a signal-strength component was beyond the scope of this project.

Two directional yagi antennas were mounted on a Eurocopter A-star helicopter, one on each side forward and below the fuselage. One antenna was mounted in the horizontal plane and one vertical. This maximized the detection range forward of the aircraft.

Range testing using ground transportation was conducted by holding the antenna out the window of the truck. We have not permanently mounted the antenna on the truck because no bears have been within range of the oilfield road system. This gives us flexibility to walk off the road system with the antenna and reader to detect distant bears. When bears approach the road system, we can mount the antenna on the permanently installed mast we currently use for conventional radio-tracking. This will give us a 1 m increase in antenna height and allow us to scan while driving the road system.

Deployment on polar bears: In spring 2006, RFID ear tags were placed on 52 polar bears (31 female, 21 male) by USGS personnel (Table 1). The signals from the ear tags were receivable from the helicopter at an altitude of 152 m (500 ft) for a distance of more than 400 m. Several bears were re-sighted within days of capture and appeared to be wearing the tags well.

In spring 2007, we deployed 20 of the smaller second generation RFID ear tags (12 female, 8 male; Table 2). Six bears that had RFID tags in 2006 were encountered in 2007 and three retained functioning ear tags (2 female, 1 male) while three had lost the tags (1 female, 2 male). A bear harvested in Canada was also reported with an RFID ear tag. The tag was removed by the hunter and returned to the USGS during the summer of 2007 and was still functioning properly upon receipt.

Deployment on grizzly bears: Twenty-two active RFID ear tags were placed on 18 female and 5 male radio-collared grizzly bears during August and early September, 2006 (Table 3). During tracking flights in October and November, 2006, 21 of these were located. Of these 21, 16 had tags that were still transmitting. During June, 2007, we conducted 2 aerial surveys and were again able to locate 21 of the tagged bears. One of these was a bear that had been killed. As of June 27 we have received signals from only 6 of 20 RFID-tagged bears known to be alive. Visual inspection from over-flights of several of the bears suggested that tags had been pulled off, rather than failed to transmit. This spring, most of the adult females had either new cubs or last year's cubs, and many of these, including several whose tags were still transmitting during an earlier June flight, had lost RFID tags by the late June survey. Females with cubs comprised all but one of the bears whose tag was not transmitting or was lost. We assumed that most of the tags were lost because cubs often tear ear tags out while playing with their mothers. The only other tag that was not transmitting was on a subadult male. This tag had transmitted in November 2006 after not receiving a signal in October. Failure of his tag may have been due to a faulty transmitter rather than loss of the tag.

Transmission range of the RFID tags exceeded our expectations. Several tags were received from aircraft at horizontal distances >1600 m, including one could be read from almost 2000 m (Table 4). We were also surprised to receive signals from inside dens. Tags from 12 bears in dens were received from aircraft, although the horizontal distance was usually <100 m even from altitudes as high as 1500 m. Range testing from the oilfield road system indicated that with the antenna polarity in the horizontal mode and hand-held at a height of 2 m, the tags could be read at distances of approximately 400 m. Ground testing on grizzly bears has not been completed because none of the tagged bears have been in the vicinity of the road system when project personnel were present.

In September and October 2006, an antenna and reader was loaned to the U.S. Fish and Wildlife Service (USFWS) conducting a study of polar and grizzly bear use of bowhead whale remains after subsistence whaling near Kaktovik. The receiving system was used from a parked truck parked within 100 m of the remains that were frequented by both polar and grizzly bears. None of the grizzly bears were radio-collared, and the marked polar bears that were observed may not have been fitted with RFID tags. No RFID signals were received from any of the bears monitored during the study (S. Miller, USFWS, pers. comm.).

Discussion

Although our initial proposal focused on semi-passive RFID tag technology, the delay in funding allowed us to determine that active tag technology showed greater benefits for our applications including greater reception range, smaller electronics for a smaller tag, and transmission of tag ID every two seconds for the same battery life (approximately four years) as that of the semi-passive tag.

We have accomplished our objectives to build RFID ear tags and reader systems that can be used on various tracking vehicles. Because funding was not available in time for tag deployment during the 2005 grizzly bear field season fewer tags were deployed on grizzly bears than we proposed. However, we were able to deploy more on polar bears than proposed. We deployed 69 tags on polar bears and 22 on grizzly bears and continue to evaluate the durability and longevity of the tags. The range of the active tags exceeded our expectations and supported our conclusion that RFID technology can provide a useful tool for grizzly and polar bear research and management. However, tag loss limits the utility of the system. Although our ability to evaluate the tags on polar bears was limited it appears that their retention may be better. Four of seven (57 %) polar bears retained their tags after one year, while only 6 of 20 (30%) of grizzly bears did. There may be ways to improve tag retention, such as modifying the tags for implanting under the skin. Although this may result in some reduction in reception range, it may still be an acceptable trade-off if tag retention is improved.

Students

Torsten Bentzen, a Wildlife Biology graduate student at UAF, assisted in the deployment of RFID ear tags on grizzly bears and with the fixed-wing and ground-based reception range tests.

Presentations

Co-PI Shideler made an informal presentation to an interagency group in Fairbanks in December 2006 and he presented the project at the annual CMI meeting in Fairbanks in February 2007. PI Quakenbush gave a presentation to the North Slope Borough Fish and Wildlife Management Committee in Barrow in December 2006.

Acknowledgements

This project is funded by the Minerals Management Service through the University of Alaska Coastal Marine Institute and with matching support provided by the North Slope Borough Service Area 10, BP Exploration (Alaska) Inc., and ConocoPhillips Alaska.

The portion of this project that requires the capture and attachment of ear tags on grizzly bears has been reviewed and approved by the Animal Care and Use Committee (ACUC) of the Alaska Department of Fish and Game (#03-0007). The portion of this study that requires the capture and attachment of ear tags on polar bears is covered under a U.S. Fish and Wildlife Service Permit (No. MA690038-9).

Literature Cited

Amstrup S. C., I. Stirling, and J. W. Lentfer. 1986. Past and present status of polar bears in Alaska. Wildlife Society Bulletin 14:241–254.

Amstrup, S. C., G. Durner, I. Stirling, N. J. Lunn, and F. Messier. 2000. Movements and distribution of polar bears in the Beaufort Sea. Canadian Journal of Zoology. 78:948–966.

Larsen, T. 1971. Capturing, handling and marking polar bears in Svalbard. Journal of Wildlife Management. 35:27–36.

Schweinsburg, R. E., L. J. Lee, and J. C. Haigh. 1982. Capturing and handling polar bears in the Canadian Arctic. Pages 267–289 *in* L. Nielsen, J. C. Haigh, and M. I. Fowler, eds. Chemical immobilization of North American wildlife. Wisconsin Humane Society, Inc., Milwaukee.

Shideler, R. T. 1993. Chapter 3: Attraction to human activity. Pages 17–24 *in* J.C. Truett, ed. Guidelines for oil and gas operations in polar bear habitats. OCS Study MMS 93-0008. USDI-MMS, Anchorage, AK. 104 pp.

Shideler, R. T. and J. L. Hechtel. 2000. Chapter 6: Grizzly Bears. Pp. 105–132 *in* J. C. Truett and S. R. Johnson, eds. Natural history of an arctic oilfield: development and biota. Academic Press, New York. 422 pp.

Stirling, I., and A. E. Derocher. 1993. Possible impacts of climatic warming on polar bears. Arctic 46:240–245.

Stirling, I., C. Spencer, and D. Andriashek. 1989. Immobilization of polar bears (*Ursus maritimus*) with Telazol® in the Canadian Arctic. Journal of Wildlife Diseases 25:159–168.

Stirling, I., N. J. Lunn, and J. Iacozza. 1999. Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic 52:294–306.

Treseder, L., and A. Carpenter. 1989. Polar bear management in the southern Beaufort Sea. Information North. 15(4):2-4.

Table 1. RFID tags deployed on polar bears in spring 2006.

Date	Bear ID	N. Lat	W. Long	Ear tagged	RFID #	Age	Sex
4-May	6520	70.688	-149.413	Right	7343	20	F
8-May	6817	71.025	-147.518	Right	4639	18	F
4-May	6836	70.712	-149.067	Right	9359	17	F
8-May	20112	70.783	-149.506	Left	5519	14	F
2-May	20125	70.690	-148.205	Right	9031	6	M
12-Apr	20132	70.694	-147.494	Right	8439	5	F
21-Apr	20151	70.902	-149.187	Right	239	4	M
29-Apr	20156	70.820	-148.287	Left	3791	6	M
4-Apr	20173			Right	3959	12	M
3-Apr	20299	71.575	156.923	Left	9023	11	F
17-Apr	20413	70.747	-148.690	Right	5871	9	F
1-May	20442	70.768	-148.867	Right	3719	14	F
25-Apr	20446	70.797	-148.955	Right	1079		F
10-May	20473	70.969	-150.957	Right	5807		M
13-Apr	20479	70.426	-147.269	Right	4231	7	F
21-Apr	20497	70.624	-147.832	Right	375	13	M
19-Apr	20539	70.631	-146.692	Right	7871	12	M
25-Apr	20553	70.865	-148.941	Right	5183	7	M
7-Apr	20643	71.455	-155.255	Right	3639	12	F
20-Apr	20656	70.819	147.608	Left	3703	6	F
6-Apr	20678			Right	4495	14	M
4-May	20710	70.903	-149.837	Right	3311	6	M
18-Apr	20733	70.499	-145.320	Right	8271	4	M
30-Apr	20751	70.983	-148.971	Right	5279	8	M
21-Apr	20758	70.877	-148.884	Right	3175	3	F
13-Apr	20802	70.426	-147.269	Left	4950	8	M
3-Apr	20825	71.575	156.923	Left	5463	2	F
3-Apr	20826	71.575	156.923	Left	5751	2	F
5-Apr	20828	71.544	-155.457	Right	5735		M
5-Apr	20829	71.577	-155.392	Left	3407		M
6-Apr	20832	71.867	-156.756	Right	5623		F
7-Apr	20837	71.501	-155.270	Right	7271		F
11-Apr	20838	70.872	-146.512	Right	5127		M
12-Apr	20839			Right	6047		F
12-Apr	20840			Left	7351		F
16-Apr	20843	71.139	-146.747	Right	6687	2	F
16-Apr	20844	71.137	-146.755	Right	7479		F
18-Apr	20846	70.439	-145.852	Right	4375		F
18-Apr	20847	70.439	-145.852	Right	5655	1	F
18-Apr	20848	70.439	-145.852	Right	311	1	F
19-Apr	20849	70.570	-145.848	Right	9791		M
20-Apr	20850	70.622	-147.463	Right	5591		F
20-Apr	20851	70.802	-147.508	Right	1967		M
30-Apr	20854	70.923	-149.624	Right	9927		M
1-May	20858	70.776	-149.133	Right	431		F
3-May	20859	70.896	-150.117	Right	4991		F
4-May	20860	70.822	-149.628	Right	4679		F
9-May	20864	70.680	-149.137	Right	7551		M
9-May	20865	70.532	-147.249	Right	8975		F
30-Apr	32255	71.027	-149.436	Right	695	2	F
6-Apr	32261	71.631	-154.862	Right	6975	8	M
3-Apr	32799	71.481	-156.417	Right	2855		F

Table 2. RFID tags deployed on polar bears in spring 2007.

Date	Bear ID	N. Lat	W. Long	Ear tagged	RFID #	Age	Sex
16-Apr	20131	70.739	-148.557	Left	5615	14	F
19-Apr	20895	70.722	-148.616	Left	98322	Adult	M
22-Apr	20177	70.671	-148.663	Left	4863	6	M
29-Apr	20485	70.383	-143.679	Right	103042	13	F
29-Apr	20899	70.383	-143.679	Left	101850	Adult	M
1-May	20900	70.097	-142.813	Left	104482	Adult	M
4-May	20734	70.244	-143.353	Left	101795	5	F
7-May	20901	70.296	-141.017	Right	99970	Adult	F
7-May	20902	70.198	-142.402	Right	104379	Adult	F
7-May	20903	70.198	-142.402	Right	99995	1	M
7-May	20904	70.198	-142.402	Right	98922	1	F
7-May	20905	70.196	-142.160	Right	101842	Adult	F
8-May	20908	70.232	-142.500	Left	6415	Adult	F
8-May	20909	70.237	-142.336	Left	99915	Adult	M
9-May	20910	70.014	-141.663	Right	102331	Adult	F
9-May	20911	70.014	-141.663	Right	104762	2	F
9-May	20912	70.014	-141.663	Right	104387	2	M
10-May	20518	70.257	-143.195	Right	100650	7	F
10-May	20913	70.240	-143.045	Right	103626	Adult	M
13-May	20915	NA	NA	Right	104978	Adult	F

Table 3. RFID tags deployed on grizzly bears in northern Alaska in summer 2006. Tag type 1 is earliest version. COYs = cubs of the year.

Date	Bear ID	Location	Ear tagged	RFID #	Tag type	Age	Sex	Comments
8-Aug	087	Franklin Bluff	Left	55967	2	Subadult	M	
8-Aug	076	Franklin Bluff	Left	52159	2	Adult	F	
8-Aug	021	Kavik R.	Left	53807	2	Adult	F	
8-Aug	116	Kavik R.	Right	58383	2	Adult	M	
9-Aug	073	Canning R.	Right	49663	2	Adult	F	2 COYs
9-Aug	016	Echooka R.	Left	54311	2	Adult	F	
9-Aug	032	Kadleroshilik R.	Right	58191	2	Adult	F	2 COYs
9-Aug	118	Canning R.	Right	59527	2	Subadult	M	
15-Aug	115	Kuparuk Oilfield	Left	55887	2	Adult	F	
15-Aug	018	Itkillik Hills	Left	56679	2	Adult	F	2 yearlings
15-Aug	007	Itkillik Hills	Left	56927	2	Adult	F	2 COYs
15-Aug	019	Itkillik Hills	Right	57047	2	Adult	F	
16-Aug	037	Itkillik Hills	Left	55743	2	Adult	F	2 COYs
16-Aug	017	Itkillik Hills	Left	57807	2	Adult	F	
17-Aug	039	Colville R.	Right	57815	1	Adult	F	2 COYs
17-Aug	068	Colville R.	Left	58911	2	Adult	F	
17-Aug	078	Colville R.	Left	60815	1	Adult	F	2 COYs
18-Aug	089	Kogru R.	Right	60567	1	Adult	F	2 COYs
7-Sep	096	Inigok Creek	Left	54399	2	Adult	M	
7-Sep	109	Judy Creek	Right	55479	2	Adult	F	2 COYs
7-Sep	023	Milne Pt. Oilfield	Right	57143	2	Adult	F	
7-Sep	102	Kogosukruk R.	Right	59479	2	Adult	F	2 yearlings

Table 4. Horizonatal and vertical signal reception distances (m) for RFID tags placed on grizzly bears. Blank spaces indicate bear was not found on survey; "0" indicates bear found but no RFID signal received; filled cells indicate subsequent surveys with no RFID signal. Bear in dens denoted with *; all bears in dens on November 2006 flight.

		Birth	Tagging	8/9/06		10/10-12/06		11/25-26/06*		4/23/07		6/6-7/07		6/13-14/07		6/26-27/07	
Bear ID	Sex	Year	Date	Hor	Vert	Hor	Vert	Hor	Vert	Hor	Vert	Hor	Vert	Hor	Vert	Hor	Vert
007	F	1989	8/15/06			0	0										
016	F	1992	8/9/06			0*	0*										
017	F	1993	8/16/06			1000	330	10	400							500	230
018	F	1993	8/15/06			10*	170						a				
019	F	1980	8/15/06			10*	420									500	170
021	F	1976	8/8/06			10*	1550									1000	230
023	F	1992	9/7/06			10	240	10	65		33*					1600	330
032	F	1989	8/9/06			1530	740	10	350			0	0				
037	F	1991	8/16/06			10	10	10	700					0	0		
039	F	1986	8/17/05			0	0										
068	F	1988	8/17/06			2000	500	10	165							1650	330
073	F	1978	8/9/06	1000	645	10	2600					0	0	0	0		
076	F	1997	8/8/06									0	0				
078	F	1993	8/17/06			800	165	10	65		65*					0	0
087	M	2001	8/8/06	1000	500			10	550							0	0
089	F	1996	8/18/09			0	0										
096	M	1997	9/7/06										650			0	0
102	F	1989	9/7/06			10	850					0	0				
109	F	1989	9/7/06			10	85							0	0		
115	F	1997	8/15/06			800	400	10	260					0	0	1000	165
116	M	1995	8/8/06			1750	500					0	0				
118	M	2002	8/9/06	500	1000	0	0	1000	165			0	0				

a. Bear 018 confirmed dead on 6/7/07

Assessment of the Direction and Rate of Alongshore Transport of Sand and Gravel in the Prudhoe Bay Region, North Arctic Alaska

Sathy A. Naidu
ffsan@uaf.edu
Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775

William Lee
Aswj13@uaa.alaska.edu
School of Engineering
University of Alaska Anchorage
Anchorage, AK 99508-8054

Thomas M. Ravens
aftmr@uaa.alaska.edu
School of Engineering
University of Alaska Anchorage
Anchorage, AK 99508-8054

John J. Kelley
ffjjk@uaf.edu
Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775

Martin C. Miller
martin.coastalocean@gmail.com
Coastal and Ocean Concepts
PO Box 1528
Sequim, WA 98362

Orson P. Smith
afops@uaa. alaska.edu
School of Engineering
University of Alaska Anchorage
Anchorage, AK 99508-8054

Zygmunt Kowalik
ffzk@uaf.edu
Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775

Task Order: 39380

Abstract

There is no quantitative information on the natural directions and rates of the alongshore transport of sand and gravel for the industrial and oil prospect areas of the North Slope coast of north Arctic Alaska. This lack of information hampers the effective planning, designing and management of coastal engineering structures and coastal activities such as dredging, beach nourishment and erosion mitigation, among others. This report provides the progress of research conducted in Year 2 (September 2006-August 2007) of a three-year study, to determine the direction and rate of alongshore sediment transport at the mixed sand-gravel beach at Narwhal Island, a micro-tidal barrier located NE of Prudhoe Bay, north Arctic Alaska.

Two approaches were adopted to determine the direction and rate of alongshore sediment transport. The first approach has consisted of continuing the determination of, empirically, the seasonal directions and volumes of alongshore sediment transport, using fluorescence-dyed sands and gravels tagged with Passive Integrated Transponders (PIT) which were point injected in June and August, 2006 at four seaward beach MTL sites and adjacent berm bases located ~54cm AMTL of Narwhal Island. The survey in July 25, 2007 could locate only one of the 200 tagged gravels originally injected on the beach. This gravel had drifted 29m westward from the point of injection.The fate of the rest of the tagged gravels is unknown. It is likely that during the 2006-2007 winter period the tagged gravels were reworked by beach ice and emplaced under sand-gravel mounds at depths beyond the PIT reader's detection limit. It is also possible that at spring some gravels were dragged offshore by retreating shorefast ice and melt water backwash. The 2007 survey showed no significant movements of the 25 tagged gravels injected at each of the berm sites, which is not surprising as the maximum 2006 summer storm surge was ~52cm AMTL. None of the random beach sand samples, collected in July 2007 along showed dyed grains, a likely consequence of combined action of intense dilution by untagged beach sands reworked by ice and removal offshore of the dyed sand by storm, melt water and ice backash. Our studies indicate that the assessment of the annual rate of sediment

transport along the north Alaskan arctic beach, using PIT-tagged gravel and fluorescent dyed-sand, has not been very successful, as tracking of the tagged particles has been precluded. However, as suggested by the 2006 summer investigations (Naidu et al., 2006), the PIT tag has potential use to assess the gravel drift rate during summer.

The second approach consisted of an attempt to measure, during July-September, 2006, the time-series of wave climate statistics of the ice-free zone north of Narwhal Island. The goal was to quantify the wave energy flux (wave power) and from it to compute the potential rate of transport of sand by alongshore currents. To achieve this goal, a Sontek Acoustic Doppler Current Profiler (ADCP) and directional wave gauge mooring was deployed on July 25, 2006 in 8m depth north of Narwhal Island. This attempt failed because of instrument malfunction. The ADCP system was redeployed on July 24, 2007 in 10m depth and retrieved on September 14, 2007. The computation of the sand transport rate is pending subject to synthesis of the wave climate statistics.

A time-intervals study of the Narwhal Island morphology indicates occurrence since 1955 of several breaches in the island and regrouping of the disjointed units. In the past 50 years, the western end of the island had migrated ~200m to the west which is consistent with the direction of sea-ice movement and coinciding with the frequent east winds during the open water summer. The net direction of migration was, however, inconsistent with the direction of storm surges which are mainly driven by winds from the NW. In addition, the island has retreated landward by ~5m/year during the past decade, which is close to the findings of others on several North Slope barriers.

Background/Relevance to Framework Issues

Since the discovery of oil in 1968 in the Prudhoe Bay region, the coastal and nearshore regions of the North Slope have been subjected to increasing industrialization from activities relating to the exploration and development of petroleum reserves. The initial focus of activities was onshore, but more recently the direction has shifted to the offshore. In support of the oil-related activities several coastal and offshore industrial infrastructures have been built (e.g., docks, causeways, offshore producing and drilling platforms, submerged marine pipelines), which will continue to grow with the expansion of the ongoing oil prospects and development of new tracts.

The possible cause-effect between the infrastructures and the natural nearshore sediment-and hydro-dynamic processes (wave, current and sea ice regimes, and storm surges), coastal geomorphology, barrier island stability, shoreline erosion, and littoral sediment drift are not fully known. The engineering structures built on the shoreline are bound to alter, to various extents, the natural regimes of wave-current-sea ice and sediment budget in the vicinity of the structures. For example, site-specific perturbations in the coastal circulation patterns and hydrography (salinity and temperature) have been reported to occur subsequent to the construction of the West Dock Causeway, NE of Prudhoe Bay and near the Endicott Causeway east of the Bay (Envirosphere Company, 1987; Hale et al., 1989). Some of these alterations are likely to impact the nearshore bathymetry and mass balance of sediments and sedimentary processes, such as enhancement down-current in the coastal erosion and depositional rates, the direction and volume of littoral sediment drift, and shift in the transport trajectories of suspended sediment plumes (Barnes et al., 1977; Barnes and Minkler, 1982; Naidu et al., 1984; Hale et al., 1989). These perturbations, in turn, could have practical consequences to the industry, such as a destructive impact on existing (or future) man-made infrastructures such as those reported widely for shorelines of the world (Shepard, 1973). For example, submerged pipelines in the North Slope region can be overburdened with sediment blanket, navigational channels - especially in between the barrier islands and/or docks - can be shoaled by enhanced sediment accumulation (Hale et al., 1989), and coastal engineering structures (causeways, docks, offshore drilling platforms, breakwater, groins) can be severely disrupted by the modified wave-current action. The nearshore region of north Arctic Alaska is a highly dynamic environment, with continuous changes in the coastal geomorphology marked, for example, by large-scale (6-28 m/yr) migration rates in barrier islands and spits (Wiseman et al., 1973; Barnes and Reimnitz, 1974; Dygas and Burrell, 1976a; Miller and Gadd, 1983) and significant shifts in longshore sediment drift, especially during episodic storms. With the predicted global climate warming and attended sea level rise and increased open water fetch resulting from sea ice retreat ((IPCC, 2001) some of the above concerns can be exacerbated.

Site-specific baseline information is available on wind-tide-wave-current and sediment movement and resuspension along the coast and littoral zone of north arctic Alaska (Matthews, 1970; Wiseman et al., 1973; Short et al., 1974; Dygas and Burrell, 1976a and 1976b; Nummedal, 1979; Owens et al., 1980; Barnes and Reimnitz, 1982; Miller and Gadd, 1983; Naidu et al., 1984; Kozo, 1984; Shi et al., 1985; Envirosphere Co, 1987; Hale et al., 1987 and references therein). Results of the seabed drifter experiments and OCSEAP projects having possible bearing on sediment transport, are synthesized in Barnes and Reimnitz (1982) and Barnes et al. (1984) respectively. However, the sediment investigations, which were focused in the Point Barrow, Pingok and Flaxman Island regions, were conducted far away from the Prudhoe Bay area where the petroleum-related activities are now concentrated in the North Slope.

In addition, all the estimates to-date on alongshore sediment drift in the North Slope are either based solely on theoretical deductions from wind-wave-current statistics (Dygas and Burrell, 1976a and 1976b; Nummedal, 1979) or study of historical charts and aerial photos ((Wiseman et al., 1973; Barnes and Reimnitz, 1974; Miller and Gadd, 1983). These assessments, however, have not been verified by actual field measurements (empirical) of the alongshore drift using, for example, tracers such as dyed-sand and tagged-gravel. Additionally, it is likely that the outcome of some of the site-specific studies referred to above cannot be extrapolated (thus, they are of limited practical use) to the region east of the Colville Delta (including our study site adjacent to Prudhoe Bay where the environmental setting is dramatically different (Naidu, 1975; Jorgenson and Brown, 2003). A point illustrating this concern is the results of the studies conducted along the Point Barrow Spit (Nummedal, 1979), where the net west to east current-wave direction is opposite to that generally prevailing east of the Colville Delta-Prudhoe Bay region. Although studies of time-series maps and air photos can offer valuable information on the net changes in the 2-dimensional geometry of shorelines and barriers and transport direction of alongshore sediment drifts, they cannot per se provide an accurate estimate of the volume or tonnage of the drift.

Some may suggest that results of the investigations conducted at temperate beaches and numerical models of alongshore sediment transport developed there are applicable to the North Slope. The processes at lower latitudes especially pertaining to sandy beaches are relatively well understood. However, the models of beach processes and calculation of littoral sediment drift developed for lower latitudes are of limited practical use at high-latitude where the environment is striking different. For example, in the Alaskan Beaufort Sea shore, where the coastal erosion rates are among the highest in the world, 1-10m yr^{-1} (Naidu et al., 1984; Reimnitz and Barnes, 1987), beaches are generally comprised of sand and gravel, and which are subjected to highly oblique wave angles during the open water season and 8-9 months of ice motion both above and below the still water level, the annual sediment transport regime can be dominated by these regional factors.

This report includes the progress of research in year 2 (September 2006- August 2007) of an ongoing 3-year project, the goal of which is to assess the direction and potential annual rate of alongshore transport of sand and gravel along the Narwhal Island, Prudhoe Bay region. The investigations conducted in year 1 were reported in Naidu et al. (2006). To meet the project's overall goal we have followed two approaches. The first approach consists of experiments conducted on Narwhal Island beach using sediment tracers [fluorescent dyed-sand and gravel tagged with tiny (12 mm long) Passive Integrated Transponder (PIT)]. The second approach includes theoretical computation of the sand transport rate based on time-series recordings of the direction of wave propagation and wave energy flux (wave power) and the resulting alongshore currents.

Objectives/Hypothesis

The specific objectives of the studies during the year 2 of the 3-year project are as follows:

Gather from NOAA the real-time statistics on the direction and speed of wind for the July-September, 2007 for Deadhorse (the weather station closest to the study site) and record, using an ACDP and wave directional gauge on a mooring, the wave climate statistics for the region seaward of the breaker zone north of Narwhal Island.

Determine from the above record the net direction of wave propagation, wave energy flux and alongshore current velocities, and from the database thus generated compute the potential alongshore sand transport rate.

Determine from beach experiments, using fluorescent-dyed sands and Passive Integrated Transponder (PIT)-tagged gravels, the seasonal alongshore direction and rate of transport of sand and gravel for the seaward beach of Narwhal Island.

The secondary objectives during the year 2 study are:

To map the baseline relief of Narwhal Island, by determining the surface profiles along selected transects across and along the length of the island using standard survey tools.

Understand the long-term morphodynamics of Narwhal Island, using time-intervals air photos, satellite images and historical maps (note: this task objective is not part of the ongoing CMI/ MMS contract, but is included in this report as a supplemental volunteer research, results of which will help to better understand the Narwhal Island's evolution on a long-term basis).

The underlying hypothesis is that, in the North Slope region the annual alongshore sediment drift is measurable by using tagged sand and gravel particles, and that estimation of the rate of alongshore sand transport is possible from the record of the wave climate statistics. An additional hypothesis is that the location and morphology of the Narwhal Island has been stable during the past ~50 years.

Study Area/Field Work

The study area consists of Narwhal Island, a microtidal (tidal amplitude ~11cm) mixed sand-gravel barrier island, and the adjacent nearshore north of the island. The island is located NE of Prudhoe Bay and Endicott Causeway in the Alaskan Beaufort Sea nearshore.

The first task in year 2 of the project consisted of all the prospective field participants to undertake the online training and tests to satisfy the safety, emergency, security and badge requirements mandated by the BP to work at their operational facilities in the North Slope.

Two approaches have been followed to determine the direction and rate of alongshore sediment transport. The first approach has been to determine empirically the seasonal directions and volumes of alongshore sediment transport, using fluorescence-dyed sands and gravels tagged with tiny (12 mm long) Passive Integrated Transponder (PIT) tags. Details on the principles governing the use of the tags and preparation of the sand and gravel samples for the above experimental study are enumerated in Naidu et al. (2006). Here, we recall briefly the field procedures followed during the first year (See Naidu et al., 2006 for details) to provide a background and link to this year's study and to facilitate better understanding of the tasks accomplished during the period of this report (year 2 of study).

In the first year the PIT- tagged gravels were grouped into four suites, each consisting of 50 individuals, and bagged. Prior to the departure to the field the ID number, discrete PIT tag code for each of the gravels in the individual suite, were identified (using the Biomark Destron Model FS2001 Reader). The Reader transmits radio frequency (RF) signals at 134.2 $kH_{z,}$ which are intercepted one at a time by a PIT tag and the corresponding ID number is relayed back to the Reader and displayed digitally on a window screen. Another four suites, each consisting of 6.5Kg of the Narwhal Island fluorescent dyed sands mixed with equal proportion of raw native sand (total 13kg sand mixture) were prepared. Each set of 50 gravels and 13kg of sand from the above suits were point injected at four seaward beach sites (set ~100m apart) at mid-tide level (MTL) on Narwhal Island. Additionally, a set of 20 tagged gravels were injected at each of the berm base located directly up beach across the MTL gravel sites The purpose of the latter was to determine the extent of gravel reworking and transport by storm surges.

The locations of the berm sites (1A, 2A, 3A and 4A) and beach sites (1B, 2B, 3B and 4B), which were established in 2006 with a GPS and marked by steel rebar stakes driven into the beach, are as follows:

Point	UTM Easting (m)	UTM Northing (m)
1A	480617	7810020
1B	480619	7810068
2A	480383	7810096
2B	480375	7810120
3A	480301	7810114
3B	480305	7810128
4A	480203	7810140
4B	480206	7810153

At beach and berm sites 1 and 2 the tagged gravels and dyed-sands were injected on June 30, 2006 and at the other two beaches and berm sites (3 and 4) the tagged particles were injected on July 26, 2006. Results of the field efforts of summer 2006, to assess the fate and transport rates of the tagged sand and gravel subsequent to their initial injection, are reported in Naidu et al. (2006). In the following are narrated the specific progress of the beach experiments subsequent to the submission of the above report.

On July 25, 2007 a survey was conducted around the four sites as a follow up of the monitoring work that was started in year 1 study. This survey included a visual search of and scanning the beach with the hand-held PIT tag Detector/Reader. The original plan was to conduct the survey at successively 1x1 meter grids, using a plastic frame moved east and west across and along the beach starting from the original point of discharge of the tagged sediments. However, this was not possible as the beach relief was marked throughout with irregular hummocky gravel mounds, which prevented laying of the frame flat and taking statistically meaningful samples of sands and scanning for the tagged gravel. During this survey only one of the 200 PIT-tagged gravels originally injected at MTL in 2006 was identified. The ID code number of the gravel was recorded and its location was established by measuring the distance and recording the direction (using a Brunton compass) of its position relative to the beach stake 1B. On September 13, 2007 a visual survey was conducted alongshore in the vicinity of the four beach sites, in attempting to locate the tagged gravels. During this survey the PIT tag reader was unavailable and the search for the gravels was guided by the bright orange paint that was coated on them at the time of injection. This survey failed to detect any of the tagged beach gravels, though several of the tagged gravels were found more or less in place at the berm site 1A. Six of the gravels from this site were bagged.

It is to be noted that most of the three field days, September 12-14, 2007 the weather was stormy (up to 25 knots wind) accompanied by high waves (average height of the breakers was 1.5-2 m), resulting in inundation of the four beach sites well into the surf zone and waves washing in several locations up over the island ridge and almost completely obliterating berm's sharp slope. There was considerable sorting and movement by waves of sand and gravel at this time throughout the island.

The second approach, as mentioned earlier, for determining the direction and rate of sand transport, is based on the determination, first, of the longshore wave energy flux (wave power) and direction of wave propagation and from this database computation of the potential rate of transport of the volume of sand, using the sand transport equations stated in the Manual of the Coastal Engineering Research Center, CERC (Rosati et al. 2002). This approach has involved recording during July 24-September 14, 2007, the time-series of wave climate statistics of the ice-free marine area in 10m water depth (~30ft) north of Narwhal Island and located at 70^o 24.0'N, 147^o 28.4'W. The recording was made by a University of Alaska Anchorage Sontek Acoustic Doppler Current Profiler (ADCP) and a wave directional gauge, mounted in a Barnacle^{tm} troll resistant housing. The deployment was from the Alaska Clean Seas tender under contract to the BP. The ADCP system has a directional wave gauge equipped with a pressure gauge capable of measuring the frequency, length and one-dimensional direction of waves. It is configured as a PUV gauge to make measurements at every successive two-hour intervals, which includes recording in the first two minutes of the dimensional current profile followed in the next 17mt the wave profile before it goes into hibernation. To determine the correlation between wind and wave climate statistics, time-series graphical plots on the speed and direction of wind and time coinciding for the period of the Barnacle/ACDP deployment has been collected from the NOAA's online database. We intend to follow up with the collection of the actual values of speed and direction of wind, which will be needed for the above correlation and eventual computation of the direction and rate of the wave-induced alongshore current and transport of sand. The Barnacle was retrieved successfully on September 14, 2007. The record, however, has not yet been downloaded and processed. Following this recovery, survey of the sea floor was conducted to record bathymetric profiles of the nearshore. This task was achieved along six longitudinal transects extending seaward from the shoreline on the west side of Narwhal Island. The intention was to extend the survey around the island, but foul weather precluded this attempt.

In addition to the above, on July 25 and September 13, 2007 topographical surveys of the Narwhal Island was conducted, using standard surveying (leveling) instrument, measuring tape and graduated staff, and employing GPS and total station surveying. The goal of these surveys is to monitor the changes in the island's 'baseline' topography which was established by us in summer 2006. The surveys were conducted along selected transects of the island crest and seaward beach and included repeating the 2006 mapping of the surface profiles along the transects. As a part of our overall investigations to better understand the morphodynamics of the Narwhal Island, including assessing the long-term net direction and rate of the island's migration, we have examined the time-intervals of air photos, satellite images and historical maps that are available since 1955 of the island.

Preliminary Results and Discussion

The beach surveys conducted on October 13, 2006 and July 25, 2007 adjacent to the four beach sites resulted in very poor recovery/detection of the PIT-tagged gravels. Only one tagged gravel out of the 200 gravels that were originally injected in June/ July 2006 was intercepted on July 25, 2007 and none on the October 13 survey. By the latter date the beach sediments were already blanketed with thick shorefast ice. The sole gravel sample was located at 29m west of site 1A. During the July 2007 survey we reworked randomly the gravel mounds located east and west adjacent to the four beach sites, in an effort to find any buried tagged-gravel, but this search proved futile. This was in contrast to the observation made on July 26, 2006, which yielded approximately 50% of the tagged gravel around site 1B and 30% around site 2B of the original 50 gravels discharged at each of these sites. Additionally, some of the tagged gravels then had drifted east and others west of the stake with generally a SE trend up to 8m of the marker stakes (Naidu et al., 2006). We are not sure of the fates of the 199 gravels remaining unaccounted for in the 2007 survey. It is quite possible that some tagged gravels remain undetected on the beach below the maximum depth of scanning by the PIT reader. It is also possible, as reported in the 2006 study (Naidu et al., 2006), that some others could have been dragged into the subtidal zone by melting shorefast ice or by the storm backwash. The other reason could be that the scanner fails to read tagged gravels that lie very close to each other. The October 2006 and July 2007 surveys also indicated that there have been no significant displacements of the tagged gravels since their injection in 2006 at the base of each of the berms. This finding is not surprising as the maximum 2006 summer storm surge was ~52cm or less and that the shorefast had not likely extended up to the berm base and, thus, precluded any reworking of the tagged gravels emplaced there.

Naidu et al. (2006) had reported that the July 26, 2006 survey in the vicinity of site 1B indicated a clump of the dyed-sands accompanied by a few tagged gravels were backwashed into ~1m subtidal zone off the site. That survey indicated also that a larger portion of the rest of the dyed sands was streaked at high-tide mark parallel to the shore, concentrated toward the west and extending ~2-3m up beach from the 1B site. However, the post-winter survey in July 2007 showed no evidence of such concentration of the dyed sands either aligned in a specific orientation or in any of the several random beach sand samples that were collected east and west of the site. We also did not observe any dyed sand concentrations about the other three beach sites in July 2007.Several possible reasons could be invoked to explain the lack of identification of the dyed-sand particles on the beach. It is suggested that one reason could be a consequence of dilution by mixing of relatively much larger proportion of untagged beach sand with tagged sand. Conceivably, such a thorough mixing could result from ice-reworking and mass shoving of beach deposits in winter, which would seem likely from the large-scale presence of beach sand and gravel mounds at the shoreward edge of ice. The other possible reason could be that the dyed-sand was lost into subtidal zone by backwash of storm waves, ice fragments and/or ice melt water during spring. It would, thus, seem that prolonged and haphazard reworking of beach sediment by shorefast ice and/or storm backwash could complicate or even preclude the assessment, using PIT tags and dyed sand, of the rate of littoral sediment transport along north Alaskan arctic beach.

The theoretical computation of the direction and rate of potential annual longshore sand transport is pending subject to processing of the data recorded by the Sontek ACDP system. A spectrum of time-series database has been recorded that includes significantly different wind and wave conditions and encompassing the early September 2007 storm.

The results of the topographic surveys of 2006 and 2007 of the Narwhal Island and the bathymetric survey conducted on September 14, 2007, have not yet been finalized into graphical format.

A preliminary database on time-interval changes in the morphology of Narwhal Island has been gathered, which indicates that the island has undergone major changes during the past 55 years, reflecting its instability and dynamic nature. In 1955, Narwhal island was a 4 km long and 30 to 200 m wide barrier, located at 145 30' W; 70 24' N, about 20 km offshore of the North Slope coast by Foggy Island Bay and near Prudhoe Bay. According to available aerial photography, by 1979, the island had been breached in 4 locations creating a five island chain. By 1984, the chain consisted of 3 pieces indicating a reformation process. In subsequent years, the chain appears to have gone through a couple of more cycles of breakup and reformation. The island is subject to wind waves, sea-ice impacts, and storm surges. Preliminary GIS analysis and recent GPS surveys indicate that, in the past 50 years, the western end of the island had migrated about 200m to the west consistent with the direction of sea-ice movement and consistent with the frequent east winds during the summer (open water) period The direction of migration was, however, not consistent with the available storm surge data which indicates that surges are mainly driven by winds from the northwest. In addition to the island's westward migration, the northern (seaward) side of the island has retreated landward by about 5m/year during the past decade. The net direction and rate of migration are consistent with the findings of earlier studies on barriers in the North Slope region.

Timeline (including deliverables)

There has been a significant delay in the start date of the project. The original start date as proposed was May 2005, but the formal contract from the MMS was not issued until September 6, 2005. Consequently, no significant field work could be conducted in 2005 and a successive cycle of delay developed. This has been exacerbated by the failure to retrieve any data from the ACDP mooring in 2006 because of instrument failure. Subsequent to this mishap a proposal was submitted to the CMI in 2007 requesting supplemental funding to redeploy the mooring system and continue to address our research goals and objectives as stated originally. Although the supplemental funding was approved in late September 2007 the funds were not made available until October. A sum total of all this has necessitated a revised timeline and a request for a no-cost extension of the project by one year from the start date to August 27, 2008.

Student Involvement

None during this reporting period.

Study Products

The readings of the ID codes of the PIT-tagged gravels that were intercepted in the field and their locations are available. The surface profiles obtained from the topographic surveys of the Narwhal Island along various transects, and the overlapping maps showing the time-interval changes in the morphology of the Narwhal Island are available tentatively in graphical format. Very soon the wave climate statistic data will be made available on a CD. A synthesis of this database will be forwarded to Dr. M. C. Miller for computation of the sand transport rate. The plots of the seafloor profiles recorded along six transects will be provided. Refer to the following section listing titles of abstracts submitted for the Annual AAAS Conference.

Preliminary Conclusions:

The major findings during the 2007 study are as follows:

1. The beach experiments, using tagged sand and gravel, offer limited scope to assess the annual alongshore sediment transport rate. However, the technique offers some scope for assessing the short-term direction and rate of alongshore gravel drifts providing the assessing is confined to one ice-free summer.

2. The recovery of the tagged gravels was generally very poor over the year. In 2 months of summer 30-50% of the tagged gravels were intercepted and they had moved ~8m/year from the injection point. In the following spring only one tagged gravel was identified among the 200 injected, and that gravel had moved ~29m westward from the injection point.

3. The fate of the tagged gravels from fall to spring is unknown. It is likely they got emplaced under gravel mounds shoved by winter shorefast ice, at depths beyond the maximum depth (0.5m) of scanning of the PIT reader. Alternatively, the gravels were lost to the subtidal zone by wave/ice backwash.

4. None of the dyed sands were identified in fall and spring beach samples, following their injection in the previous summer. Most likely they were either lost to the subtidal zone or diluted by mixing of ambient beach sand reworked by shorefast ice.

5. The 2007 survey showed no significant movements of the 25 tagged gravels discharged at each of the berm sites in summer 2006, which is not surprising as the maximum 2006 summer storm surge was ~52cm AMTL.

6. The Narwhal Island geomorphologic history indicates occurrence since 1955 of several breaches in the island and regrouping of the islets. In the past 50 years the island had migrated ~ 200m westward, and during the past decade had retreated landward by ~5m/year a trend similar to several North Slope barriers.

The theoretical computation of the alongshore sand transport rate is pending, subject to processing of the wave climate statistical data recorded in summer 2007.

Presentations

During this reporting period three Quarterly Reports were submitted to the CMI, and a Powerpoint talk on the progress of research was presented by Dr. Kelley at the 2007 CMI/MMS Annual Research Review on February 6, 2007.Additionally, the following two oral presentations were given in Anchorage.

Naidu, A. S., Kelley, J. J., Kowalik, Z., Lee W., Miller, M. C., Ravens, T. M., Smith, O. P. and Streever, W. 2007. Assessment of longshore transport rates of gravel and sand on Narwhal Island, north Arctic Alaska: approaches, challenges and progress. Proc. 58th Annual AAAS meeting, September, 2007, Anchorage.

Ravens, T. M., Naidu, A. S. and Lee W. 2007. Morphodynamics of a North Slope barrier island (Narwhal Island, North Arctic Alaska) 1955-2007. Proc. 58th Annual AAAS meeting, September, 2007, Anchorage.

Acknowledgements

This study has been funded by the Minerals Management Service, U. S. Department of the Interior through Cooperative Agreement 1435-01-98-CA-33090 (Task Order 0105T039380) between the MMS Alaska Region and the Coastal Marine Institute, University of Alaska Fairbanks. Matching funds were provided by the Institute of Marine Science, University of Alaska Fairbanks; the School of Engineering, University of Alaska Anchorage; the British Petroleum Exploration, Inc (Alaska), Anchorage; and the Coastal and Ocean Concepts, Sequim, Washington State.

Thanks are due to Tony D'Aoust for assistance in the field. Bill Streever, Environmental Studies Leader, BP Exploration, Inc (Anchorage) has been of great help by actively participating in the field measurements and beach surveys. The encouragements by Vera Alexander and M. Castellini, the respective past and present Directors of the CMI, R. Prentki (Project ROTC) and C. Cowles of the MMS (Anchorage) are appreciated.

Thanks are also due to Wilson Cullor and Dayne Haskell of BP (Anchorage) for arranging the field logistics, and to Kathy Carter, Mary Johnsen and Mary Herkstroeter in the report preparation and coordinating the project.

Literature Cited

Barnes, P. W. and E. Reimnitz. 1974. Sedimentary processes on arctic shelves off the northern coast of Alaska. In J. C. Reed and J. E. Sater (Eds.), The Coast and Shelf of the Beaufort Sea. Arctic Inst. North America, Arlington, VA, 439-475.

Barnes, P. W., E. Reimnitz, G. Smith and D. McDowell. 1977. Bathymetric and shoreline changes in northwestern Prudhoe bay, Alaska. Northern Engineer, 9:7-13.

Barnes, P. W. and P. W. Minkler. 1982. Sedimentation in the vicinity of a causeway groin, Beaufort Sea, Alaska. USGS Open File Rept. 82-615.

Barnes, P. W. and E. Reimnitz. 1982. Net flow of near-bottom waters on the inner Beaufort Sea shelf as determined from seabed drifters. USGS Open-File Rept. 82-717 pp.

Barnes, P. W., D. M. Schell and E. Reimnitz (Eds.). 1984. The Alaskan Beaufort Sea: Ecosystems and Environments. Academic Press, NY, 466.

Dygas, J. D. and D. C. Burrell. 1976a. Dynamic sedimentological processes along the Beaufort Sea coast of Alaska. In: In: D. W. Hood and D. C. Burrell (Eds.), Assessment of the Arctic marine environment: selected topics. Ocl. Pbl. 4, Inst. Marine Sc., Univ. Alaska, Fairbanks, AK, 189-203.

Dygas, J. A. and D. C. Burrell. 1976b. Response of waves and currents to wind patterns in an Alaskan lagoon. In: D. W. Hood and D. C. Burrell (Eds.), Assessment of the Arctic marine environment: selected topics. Ocl. Pbl. 4, Inst. Marine Sc., Univ. Alaska, Fairbanks, AK, 263-285.

Envirosphere Company, 1987. Endicott Environmental Monitoring Program. Final Rept. to U.S. Army Corps of Engineers, Alaska District, Anchorage, AK.

Greene, H. G. 1970. Microrelief of an Arctic beach. Jour. Sedimentary Petrology, 40:419-427

Hale, D. A., M. J. Hameedi, L. E. Hachmeister, and W. J. Stringer. 1989. Effects of the West Dock causeway on nearshore oceanographic processes in the vicinity of Prudhoe bay, Alaska. Rept. for the USEPA, Region 10, NOAA/OAD, U. S. Dept. Commerce, Anchorage, AK. 50 pp

Hume, J. D. and M. Schalk. 1967. Shoreline processes near Barrow, Alaska: a comparison of the normal and the catastrophic. Arctic (20):86-103.

IPCC (Intergovernmental Panel on Climate Change). 2001. IPCC Third Assessment Report- Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, U K. 639-693.

Jorgenson, T. and J. Brown. 2004. Classification of the Alaskan Beaufort Sea coast and estimates of sediment and carbon inputs from coastal erosion. In: V. Rachold and G. Cherkashov (eds.), Report 4th International Workshop on Arctic Coastal Dynamics, St Petersburg (Russia), Ber. Polarforsch. Meeresforsch, 482:32.

Kozo, T. L. 1984. Mesoscale wind phenomena along the Alaskan Beaufort Sea coast. In: In: Barnes, P. W., D. M. Schell and E. Reimnitz (Eds.). The Alaskan Beaufort Sea: Ecosystems and Environments. Academic Press, NY, 23-45.

Matthews, J. B. 1970. Tides at Point Barrow. The Northern Engineer. 2:12-13.

Miller, M. C. and P. Gadd. 1983. Shoreline processes near Flaxman Island, U. S. Beaufort Sea, Alaska. Proc. Workshop on Regional Coastal Erosion and Sedimentation Calgary, Alberta, pp. 69-91.

Naidu, A. S., T. C. Mowatt, S. E. Rawlinson and H. V. Weiss. Sediment characteristics of the lagoons of the Alaskan Beaufort Sea coast, and evolution of Simpson Lagoon. In: Barnes, P. W., D. M. Schell and E. Reimnitz (Eds.), The Alaskan Beaufort Sea: Ecosystems and Environments. Academic Press, NY, 275-292.

Naidu, S., J. Kelley, Z. Kowalik, W. Lee, M. Miller, and O. Smith. 2006. Assessment of the direction and rate of alongshore transport of sand and gravel in the Prudhoe Bay region, North Artic Alaska. Annual Report No.13, Coastal Marine Institute, Univ. Alaska Fairbanks, Fairbanks, AK, 1-10.

Nummedal, D. 1979. Coarse –grained sediment dynamics- Beaufort Sea, Alaska. Proc. 5th Conference on Port and Ocean Engineering under Ice Arctic Conditions, Trondheim, V.II:845-858.

Owens, E. H., J. R. Harper and D. Nummedhal. 1980. Proc. 17th Intn'l. Coastal Engr. Conf., ASCE/ Sydney, 1344.

Rosati, J., T. Walton and K. Bodge. 2002. Longshore Sediment Transport. In: Coastal Engineering Manual, Part III, Chapter 2. US Army Corps of Engineer, Engineering Research and Engineering Development Center (ERDC), Vicksburg, MS. EM 1110-2-1100 (Part III), 30 April 2002. 113 pp.

Shepard, F. P. 1973. Submarine Geology. Harper and Row, New York, NY.

Shi, N. C., L. H. Larsen and J. P. Downing. 1985. Predicting suspended concentration on continental shelves. Marine Geology, 62:

Short, A. D., J. M. Coleman, and L. D. Wright. 1974. Beach dynamics and nearshore morphology of the Beaufort Sea coast. Alaska. In J. C. Reed and J. E. Sater (Eds.), The Coast and Shelf of the Beaufort Sea. Arctic Inst. North America, Arlington, VA, 477-488.

Wiseman, Wm. J., J. M. Coleman, A.Gregory, S. A. Hsu, A D. Short, J. N. Suhayda, C. D. Walters, Jr., and L.D. Wright. 1973. Alaskan Arctic coastal processes and morphology. Louisiana State Univ., Coastal Studies Inst., Tech. Rept. 149, 171 pp.

Synthesis of Time-interval Changes in Trace Metals and Hydrocarbons in Nearshore Sediments of the Alaskan Beaufort Sea: A Statistical Analysis

Sathy A. Naidu
ffsan@uaf.edu
Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775

John J. Kelley
ffjjk@uaf.edu
Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775

M. Indira Venkatesan
indira@ucla.edu
Institute of Geophysics
& Planetary Physics
UCLA
Los Angeles, CA 90095

Debasmita Misra
ffdm1@uaf.edu
College of Engineering and Mines
University of Alaska Fairbanks
Fairbanks, AK 99775

Arny Blanchard
arnyb@ims.uaf.edu
Institute of Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775

Task Order: 39921

Abstract

The goal of the project is to consolidate, conduct statistical analyses and synthesize the trace metal and hydrocarbon data on nearshore sediments of the Alaskan Beaufort Sea. This synthesis has been restricted to data procured by Dr. A. S. Naidu of the Institute of Marine Science, UAF and his associates on their CMI/MMS- and OCSEAP-funded projects on nearshore sediments from Elson Lagoon (EL-), Colville Delta-Prudhoe Bay (BS-) and Beaufort Lagoon (BL-) region. The data comprises of a suite of trace metals [arsenic (As), barium (Ba), cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), manganese (Mn), nickel (Ni), Tin (Sn), vanadium (V), zinc (Zn) and mercury (Hg)] and hydrocarbons (normal and isoprenoid alkanes, triterpenoids, steranes, and polynuclear aromatic hydrocarbons, PAHs). The above analytes are selected because they are generally associated with contaminant inputs from petroleum-, municipal- and/or military-related activities. The specific objectives of the study are to gain better understanding of the distribution, sources (natural and anthropogenic), regional and time-interval differences of the metals and hydrocarbons, and extent of contamination of the region during the past 30 years. The above database has been synthesized; statistical analysis and interpretation are in progress. Results of the study will be useful to the formulation by Federal and State agencies of plans for coastal ecological risk assessment and management options, in context of contaminant inputs from the OCS gas and oil developmental activities in the Beaufort Sea.

Introduction

During the past 30 years there has been increasing industrial growth in the North Slope of northern Arctic Alaska, relating to the activities of exploration and development of the onshore and offshore petroleum reserves. Concurrent to this growth there has been increasing urbanization of the villages along the North Slope coast (e.g., Barrow, Kaktovik). Additionally, there have been military-related [Distant Emergency Warning (DEW) line stations, rocket firing experiments] and enhanced municipal activities (sewage-treatment, power-generation, gravel mining). The petroleum-related developmental tasks include seismic surveys, drilling from onshore and offshore platforms, marine boat traffic, building of causeways, laying of submarine pipelines, among others. It is likely that these activities have affected the natural environment, but the extent of the possible perturbations is unknown. There is a concern that such anthropogenic activities may lead to contamination of the environment with metals and hydrocarbons, which could have a deleterious impact on marine biota. More recent concern relates to the Arctic National Wildlife Refuge (ANWR), particularly the 1.5 million acre coastal plain, which has potential petroleum reserves (titles the 1002 area). This region is one of the most contentious areas for oil drilling, because of the presence of a variety of wildlife habitats (Douglas et al., 2002). The major goal of this study is to assess the historical changes in heavy metals and hydrocarbons, with an objective to identify contamination in the nearshore of the Alaskan Beaufort Sea following recent anthropogenic activities. Selected hydrocarbon biomarkers (i.e., individual n-alkanes from nC-13 to nC-33, pristine, phytane, naphthalene and its monomethyl isomers, phenanthrene, fluoranthene, pyrene, benzanthraacene, chrysene, benzofluoranthenes, indenopyrene, perylene, benzo(ghi) perylene, 17α(H),21β(H)- and 17β(H),21β(H)-hopanes, diploptene), and the stable carbon and nitrogen isotopes of sediments (Naidu et al., 2000), that are available from Dr. Naidu's MMS-funded projects for 2001, 2003 and 2005 will help assess the loadings from different sources such as land plant input, petroleum and combustion.

It has been theorized that polar food chains are relatively sensitive and susceptible to contaminants, as discussed in Chapman and Riddle (2005). Several environmental factors unique to the Arctic may specially contribute to higher levels of contaminant accumulation and biomagnification of toxic metals and organics. For example, the arctic marine organisms which are lipid-rich are prone to especially accumulate lipophilic (fat loving) contaminants and the relatively short/simple linear food chains of the Arctic can transfer contaminants readily from the lower to the higher trophic levels resulting in contaminant biomagnification in marine subsistence food sources (Ayotte et al., 1995; Mulvad et al., 1996; Johansen et al., 2000 and references therein). Additionally, extended period in the sensitive early life stages of organisms including brooding, resulting from slow development time, and "the consequences of the epontic (under ice) life style to contaminant exposure pathways"-- in conjunction with summer phototoxicity-- has a potential to especially lead to higher contaminant bioaccumulation in the Arctic (Chapman and Riddle, 2005).

Background and Rationale

Responding to the above concern, several investigations have been conducted since early 1970s to gather time-intervals data on metals and hydrocarbons in north Alaskan arctic nearshore sediments, with an objective to monitor contaminants. Marine sediments were preferred for this task as they represent a suitable environmental integrator and sink for particle-reactive contaminants (Forstner and Witmann, 1979; Chapman et al., 1998). Impacted sediments could be a major source of contaminants to the benthos (Geffard et al., 2002; Lee and Wiberg, 2002; Mountouris et al., 2002) and other organisms, which have a close link with sediments (Naidu et al., 2001 and references therein). The earliest quantitative data on trace metals available for the nearshore sediments of the Alaskan Beaufort Sea are those collected under the auspices of the projects funded by the EPA-Alaska Sea Grant, U.S. Geological Survey, and Outer Continental Shelf Environmental Assessment Program (OCSEAP) (Naidu and Mowatt, 1975; Sweeney, 1984; Sweeney and Naidu, 1989). Subsequent regional investigations (Elson Lagoon, Colville Delta-Prudhoe Bay, and Beaufort Lagoon) on sediment trace metals, funded by the Minerals Management Service (MMS) and Coastal Marine Institute (CMI), were by Boehm et al. (1987), Crecelius et al. (1991), Naidu et al. (2001, 2003, and 2005), and Misra et al. (2006). Additional site-specific studies were conducted to assess the environmental impact of discharge of metals entrained in drilling effluents (Northern Technical Services, 1981; Snyder-Conn et al., 1997) and of activities near offshore drilling platform (Trefry et al., 2003). Several investigations funded by the OCSEAP, MMS and CMI provide baselines and post-industrial time-intervals data on hydrocarbons (n-alkanes, polycyclic aromatic hydrocarbons, triterpanes and steranes) in nearshore sediments of the North Slope region (Shaw et al., 1979; Venkatesan and Kaplan, 1982; Boehm et al., 1987; Steinhauer and Boehm, 1992; Naidu et al., 2001, 2003, 2005).

It is clear from the above review that substantial high quality database exist on the concentrations of trace metals and hydrocarbons in the nearshore sediments of the Alaskan Beaufort Sea. This is a region of intense industrial and municipal activities relating to ongoing and prospective oil fields. However, no effort has been made to compile and consolidate all the trace metal and hydrocarbon data into a Metadata form, assess the quality of the data collected in individual studies, and conduct rigorous statistical analysis on all the metal and hydrocarbon inventories gathered to-date. Some attempts made so far to understand the sources (anthropogenic and natural) of metals and hydrocarbons and geochemical processes/pathways are limited to specific project areas. It is possible that regional differences exist in nearshore sediment metal and hydrocarbon chemistries along the region, but this has not been verified through rigorous statistical analyses. Further, no attempt has been made to assess if there are any significant correlations between the contents of the individual trace metals, hydrocarbon biomarkers and some physicochemical sediment parameters (grain size distribution, organic carbon and organic matter contents and their carbon and nitrogen isotopic compositions, for example). This information would be important to improve understanding of the concentrations, distribution, sources and geochemical partitioning of the metals and hydrocarbons. Also regional disparities in the sediment chemical data have not been statistically examined in context of the regional differences in the chemical composition of possible sources, such as coastal snow samples (proxy for atmospheric contaminant source inputs) and several possible terrigenous sources. We believe that without a systematic statistical analysis of the existing chemical data on site-specific and regional scale it will be difficult to assess any regional differences in the database in context of potential sources, extent of anthropogenic contaminants and their possible provenances, and to understand the geochemical processes that govern the differences.

Marine lithogenous sediments are a composite of a complex mixture of several subcomponents derived from genetically different sources and of contrasting compositions [e.g., particulates with a range of grain sizes (gravel to clay) with differences in mineralogy, and contents of organic carbon/matter, oxides/hydroxides of Fe and Mn, among others]. The relative fractional differences in the abundances of these subcomponents can result in disparities in the trace metal and hydrocarbon concentrations in gross sediments. Thus, comparison of the chemistries of different sediment types becomes meaningless unless the chemistries of sediments of various compositions are normalized to the subcomponents. In this context, several sediment subcomponents (Al, Li, Fe, per cent mud, organic matter, granulometry) have been used for normalizing trace metal and hydrocarbon abundances (Loring, 1991; Daskalakis and O'Connor, 1995; Naidu et al., 2001;Trefry et al., 2003; Mucha et al., 2005). The Technical Scientific Committee (TSC) of CMI/MMS has commented that we consider the recommendations included in the numerous reports by Battelle on the Arctic Nearshore Impact Monitoring in the Development Area (ANIMIDA) and the Beaufort Sea Monitoring Program (BSMP) projects in the North Slope for normalizing the trace metal concentrations reported in our MMS-funded studies to Al or Fe, and those on hydrocarbons to organic matter or organic carbon. An example normalizing the trace metal concentrations to Al of the North Slope nearshore sediments is included in Trefry et al. (2003). The use of Al is based on the premise that it is a measure of the clay (aluminosilicate) content and, thus, also a reliable proxy for granulometric variation between sediments. The stated logic is that more the Al would mean a higher fraction of clay in the gross sediment which, in turn, will lead to greater scavenging of particle-reactive trace metals. Although Al has been used widely for normalizing sediment chemistry there can be short falls occasionally in its sole application, such as when there are other subcomponents (organic matter and/or oxides/hydroxides of Fe and Mn) equally appropriate for normalizing to. The sole use of Fe is also beset with problems. The use is based on the assumption that most of the sediment Fe is bound in oxide/hydroxide phase which is very prone to adsorbing particle-reactive metals. This may not be true as significant amount of the total Fe in sediment can be tightly bound in crystal lattice of relatively inert refractory minerals (magnetite, hematite, ilmenite, ferromagnesian silicates), which have relatively low capacity to adsorb trace metals.

To resolve the above problem Naidu et al. (2001, 2003, 2005) and others, for example, Boehm et al. (1987) in their BSMP studies, have preferred to analyze trace metals in the mud fraction (<63µm size) of nearshore sediments from the North Slope region. The justification is that the mud fraction, which almost invariably concentrates the Fe oxide/hydroxide, organic matter, Al, clay minerals, will also have the largest capacity to bound trace metals relative to coarser particles. We will, thus, include in this synthesis, the trace metal database in the mud fraction from the MMS-funded projects (Boehm et al., 1987; Naidu et al., 2001, 2003, 2005). In case of Dr. Naidu's OCSEAP trace metal data, which are based on the gross sediments (Naidu, 1982; Sweeney, 1984; Sweeney and Naidu, 1989), we have normalized those to the mud fraction so that they can be integrated into and made compatible with the database that have been obtained in the MMS projects. All the hydrocarbons data on MMS-funded projects in the

Beaufort Sea nearshore are on gross sediments. As recommended by the MMS/TSC we have normalized the hydrocarbon database to organic matter contents, which are available in the Final Reports submitted to the MMS (Boehm et al., 1987; Naidu et al., 2001; 2003; 2005).

Objectives/Hypothesis

Objectives: Our overall objective is to consolidate and synthesize all the data gathered by Dr. Naidu and associates on their CMI/MMS- and OCSEAP-funded projects on a suite of trace metals [arsenic (As), barium (Ba), cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), manganese (Mn), nickel (Ni), Tin (Sn), vanadium (V), zinc (Zn) and mercury (Hg)] and hydrocarbons (normal and isoprenoid alkanes, triterpenoids, steranes, and polynuclear aromatic hydrocarbons, PAHs) that are available (published, unpublished reports) on surface sediment samples of the nearshore of the North Slope of Arctic Alaska. The specific objectives are to (i) evaluate the quality of the data, in context of the guidelines stipulated by the NOAA (ii) conduct statistical analysis of the data to identify local and regional differences, distribution pattern(s) and assess the time-intervals and historical changes in the trace metals, and (iii) assess changes in the above variables in context of the regional variations and differences within individual study areas in natural sources and anthropogenic contamination.

Hypothesis: The overall hypothesis of our study is that the nearshore region of the North Slope has remained a relatively pristine environment and free of contaminants, despite the petroleum-related industrial, municipal and military activities during the past 30 years. An additional hypothesis is that there are no significant regional differences in the trace metal and hydrocarbon concentrations in sediments.

Methods/Analyses

Database (Source and Normalization): The area for this synthesis has been limited to the marine region extending from the shore to about 15 km seaward including the Federal OCS region that begins 4.83 Km beyond the coast. This region encompasses either operating, future oil prospects, or slated oil lease sale areas. The first task was to develop a bibliography, using computer or library search of potential sources, on the published and unpublished reports and database on the concentrations of trace metals (As, Ba, Cd, Cr, Cu, Pb, Mn, Ni, Sn,V, Zn and Hg) and hydrocarbons (normal and isoprenoid alkanes, triterpenoids, steranes, and polynuclear aromatic hydrocarbons, PAHs) in nearshore sediments and of representative fluvial systems, crude and natural oil seeps of the north arctic Alaska.

Following the recommendations of the TSC our synthesis has been restricted to trace metal and hydrocarbon data on sediments gathered by Dr. Naidu and associates on their CMI/MMS- and OCSEAP-funded projects on the Colville Delta-Simpson Lagoon-Prudhoe Bay (Naidu, 1982; Sweeney and Naidu, 1989; Naidu et al., 2001), Elson Lagoon (Naidu et al., 2003) and Beaufort Lagoon (Naidu, 1982; Naidu et al., 2005). Database that are available (Naidu et al., 2001, 2003, 2005 and references therein) include trace metals and hydrocarbons listed above for a number of sites along the coastal waters of Beaufort Sea [Elson Lagoon (N= 3), Colville Delta-Simpson Lagoon-Prudhoe Bay-Barter Island (N= ~100), Beaufort Lagoon (N= ~42)]. We have ascertained that for the statistical analysis (regional and time-interval comparison, trend analysis, PCA) the data from all the above investigations are compatible with each other, as discussed in the following.

To achieve our goal, we have compared the time-interval concentrations of each of the heavy metals between decadal collections where available (1975 to 2005). To make this comparison valid, the levels of variability within samples, sites, and regions need to be assessed and accounted for. Further, the comparison between regions (and within a region) will be compatible only if the data are normalized against variables that influence the sediment chemistry. As mentioned earlier we have normalized all the trace metal data to the percent mud fraction (<63 μm size) of the sediments, and the hydrocarbon data to organic matter in sediments.

Statistical Analyses: Multivariate methods were used to elucidate trends among stations for the metals data. Cluster analysis and principal components analysis (PCA) were used to assess similarity among stations based on available metals data. Since metal sampling varied from year-to-year and among regions, analyses were split into the major regions and analyses based on the metals measured at all sites within regions. For the Beaufort Lagoon region, seven metals, Cr, Cu, Fe, Mn, NI, V, and Zn, were measured at all stations. For the Beaufort Sea region, six metals, Ba, Cd, Cr, Cu, V, and Zn, were available. Concentrations were ln-transformed prior to multivariate analyses. Bubble plots of metals concentrations and environmental variables were generated using the first two axes of the PCA analysis. Analyses were performed using the statistical programs R and Statistica. The package Vegan () for R was used to perform the PCA for the metals data, fit the environmental variables to the stations ordination, extract the axes, and plot the overlays.

Principal components analysis was used to elucidate trends among stations for the hydrocarbon data. The PCA analyses were performed to distinguish natural and anthropogenic sources of inputs. Analyses of the hydrocarbon data were also separated by region. Concentrations were ln(X+1) transformed prior to multivariate analyses. The value "1" was added due to zero values in the data set.

The synthesis of the data as outlined above should help in better understanding the geochemistry of the region in its entirety. The results of these analyses are expected to document differences in regions sampled, similarity to anthropogenic and natural sources, changes over three decades, and sources of error (e.g., analytical, sampling, and natural error) and associated levels of variability.

Results and Discussion

QA/QC of the Database: We believe that the QA/QC of the analytical methods adopted for the determination of the sediment trace metals and hydrocarbons contents is excellent, based on the procedures followed (Naidu et al. 2001, 2003 and 2005), which included successful participation by the analytical laboratories in the interlaboratory calibration exercises conducted by NOAA. Statistical procedures described are widely accepted and have been applied to similar studies in Alaska (Naidu et al., 1997, Blanchard et al., 2002).

The data on the trace metals and hydrocarbons has been tabulated separately in the Microsoft Access database, delineating the database by study areas and years of collection [cf. ftp://ftp.sfos.uaf.edu/naidu/cmistat2007/]. This database has also included data, corresponding to each of the samples analyzed, on other sediment variables (station coordinates, water depths, sediment grain size, organic matter and water contents, stable isotopes of carbon and nitrogen) that are deemed useful as factors influencing the concentrations of the metals and hydrocarbons and which will supplement interpretation of the sources of the chemicals involved. Data on the above variables are available with us for all of the MMS and OCSEAP samples corresponding to the trace metal and hydrocarbon database (Naidu and Mowatt, 1975; Naidu, 1982, 1985; Boehm et al., 1987; Naidu et al., 2000, 2001, 2003 and 2005).

Statistical Analysis of Heavy Metals: The multivariate analysis of the data for 1977 and 1985 suggests minor differences in the regions sampled in that time period. Beaufort Lagoon sites (BL-) tend to be clustered separately from Colville Delta-Prudhoe Bay (referred to as Beaufort Sea in the Figures and Tables for ease) sites (BS-) in the dendrogram from cluster analysis (Fig. 1). The regions also position separately in the principal components analysis (PCA) (Fig. 2) but the separation is not strong. The four variables in common with the Colville Delta-Prudhoe Bay sampling locations from 1977 to 1985, chromium, copper, vanadium, and zinc, are highly correlated as indicated by their similar positions in the PCA variable projection (Fig. 2).

The multivariate analysis of the data for 1999 and 2003 suggests slightly larger differences in the regions sampled in that time period due to the inclusion of Elson Lagoon. The Beaufort Lagoon (BL-) and Elson Lagoon (EL-) sites tend to be clustered separately from Colville Delta-Prudhoe Bay sites (BS-) in the dendrogram from cluster analysis (Fig. 3). The regions also position separately in the principal components analysis (PCA) (Fig. 4) but the separation is not strong for the Beaufort Lagoon and Colville Delta-Prudhoe Bay locations. The Elson Lagoon sites are more distinctly separate from the other locations. Most of the variables in common with the Colville Delta-Prudhoe Bay sampling locations from 1999 to 2003 are highly correlated as indicated by their similar positions in the PCA variable projection (Fig. 4). The exceptions are barium and cadmium.

Whisker plots of selected metals suggest some change in concentrations over time. Barium concentrations were low in 1985 and significantly increased in 1999 to 2003 (Fig. 5). Cadmium concentrations increased in the Colville Delta-Prudhoe Bay from 1985 to later years with the exception of Elson Lagoon 2001 (Fig. 5). Sediment concentrations of copper also increased over time with significant increases over the period 1977 to 2003. A temporal variation of barium, cadmium, and copper (Fig. 6) suggest that there has been increase in concentration of all three over the last three decades in the Beaufort Sea. However, whether these increase are statistically significant or have any causative origin is yet to be assessed.

Correlations of metals to environmental parameters indicate little trend among metals and additional sediment parameters. For 1977 to 1985, there is moderate evident of a spatial trend in metals as only copper has a moderate correlation with Latitude and Longitude (Table 1). Zinc has a smaller but non-negligible spatial trend as suggested by this metals weak association with Latitude and Longitude. All four metals are highly correlated with PCA Factor 1, as indicated by the PCA variable projection (Table 1, Fig. 2). Vanadium is moderately correlated with mud indicating that environmental associations are important. PCA Factor 1 is most highly correlated with Latitude and Longitude, again suggesting moderate spatial trends in the data (Table 2). For 1999 to 2003, there is greater evidence of spatial trends in metals concentrations as 3 of the metals sampled in 1977 to 1985 are moderately correlated to Latitude and Longitude in 1999 to 2003 (Table 3). Zinc and Arsenic are moderately correlated to percent organic matter in 1999 to 2003 and a number of metals are moderately associated with CO_3. Most metals are strongly correlated with PCA Factor 1 with the exception of barium and cadmium. Barium is weakly correlated to both PCA factors and cadmium is highly correlated with Factor 2. Factor 1 for 1999 to 2003 is weakly correlated to Latitude and Longitude and more strongly associated with CO_3 whereas Factor 2 has moderate correlations with Latitude, Longitude, and CO_3 (Table 4).

Preliminary Conclusion

The preliminary statistical analyses suggest that there is a substantial spatial influence on the heavy metal concentrations in the Beaufort Sea nearshore as suggested by examination of data gathered over the three-decade period of investigation. The changes over time appear small, overall, and may be due to the inclusion of the limited database from Elson Lagoon in the later period. However, some metals do increase from the earlier to the later sampling periods. The reasons for these increases have not been resolved, but could be due to anthropogenic intervention and/or to time-interval differences in sediment types. The spatial trends (correlations to Latitude and Longitude) appear to be slightly weaker in the later sampling period, but the stronger association of the PCA axes to CO_3 is a matter that needs to be assessed further.

Correlation analyses between selected hydrocarbons such as 23 n-alkane (Algal source), 27 n-alkane (Terrestrial, e.g., higher plant origin), 30 ββ-hopane (Bacterial origin), Fluoranthene and Pyrene (Combustion origin), C2 (dimethyl)phenanthrenes/anthracenes and C2 (dimethyl) naphthalene (Petroleum origin) and Perylene (Diagenetic origin) and selected heavy metals would help inferences on the sources of the metals and extent of their contamination due to anthropogenic activities. Such analyses are in progress.

Future Plans

The results of the statistical analyses are currently being interpreted. Results of the statistical analyses (linear regressions, ANOVA, cluster dendrograms, Principal Component Analysis and Stepwise Multiple Discriminant Analysis plots, student "t" test, among others) will be submitted to CMI either in computer-aided graphic or tabulated form incorporated in an electronic file. The data will also be available at ftp://ftp.sfos.uaf.edu/naidu/cmistat2007/.

The Final Report will synthesize all the data, interpret and discuss the possible reasons for variations in metal and hydrocarbon chemistries between the regions and within individual study areas, especially in context of sources, likely geochemical processes and anthropogenic contamination. We intend to publish the results in at least two peer-reviewed journals, one relating to the trace metals and the other to hydrocarbons.

Study Products

- Data on trace metals and hydrocarbons on sediments have been tabulated in the Excel spreadsheet and transferred to a Microsoft Access database and is accessible from the following website,
- ftp://ftp.sfos.uaf.edu/naidu/cmistat2007/
- The database includes the location coordinates and water depth, grain size distribution, organic carbon/organic

matter, water contents, carbon and nitrogen isotopes on organic fraction of sediment corresponding to each of the sample station. Additionally, the data sets have been delineated into study areas and year of study.

- As required by the CMI, the Quarterly Progress reports per the timeline have been submitted for the last three quarters.
- CMI Annual Research Review Presentation on February 6, 2007.
- Presentation entitled, "A Synthesis of Three Decades of Investigations On Heavy Metals in Coastal Sediments of North Artic Alaska" was presented by D. Misra (co-authored by A.S. Naidu, J.J. Kelley, M. I. Venkatesan, and F.J. Mueter) during the 2006 Annual Meeting and International Conference of the American Institute of Hydrology in Baton Rouge, LA (May 21-24).
- Misra, D., S.A. Naidu, J.J. Kelley, M.I. Venkatesan, and F. J. Mueter, 2006. Heavy Metals and Hydrocarbons in Beaufort Lagoon Sediments, North Arctic Alaska. In: Coastal Environment and Water Quality (eds. Xu, Y.J. and Singh V.P.), Water Resources Publications, LLC, Highlands Ranch, CO, USA, ISBN 1-887201-47-5, pp. 3-16.

Acknowledgments

This study has been funded by the Minerals Management Service, U.S. Department of the Interior through Cooperative Agreement 1435-01-98-CA-33090 (Task Order 39921) between the MMS Alaska Region and the Coastal Marine Institute, University of Alaska Fairbanks. Matching funds were provided by the Institute of Marine Science and the College of Engineering and Mines, University of Alaska Fairbanks, and the University of California, Los Angeles. The continued encouragement by Mike Castellini, Director, CMI, and the excellent cooperation of Kathy Carter and Mary Johnsen of CMI, Kate Wedemeyer, Cleve Kowles, and N.R. Prentki of MMS Anchorage, throughout this study is appreciated.

Literature Cited

Ayotte, P. E., E.Dewailly, S. Bruneau, H. Careau and A. Vezina. 1995. Arctic air pollution and human health: what effects should be expected? Sci. Total Environ., 160/161:529-537.

Blanchard, A. L., H. M. Feder, and D. G. Shaw. 2002. Long-term investigation of benthic fauna and the influence of treated ballast water disposal in Port Valdez, Alaska. Mar. Poll. Bull., 44:367-382.

Boehm, P.D., M. Steinhauer, E. Crecelius, J. Neff and C. Tuckfield. 1987. Beaufort Sea Monitoring Program: Analysis of trace metals and hydrocarbons from outer continental shelf (OCS) activities. Anchorage, AK, USDOI, MMS, Alaska OCS region. OCS Study MMS 87-0072. Final Report to MMS. 2 vols.

Chapman, P. M., F. Wang, C. Janssen, G. Persoone and H. E. Allen. 1998. Ecotoxicology of metals in aquatic sediments: binding and release, bioavailability, risk assessment and remediation. Ca. J. Fish. Aqat. Sci., 5:2221-2243.

Chapman, P. M. and M. J. Riddle. 2005. Polar marine toxicity – future research needs. Mar. Pollu. Bull., 50:905-908.

Crecelius, E.A., J.H. Trefry, M.S. Steinhauer and P.D. Boehm. 1991.Trace metals in sediments from the inner continental shelf of the western Beaufort Sea. Environ. Geol. Water Sci. 18:71–79.

Daskalakis, K.D., and T.P. O'Connor. 1995. Normalization and elemental sediment contamination in the coastal United States. Environ. Sci. Technol. 29:470–477.

Douglas, D.C., P.E. Reylonds, and E.B. Rhode. (eds.). 2002. Arctic Refuge Coastal Plain Terrestrial Wildlife Research Summaries. Biological Sciences Report, USGS/BRD/BSR-2002-0001, U. S. Geol. Survey, Reston, VA. pp.75.

Forstner, U. and G.T.W. Wittman. 1979. Metal Pollution in the Aquatic Environment. Springer-Verlag, Berlin. 486 pp.

Geffard, O., H. Budzinski, E. His, M.N.L. Seaman and P. Garrigues. 2002. Relationships between contaminant levels in marine sediments and their biological effects on embryos of oysters, Crassostrea gigas. Environ. Toxicol. Chem., 21:2310-2318.

Johansen, P., D.C.G. Muir and J. Law. 2000. Contaminants in the Greenland environment. Sci. Total Env., 245:1-2.

Lee, H. J. and P. L.Wiberg. 2002. Character, fate, and biological effects of contaminated, effluent-affected sediment on the Palos Verdes margin, Southern California: an overview. Cont. Shelf Res., 22:835-840.

Loring, D.H. 1991. Normalization of heavy-metal data from estuarine and coastal sediments. ICES J. Mar. Sci. 48:101–115.

Misra, D., S.A. Naidu, J.J. Kelley, M.I. Venkatesan and F.J. Mueter. 2006. Heavy Metals and Hydrocarbons in Beaufort Lagoon Sediments, North Arctic Alaska. In: Coastal Environment and Water Quality (eds. Xu, Y.J. and Singh V.P.), Water Resources Publications, LLC, Highlands Ranch, CO, USA, pp. 3-16.

Mountouris A., E. Voutsas and D. Tassios. 2002. Bioconcentrations of heavy metals in aquatic environments: the importance of bioavailability. Mar. Pollu. Bull., 44:1136-1141.

Mucha, A.P., C.M. Almeida, A.A. Bordalo and M.T. Vasconcelos, 2005. Exudation of organic acids by a marsh plant and implications on trace metal availability in the rhizosphere of estuarine sediments, Estuar. Coast. Shelf Sci., 65:191–198.

Mulvad, G., H.S. Pedersen, J.C. Hensen, E. Dewailly, E. Jul, M.B. Pedersen, B. Bjerregaard, G.T. Malcom, Y. Deguchi and J.P. Middaugh. 1996. Exposure to Greenlandic Inuit to organochlorines and heavy metals through the marine food-chain: an international study. Sci. Total Environ., 186:137-139. .

Naidu, A.S. 1982. Aspects of size distributions, clay mineralogy and geochemistry of sediments of the Beaufort Sea and adjacent deltas, North Arctic Alaska. Final report to NOAA–OCSEAP Office, Boulder, Colorado. 114 p.

Naidu, A. S. and T.C. Mowatt. 1975. Aspects of size distributions, mineralogy and geochemistry of deltaic and adjacent shallow marine sediments, North Arctic Alaska. In V. Alexander and 15 others, Environmental studies of an arctic estuarine system – Final Report, EPA-660/3-75-026, U. S. EPA,Corvallis, Or.143-205.

Naidu, A.S., L.W. Cooper, B.P. Finney, R.W. Macdonald, C. Alexander and I.P. Semiletov. 2000. Organic carbon isotope ratios ($\delta^{13}C$) of Arctic Amerasian continental shelf sediments. In R. Stein [ed.], Circum-Arctic River Discharge and Its geological Record, Int. J. Earth Sci., Spec. Issue, Vol. 89: p. 522–532.

Naidu, A. S., J.J. Goering, J.J., Kelley, and M.I. Venkatesan. 2001. Historical changes in trace metals and hydrocarbons in the inner shelf sediments, Beaufort Sea: prior and subsequent to petroleum-related developments. Final Report to Coastal Marine Institute, Univ. Alaska Fairbanks, Fairbanks, AK. OCS Study MMS 2001-061. Pp.80.

Naidu, A. S., J.J. Kelley, J.J., Goering and M.I. Venkatesan. 2003.Trace metals and hydrocarbons in sediments of Elson Lagoon (Barrow, Northwest Arctic Alaska) as related to Prudhoe Bay industrial region. Final Report submitted to Coastal Marine Inst., Univ. Alaska Fairbanks, Fairbanks, AK. Pp. 33.

Naidu, A. S., J.J. Kelley, D. Misra.and M.I. Venkatesan. 2005. Trace metals and hydrocarbons in sediments of the Beaufort Lagoon, Northeast Arctic Alaska, exposed to long-term natural oil seepage, recent anthropogenic acivities and pristine conditions. Final Report to Coastal Marine Institute, Univ. Alaska Fairbanks, Fairbanks, AK. In Press.

Northern Technical Services. 1981. Beaufort Sea Drilling Effluent Disposal Study. NORTECH, Anchorage, 329 pp.

Shaw, D.G., D.J. McIntosh and E.R. Smith. 1979. Arene and alkane hydrocarbons in nearshore Beaufort Sea sediments. Estuar. Coast. Mar. Sci. 9:435–449.

Snyder-Conn, E., J.R. Garbarino, G.L.Hoffman and A.Oelkers. 1997. Soluble trace elements and total mercury in arctic Alaskan snow. Arctic 50:201–215.

Steinhauer, M.S., and P.D. Boehm. 1992. The composition and distribution of saturated and aromatic hydrocarbons in nearshore sediments, river sediments, and coastal peat of the Alaskan Beaufort Sea: Implications for detecting anthropogenic hydrocarbon inputs. Mar. Environ. Res. 33:223–253.

Sweeney, M.D. 1984. Heavy Metals in the Sediments of an Arctic Lagoon, Northern Alaska. M.S. Thesis, Univ. of Alaska Fairbanks, 256 p.

Sweeney, M.D., and A.S. Naidu. 1989. Heavy metals in the sediments of the inner shelf of the Beaufort Sea, northern arctic Alaska. Mar. Pollut. Bull. 20:140–143.

Trefy, J.H., R.D. Rember, R.P. Trocine and J.S. Brown. 2003. Trace metals in sediments near offshore oil exploration and production sites in the Alaskan Arctic. Env. Geology, 45:149-160.

Venkatesan, M.I. and I.R. Kaplan. 1982. Distribution and transport of hydrocarbons in surface sediments of the Alaskan outer continental shelf. Geochim. Cosmochim. Acta 46:2135–2149.

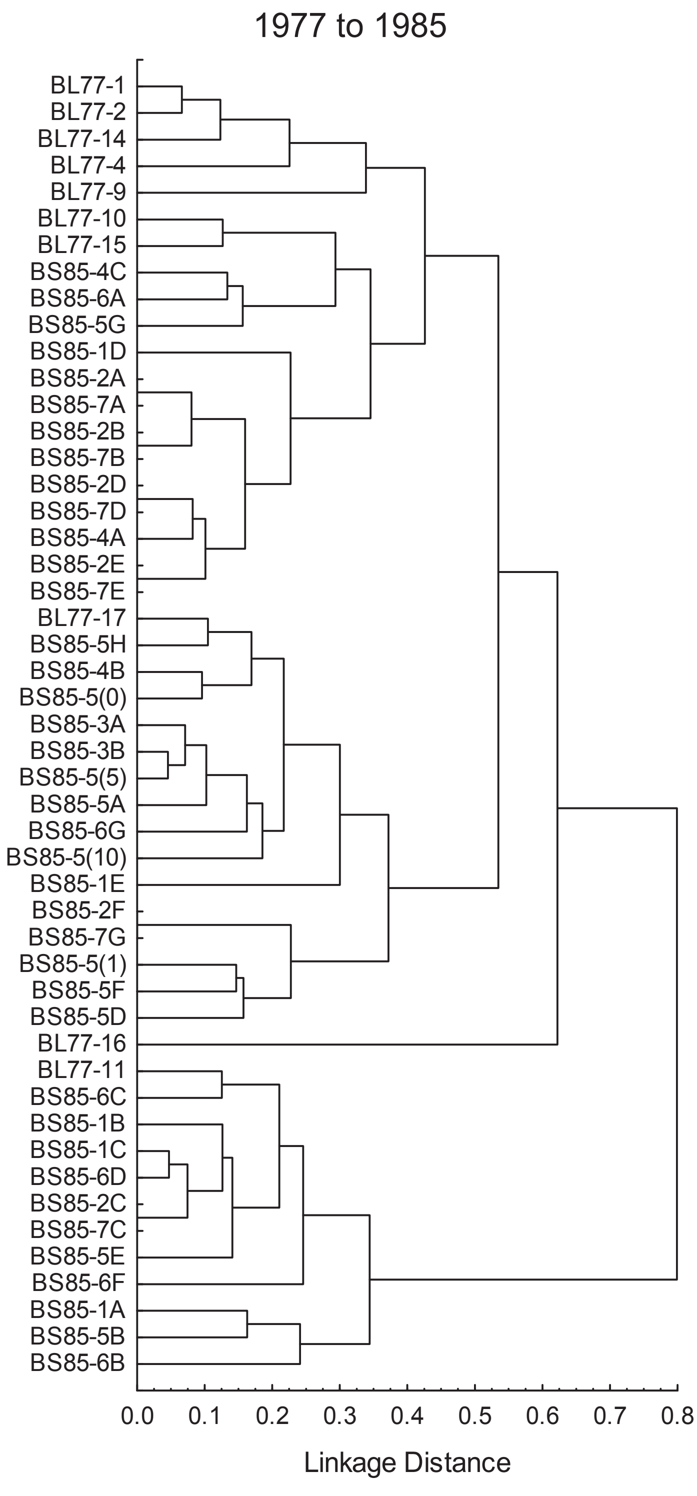
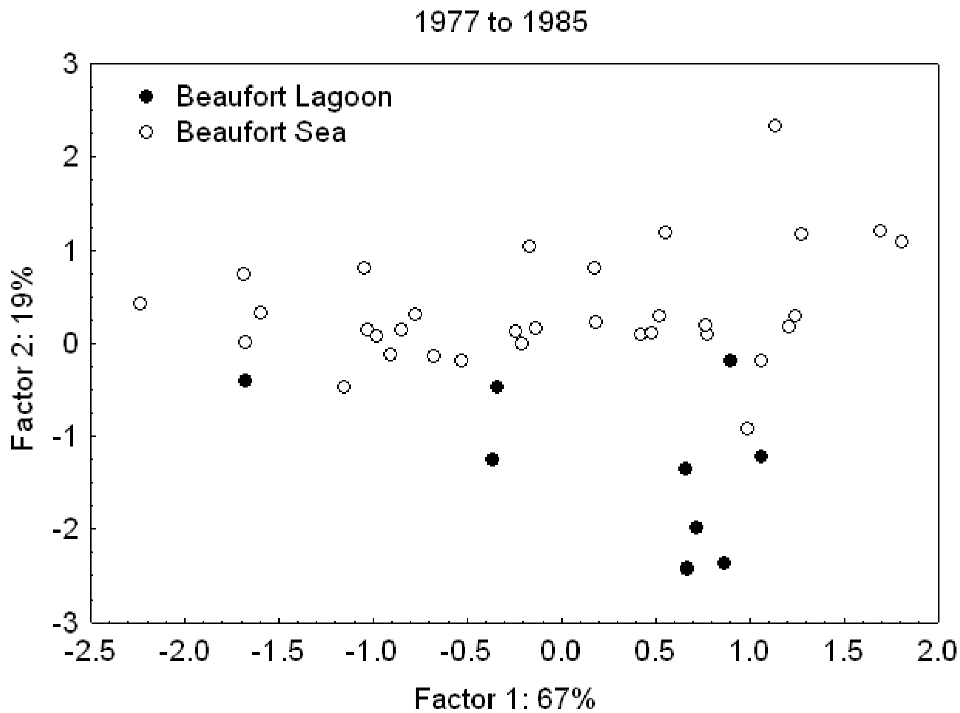


Figure 1. Cluster analysis of ln-transformed metals data for the Beaufort Sea, 1977 to 1985.



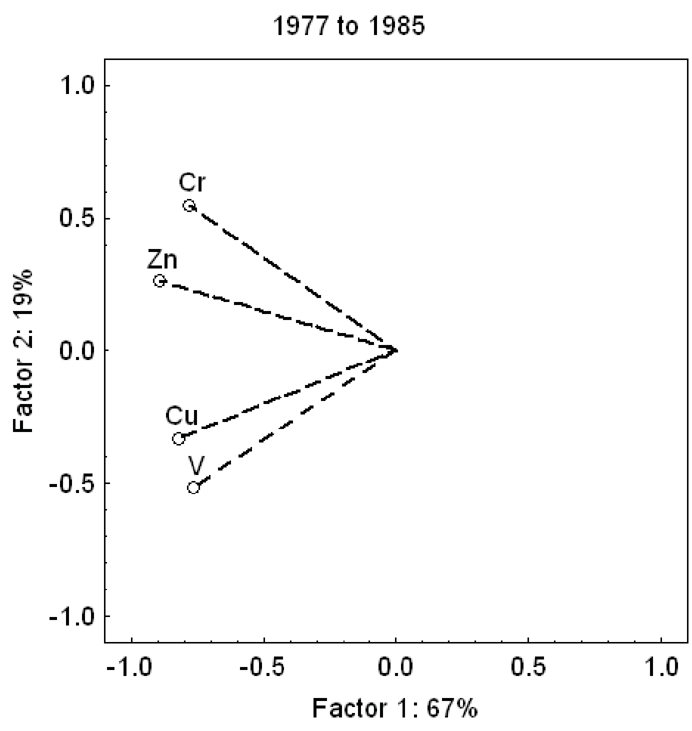


Figure 2. Scores plot (top) and variable projection (bottom) from principal components analysis of the Beaufort Sea metals, 1977 to 1985.

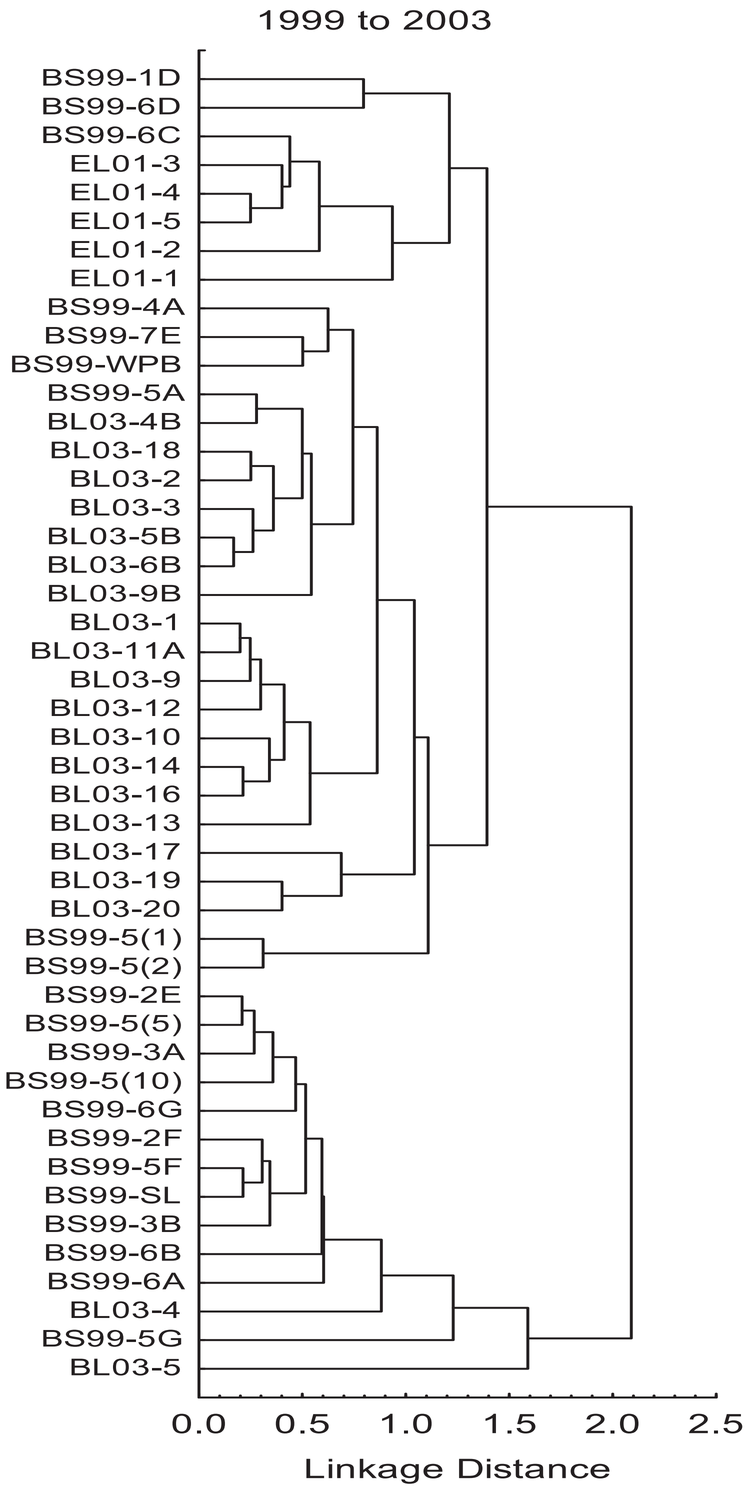


Figure 3. Cluster analysis of ln-transformed metals data for the Beaufort Sea, 1999 to 2003.

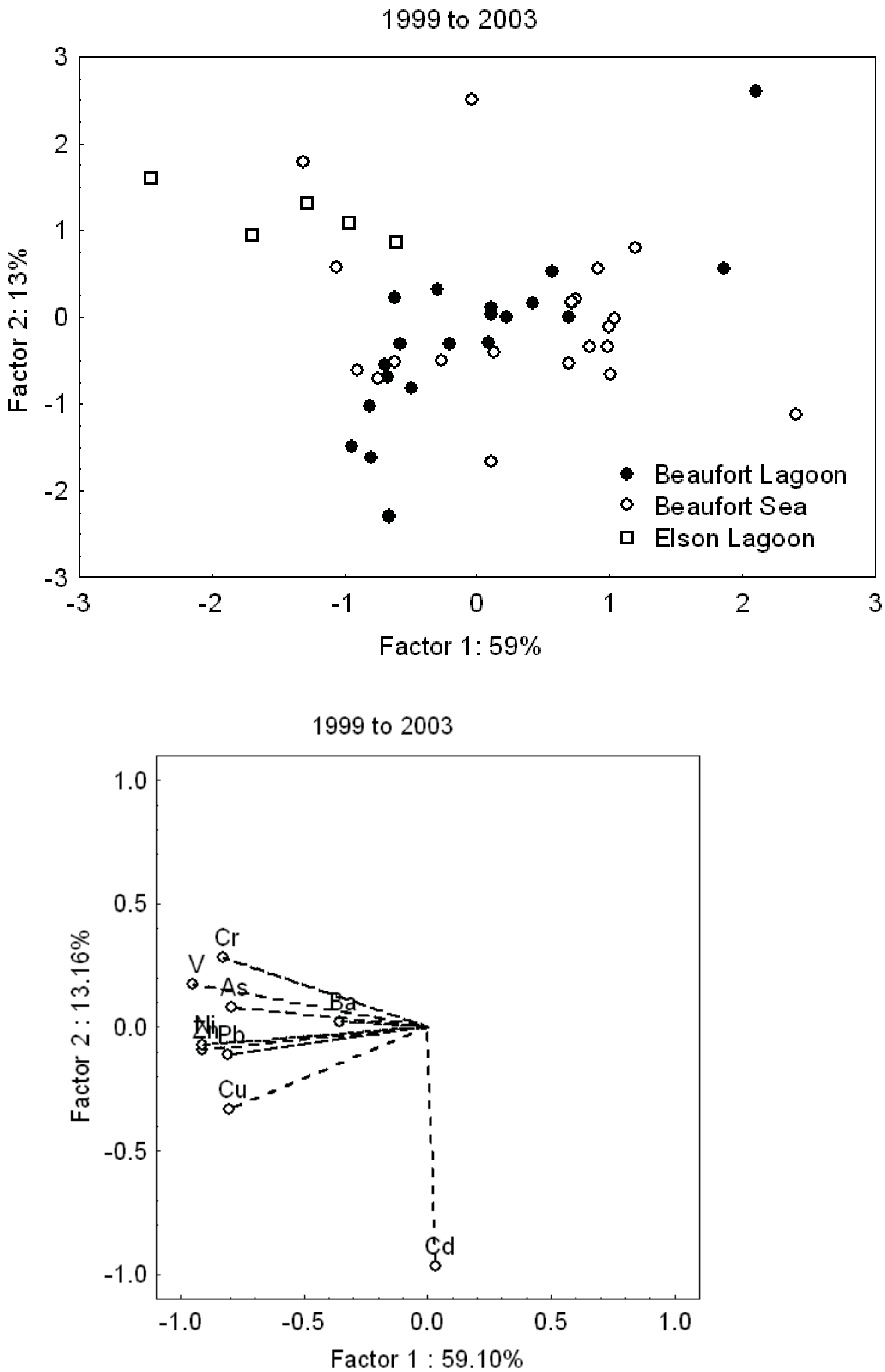


Figure 4. Scores plot (top) and variable projection (bottom) from principal components analysis of the Beaufort Sea metals, 1999 to 2003.

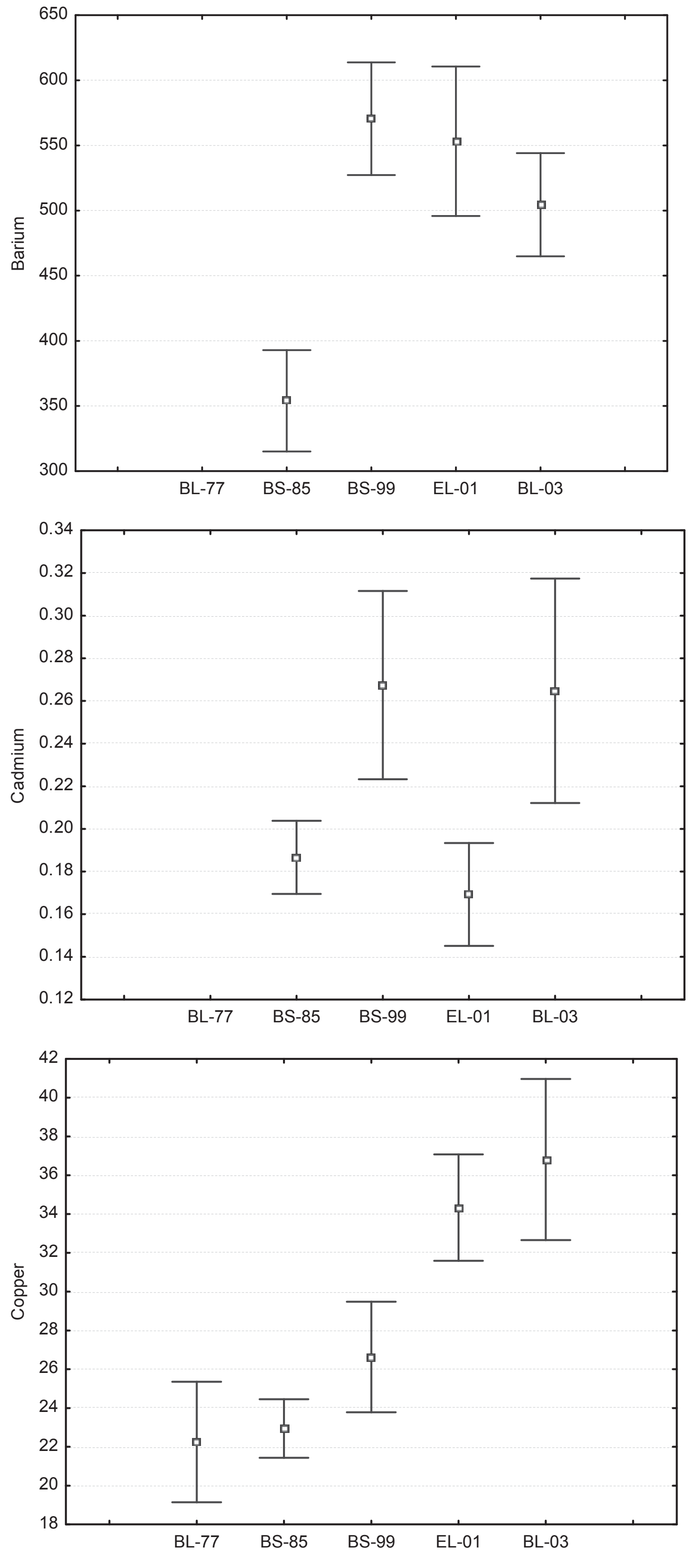


Figure 5. Temporal and spatial variations of Ba, Cd, and Cu.

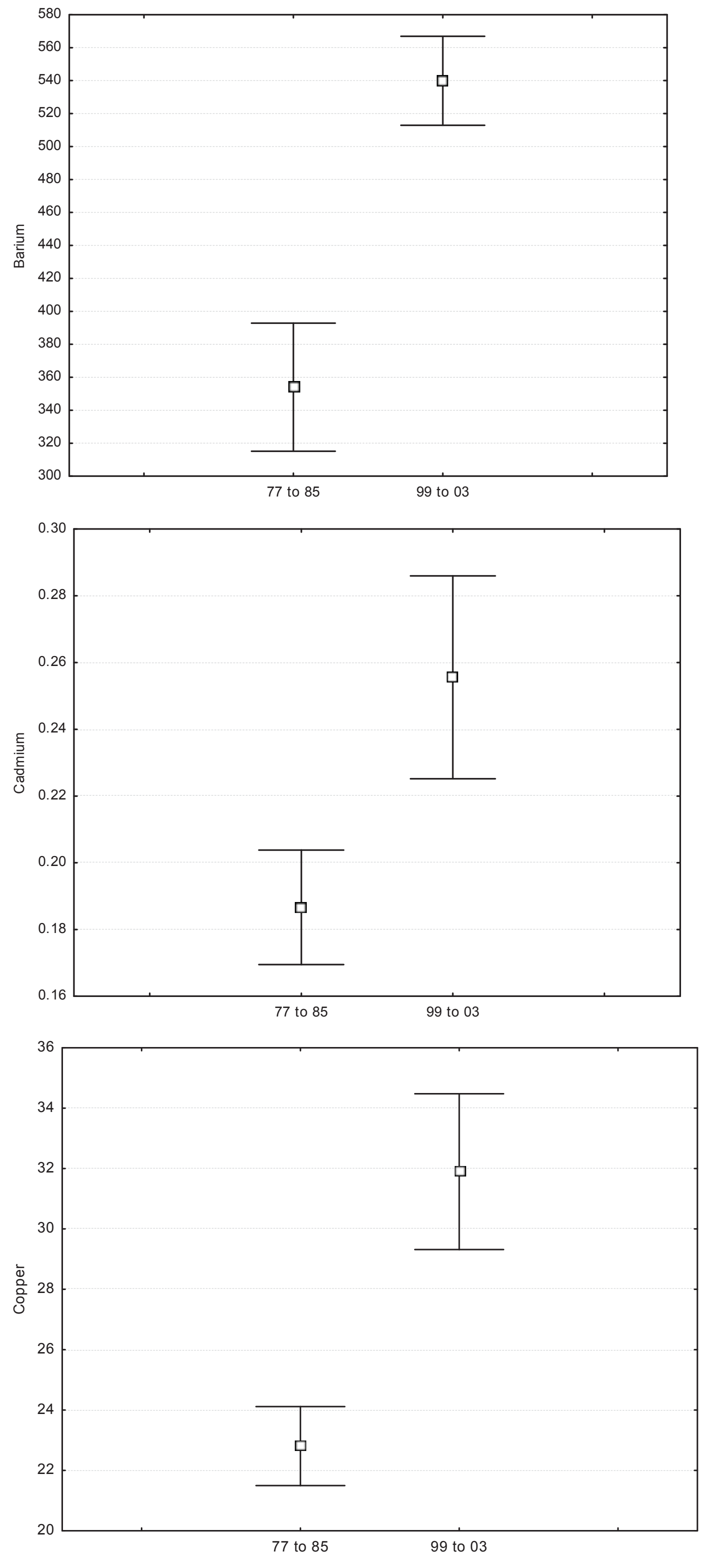


Figure 6. Temporal variation of Ba, Cd, and Cu across Beaufort Sea Locations.

Table 1. Correlations between environmental parameters, PCA factor scores, and metals concentrations for the Beaufort Sea, 1977 to 1985. Large-sized correlations (|r|>0.7) are marked in bold while medium-sized correlations (0.4<|r|≤0.7) are underlined.

Metal	Latitude	Longitude	Mud (%)	OM(%)	CO_3 (%)	Factor 1	Factor 2
Cr	0.43	-0.45	-0.06	-0.16	-0.21	**-0.78**	0.55
Cu	0.05	-0.03	0.09	-0.16	-0.27	**-0.82**	-0.33
V	-0.15	0.20	0.44	0.13	-0.09	**-0.77**	-0.52
Zn	0.33	-0.33	-0.01	-0.18	0.18	**-0.89**	0.26

Table 2. Correlations between PCA factor score and environmental parameters for the Beaufort Sea, 1999 to 2003. Large-sized correlations (|r|>0.7) are marked in bold while medium-sized correlations (0.4<|r|≤0.7) are underlined.

PCA Factor	Latitude	Longitude	Mud (%)	OM(%)	CO_3 (%)
Factor 1	-0.21	0.19	-0.13	0.12	0.13
Factor 2	**0.51**	**-0.57**	-0.39	-0.20	0.06

Table 3. Correlations between environmental parameters, PCA factor scores, and metals concentrations for the Beaufort Sea, 1999 to 2003. Large-sized correlations (|r|>0.7) are marked in bold while medium-sized correlations (0.4<|r|≤0.7) are underlined.

Metal	Latitude	Longitude	Mud (%)	OM(%)	CO_3 (%)	Factor 1	Factor 2
Cr	0.40	-0.35	-0.06	0.01	-0.43	**-0.83**	0.28
Cu	-0.22	0.25	0.13	-0.04	-0.27	**-0.80**	-0.33
V	0.49	-0.44	-0.00	0.34	-0.46	**-0.95**	0.17
Zn	0.47	-0.45	0.13	0.41	-0.35	**-0.91**	-0.09
As	0.35	-0.31	-0.23	0.46	-0.19	**-0.80**	0.08
Ba	0.24	-0.27	0.33	0.32	-0.39	-0.36	0.02
Cd	-0.31	0.26	-0.08	0.16	0.58	0.03	**-0.97**
Ni	0.21	-0.17	0.07	0.09	-0.53	**-0.91**	-0.07
Pb	0.02	0.04	-0.17	0.19	-0.29	**-0.81**	-0.11

Table 4. Correlations between PCA factor score and environmental parameters for the Beaufort Sea, 1999 to 2003. Large-sized correlations (|r|>0.7) are marked in bold while medium-sized correlations (0.4<|r|≤0.7) are underlined.

PCA Factor	Latitude	Longitude	Mud (%)	OM(%)	CO_3 (%)
Factor 1	-0.21	0.19	-0.13	0.12	0.13
Factor 2	**0.51**	**-0.57**	-0.39	-0.20	0.06

Idealized Process Model Studies of Circulation in the Landfast Ice Zone of the Alaskan Beaufort Sea

Thomas Weingartner
weingart@ims.uaf.edu
Institute of Marine Science
University of Alaska Fairbanks
P.O. Box 757220
Fairbanks, AK 99775-7220

Jeremy Kasper
kasper@sfos.uaf.edu
Institute of Marine Science
University of Alaska Fairbanks
P.O. Box 757220
Fairbanks, AK 99775-7220

Task Order: 39953

Abstract

Immobile, landfast ice covers the region inshore of the 20 m isobath over arctic shelves and prevents the direct transfer of wind stress to the inner shelf in winter. Thus the outer shelf circulation is directly wind-forced whereas inner shelf dynamics are controlled by remotely-established pressure gradients and frictional coupling of the flow field to the bottom and the under-ice boundaries. To demonstrate the first order effect of landfast ice on the shelf circulation, an analytic description of the mean coastal flow beneath the landfast ice was developed following Csanady's "arrested topographic wave" model. For comparison, the Regional Ocean Modeling System (ROMS) was used to investigate the 2-D behavior of a mound of water along a straight coast with friction applied at the bottom and at the surface to mimic frictional coupling between the landfast ice and the ocean. The ice-water friction coefficient was varied spatially to examine three cases: constant, linearly increasing offshore, and random. The numerical model was forced with different offshore wind profiles to investigate the response of the inner and outer shelves to offshore winds. The circulation response to winds differs markedly between the inner and outer shelf and there is only limited exchange across the landfast ice edge throughout winter. This implies that dissolved and suspended materials remain trapped to the inner shelf throughout winter. The underice flow field is sensitive to the magnitude of the ice-water friction but is insensitive to the spatial structure of the frictional coupling.

Introduction

Nearshore circulation processes on arctic shelves differ from ice-free seas because of the presence of landfast ice, which inhibits the transfer of momentum from the wind to the ocean and is frictionally coupled to the underice flow. Consequently, dynamical principles gleaned from ice-free shelves are not completely applicable to the landfast ice zones surrounding the Arctic Ocean.

Winds and river runoff influence the dynamics and circulation pathways over the innermost portion (water depths < ~ 20 m) of most continental shelves. While this is true for Arctic shelves as well, the effects of wind stress and buoyancy are substantially modulated by the annual freeze/thaw cycle, which controls the phasing and duration of the landfast ice season and river discharge (Weingartner et al., 2005).

Landfast ice, which is anchored at the coast along the 2 m isobath (Reimnitz, 2001) and extends offshore to the 20 - 40 m isobath (Reimnitz, 1984; Macdonald and Carmack, 1999) covers the inner shelf from October through June. Its effects on the circulation are illustrated in Figure 1, which shows times series of ice thickness, ice displacement, and the along-shore currents in the nearshore (10 km offshore and ~7 m water depth) Alaskan Beaufort Sea. In the absence of landfast ice local winds, along-shore pressure gradients, and bottom friction dominate the momentum balance. Currents are swift (~20 - 100 cm s^{-1}) and both currents and sea-level are coherent with one another and the local winds. During the landfast ice season, the underice currents are weak (< 5 cm s^{-1}), variable, and uncorrelated with wind and sea level fluctuations.

The landfast ice influences the ocean dynamics in several ways. First, being immobile, landfast ice inhibits momentum transfer from the

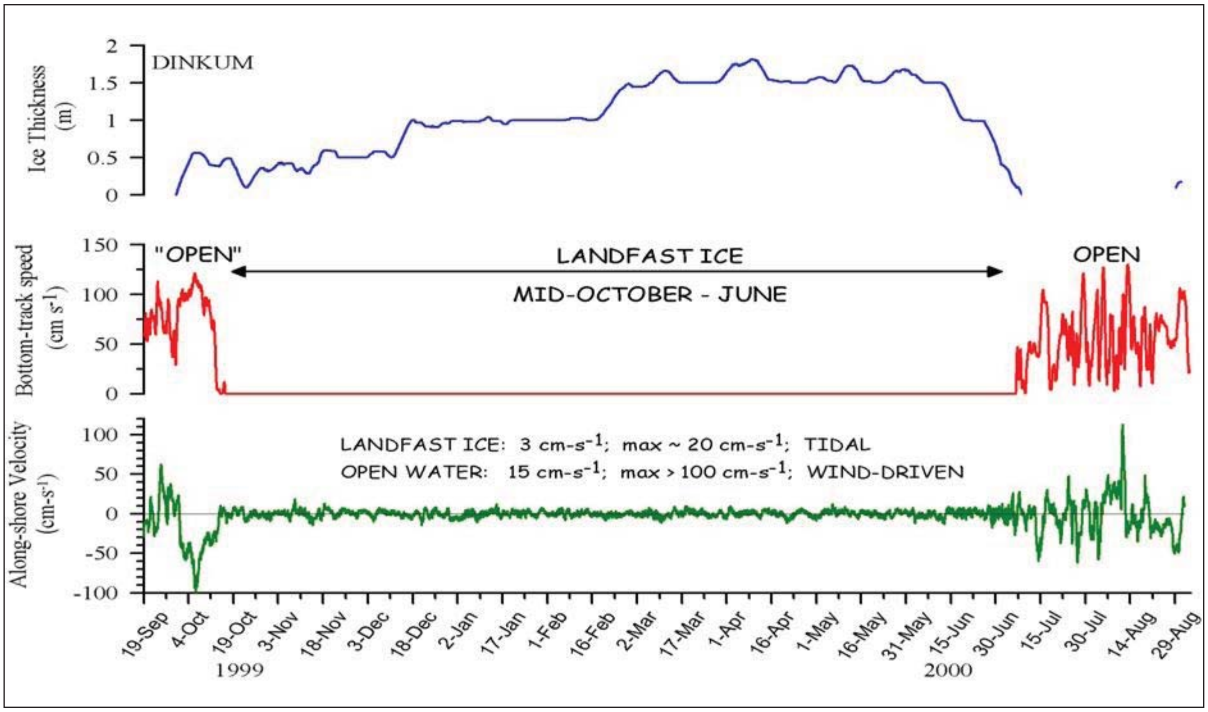


Figure 1. Seasonal cycle of ice thickness (top panel), bottom-track speed (middle panel), and along-shore currents (bottom panel). The bottom track speed indicates when the surface is in motion and zero bottom track speed indicates when landfast ice has set-up [from Weingartner et al., 2005].

wind to the ocean. Thus the only motive force for the variable currents is a fluctuating alongshore pressure gradient. The latter is set-up by remote processes associated with larger scale wind or ocean circulation fields. Second, the underside of the ice is frictionally coupled to the currents so that during the landfast ice season the momentum balance is between the along-shore pressure gradient force and the opposing influence of friction at the seabed and beneath the ice. Thus the weak currents of the landfast ice season are due to the absence of direct wind-forcing and friction. The third affect is due to the abrupt transition between the landfast ice edge and the freely drifting, offshore pack ice. This causes a large cross-shelf shear in the surface stress (or a surface stress curl). Although there are no observations from this transition region, it is expected that the curl will force an along-shore ice edge jet and a cross-shelf circulation cell. The onshore extent of this three-dimensional circulation field is unknown, although it is likely confined to within 1 - 2 Rossby deformation radii of the ice edge (~10 – 15 km). This suggests that the circulation field across the landfast ice zone might be different in that the outer region may be coherent with the local winds, while the inner shelf is not. It also suggests that water exchange between the landfast ice zone and offshore is inhibited throughout winter.

A key control affecting the underice circulation field is frictional coupling between the ice and the water. The coupling is poorly understood, however, and has received little observational attention. It very likely depends on both the under-ice topography and current speed. For example, the underice topography on windward shelves, such as the Alaskan Beaufort Sea, is highly deformed due to collisions at the seaward boundary with pack ice. Ridging intensity and keel depths generally increase offshore and throughout the freezing season, although these parameters can vary substantially in the alongshore direction (Tucker et al., 1979). These considerations suggest that ice-water friction will vary over a variety of time and space scales and thus complicate the circulation response to wind and/or buoyancy forcing. Conceivably this variability leads to the poor correlations between winds (whether local or remote) and underice currents and sea level. It could also lead to small along- and cross-shore spatial correlation scales in the underice current field and affect the spreading of underice river plumes.

Objective and Methods

The overall goal of this study is to better understand the physical processes controlling circulation in the landfast ice zone of arctic shelves when forced by winds and buoyancy and subjected to various parameterizations of the ice-water stress.

To achieve the study objective, a simple analytic model was developed and numerical process models were applied to examine simple cases that still retain the essential physics. The modeling approach allows us to consider complex physical processes, while simultaneously avoiding more complicated efforts required to run and to analyze numerical models constructed for realistic ocean simulations. Moreover, the idealized models permit applying simple, easily controllable boundary conditions while retaining the high spatial resolution required to elucidate the physics. These are important considerations for examining the model response to river runoff introduced at the coast and for the various ice-water friction scenarios, which are easily manipulated in the experiments.

The Regional Ocean Model System (ROMS; Song and Wright, 1998; Shchepetkin and McWilliams, 2005) was used to conduct the experiments. ROMS is a finite difference, free surface model which uses stretched, terrain following coordinates in the vertical

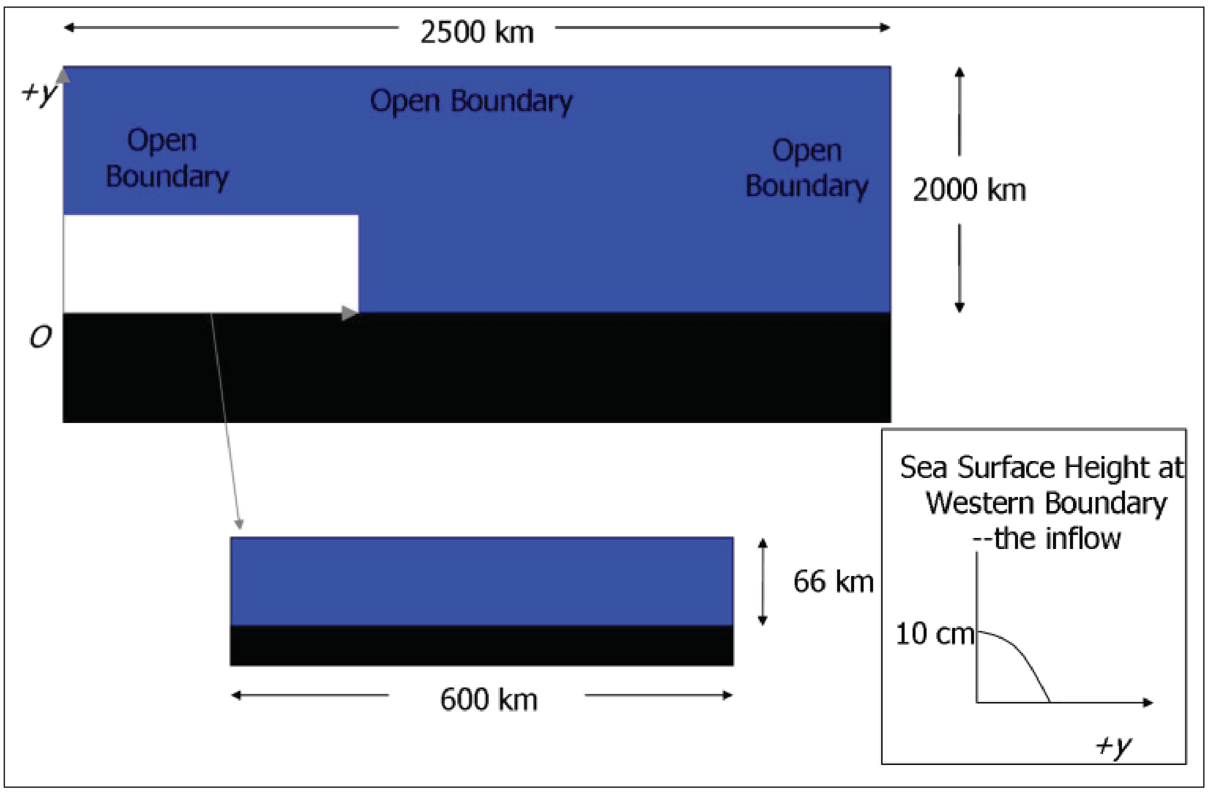


Figure 2. Cartoon of the model setup. The largest rectangle is the full model domain: a 2500 km long (East to West) by 2000 km wide (South to North) rectangle. There are open boundaries along the Eastern, Northern and Western boundaries. Black indicates the southern coast line. Within the larger box, model results are sampled from the smaller 600 km long by 66 km wide rectangle indicated by the white area within the large rectangle. This box within a box setup ensures that the domain is isolated from any boundary-edge effects. Model resolution is 2 km in both directions. The cartoon in the lower right hand corner simply indicates that the inflow (an elevated sea surface height) is constrained to within a small distance of the coast. Positive y points offshore (North) and positive x points East. In all subsequent inflow experiments, the inflow is simply an elevated sea surface height of 10 cm at the western boundary.

(s-coordinate, Song and Haidvogel, 1994). The s-coordinate model is desirable when dealing with continental shelf topography and allows for increased resolution in the top and bottom boundary layers. It incorporates the well-known Mellor-Yamada level 2.5 (Mellor and Yamada, 1982) mixing scheme, where eddy diffusivity is calculated based upon the local flow and stratification.

Several simplifications are involved in the modeling. First, we ignore ice dynamics/ thermodynamics. Instead, landfast ice enters the model experiments only through the ice-water stress representation and by prescribing the distance from the coast to the offshore boundary where wind stress directly affects the ocean. This simplification circumvents the need to couple complex nearshore ice physics to the ocean model. For our Alaskan Beaufort shelf setting, wind stress is applied to the ocean surface outside of the landfast ice domain, which will extend ~20 km offshore in our experiments.

Second, we employ a bathymetry that mimics the Alaskan Beaufort shelf bottom slope and depths. We ignore along-shore variations in topography and coastline orientation. These simplifications ensure that the modeled flows result only from physical processes associated with the imposed boundary conditions or underice stress parameterizations. We note that these approximations are reasonable given the Beaufort shelf's relatively simple bathymetry and nearly straight coast. The model domain is a 600 km long shelf, oriented east-west, with a coastal wall at the southern boundary and with open boundary conditions elsewhere. Model results show that this set-up works well for experiments involving only wind stress and inflows at either end of the channel. Figure 2 is a cartoon representation of the model domain.

Results and Discussion

To describe the Beaufort Shelf winter time circulation (circulation beneath landfast ice) Weingartner et al. (2005) constructed a simple, vertically averaged flow model, equation (1.1) that includes sea surface slope and a best guess as to the effects of surface and bottom friction on the flow.

(1.1)

$$\underbrace{\frac{\partial u}{\partial t}}_{\text{Time evolution of currents}} = \underbrace{-g\frac{\partial \zeta}{\partial x}}_{\text{Sea Surface Slope}} - \underbrace{\frac{2ru}{h}}_{\text{Bottom and Surface Friction}}$$

The alongshore velocity is u (m/s), g is the acceleration due to gravity (m/s^2), ζ is the sea surface height (m), h is the depth (m) and r is the friction coefficient (m/s). This simple model motivated the construction of a analytic model to understand flow under landfast ice.

Csanady's 1978 "arrested topographic wave" (ATW) was adopted as a starting point for the analytic model. Csanady's vertically averaged model was constructed to describe the average subtidal flow along a coastline. The ATW model, equations (1.2), do not include ice but do include Coriolis, sea level slope, and bottom friction. Similar to equation (1.1), bottom friction is proportional to a friction coefficient (r_b= 10^{-4} m/s) so that a larger friction coefficient leads to proportionally larger influence of bottom friction on the flow. The only forcing included in the ATW solution is an inflow-an elevated sea level at the western boundary.

(1.2)

$$\left.\begin{array}{ll} \text{Alongshore Direction} & \underbrace{-fv}_{\text{Coriolis}} = \underbrace{-g\frac{\partial \zeta}{\partial x}}_{\text{Sea Level Slope}} - \underbrace{B_x}_{\text{Bottom Friction}} \\ \text{Cross Shore Direction} & fu = -g\frac{\partial \zeta}{\partial y} \\ \text{Continuity} & \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = 0 \\ \text{Bottom Friction} & B_x = \frac{r_b u}{h} \end{array}\right\}$$

where v is the cross shore velocity (m/s) and f =10^{-4}s^{-1} is the Coriolis parameter. Note that in equation (1.1) the friction term was twice that of the ATW equations to include the effects of landfast ice. A little math transforms the ATW equations into a diffusion equation

(1.3)

$$\frac{\partial \zeta}{\partial x} = \kappa \frac{\partial^2 \zeta}{\partial y^2}$$

where $K = r_b / fs$ is the diffusivity coefficient and s is the bottom slope (10^{-4} m/km). The solution to equation (1.3) is shown in Figure 3. The nature of equation (1.3) is such that the larger the bottom friction (larger r_b) the more the inflow diffuses offshore. Including landfast ice as a surface friction and therefore perhaps doubling the friction an inflow

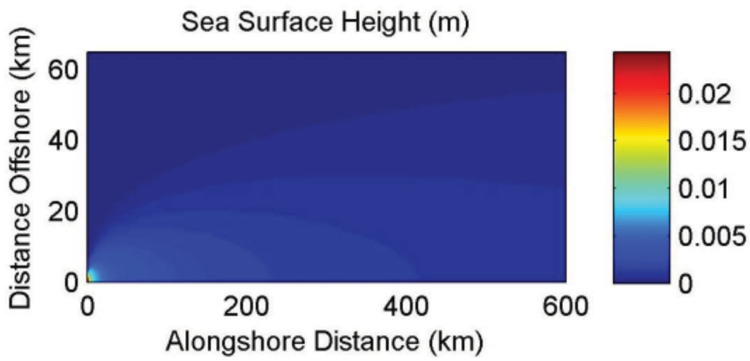


Figure 3. ATW solution. The inflow is an elevated sea surface height (10 cm), a small mound of water at the western boundary. This is a very typical diffusive type equation in that the sea surface height is diffused/moved offshore by bottom friction with distance alongshore. Also note that a relatively small sea surface height can influence the flow at very long distances. Note differences in scale due to model differences between this and subsequent plots.

should diffuse further offshore than in the ice free case. Subsequent analytical and numerical results bear this supposition out.

The inclusion of landfast ice in the ATW equations complicates the math. Equations (1.4) include the effects of landfast ice. Terms in blue indicate terms that were included in the ATW equations. Landfast ice is included as a surface friction. Similar to bottom friction, landfast ice is proportional to a friction coefficient, r ~O(10^{-4} m/s). The sign of the surface and bottom friction is the same i.e. both landfast ice and bottom friction apply a force to the left of the direction of propagation: in our case, offshore.

(1.4)

$$\underbrace{-fv}_{\text{Coriolis}} = \underbrace{-g\frac{\partial\zeta}{\partial x}}_{\text{Sea Level Slope}} - \underbrace{B_x}_{\text{Bottom Friction}} - \underbrace{S_x}_{\text{Surface Friction}}$$

$$fu = -g\frac{\partial\zeta}{\partial y} - B_y - S_y$$

$$\frac{\partial(uh)}{\partial x} + \frac{\partial(vh)}{\partial y} = 0$$

$$B_x = r_b u/h$$

$$B_y = r_b v/h$$

$$S_x = ru/h$$

$$S_y = rv/h$$

Manipulating equations (1.4) to obtain a single equation leads to equation (1.5). In comparison to the ATW, the landfast ice model is not as elegant but the nature of the solution, as shown in Figure 4, is similar to the ATW with some important differences.

(1.5)

$$\frac{\partial^2\zeta}{\partial x^2} = \frac{\partial^2\zeta}{\partial y^2} + \frac{1}{(r+r_b)}\frac{\partial r}{\partial y}\frac{\partial\zeta}{\partial y} - \frac{sf}{(r+r_b)}\frac{\partial\zeta}{\partial x}$$

Note the differences in scale between Figures 3 and 4. The important differences are differences in patterns such as the slightly greater distance the mound is diffused offshore in the ice covered case (Figure 4) and under the landfast ice, sea surface height is more uniform in the cross shore direction. The differences are in agreement with the fact that under the ice, friction is double the ice free case.

Further analytic experiments were conducted examining the effect of a variable (with distance offshore) surface friction coefficient on the under ice flow. From these experiments it was concluded that magnitude of the surface friction coefficient is important to the alongshore extent of the sea surface height distribution and that knowing the magnitude of the surface stress coefficient is critical to understanding under ice flow. The analytic model results also show that the cross-shore coherence scale may be on the order of the offshore landfast ice extent. Overall, these analytic models help to illustrate the effect of landfast ice on the ocean circulation beneath the ice and to interpret observational data from the area. The analytic model results also serve as a useful

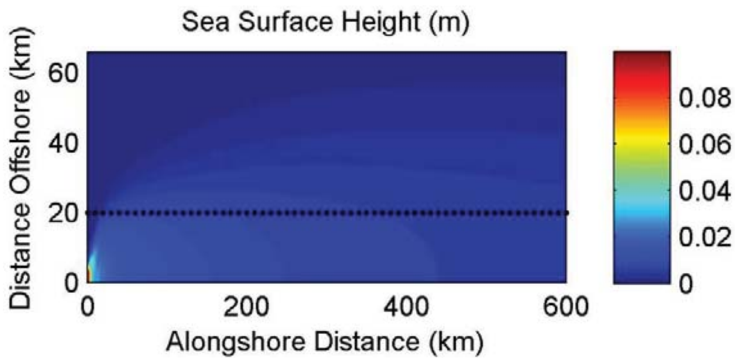


Figure 4. Analytical landfast ice covered model solution. The dotted line at ~20 km offshore marks the edge of the landfast ice. Inshore of the ice edge the ice is modeled as a constant (in space) surface friction. Offshore of the ice edge the surface friction coefficient is 0.

test to check the performance of the more complicated experiments carried out using the ROMS.

For comparison to the analytic models, ROMS was configured to solve only the vertically averaged portion of the equations of motions. As in the analytical models, linear bottom and surface frictions were used. The ROMS model domain is shown in Figure 2. The first suite of experiments conducted with ROMS examined the exact situation the analytic models described: an inflow, an elevated sea surface height (10 cm) at the western boundary, constrained to within small distance of the coast line. ROMS was configured to examine both the ice free and landfast ice covered cases. All ROMS results are plotted after steady state is reached (~20 days). Within the model domain, the inflow is allowed to evolve solely based on the vertically averaged equations of motion. Results for the ice free case are

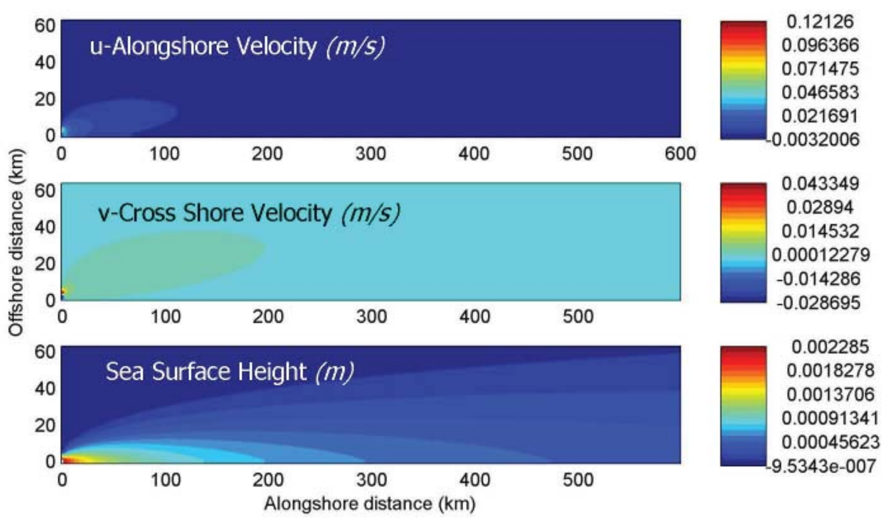
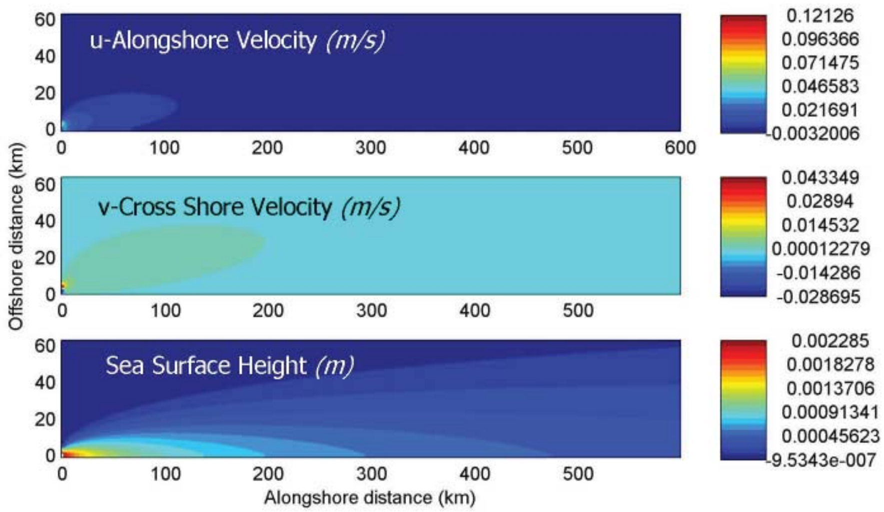


Figure 5. Steady state, ice free, ROMS result. The model was forced with a steady inflow through the western boundary (Alongshore distance 0 km). The height of the inflow is specified at the boundary as 10 cm but due to ROMS' handling of boundary values, the value that enters model domain at the western edge is diminished. At the boundary, the offshore extent of the inflow is small (<5 km). Positive along-shore velocity indicates flow to the east. Positive cross-shore velocity indicates flow offshore. Of note is that under the influence of bottom friction, the inflow (sea surface height) that was initially constrained to the nearshore is slowly diffused offshore with increasing distance alongshore.

Figure 6. Steady state, ice covered ROMS result. The black dotted line at ~20 km offshore indicates the edge of the landfast ice. Inshore of the dotted line fast ice is present and is modeled as a constant surface friction coefficient: r~O(10-4) m/s. Offshore of the dotted line there is no ice (zero surface friction coefficient). The important features to note are the discontinuity in velocities at the ice edge. In comparison the ice free case the alongshore extent of the alongshore velocities is short (< 50 km) suggesting that the coherence scale of under ice velocities is similarly short but that the alongshore coherence of the sea surface height is long. This is in agreement with Weingartner et al. 2005.



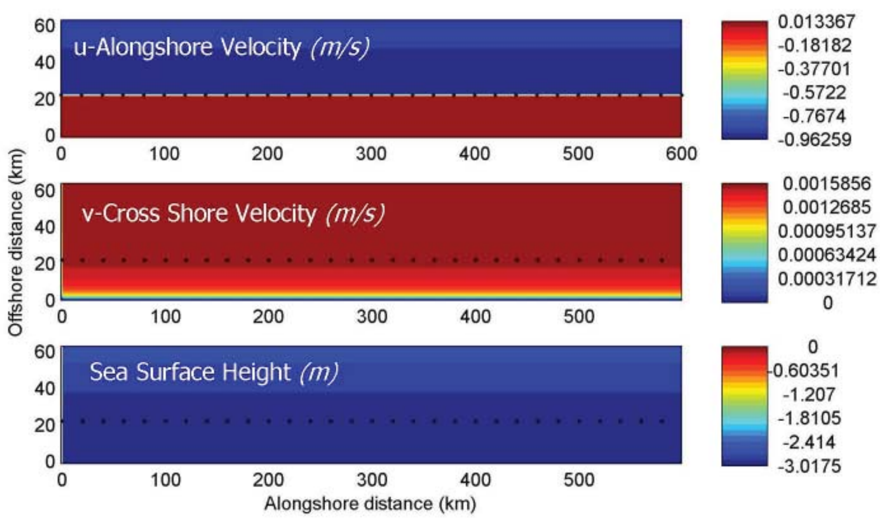
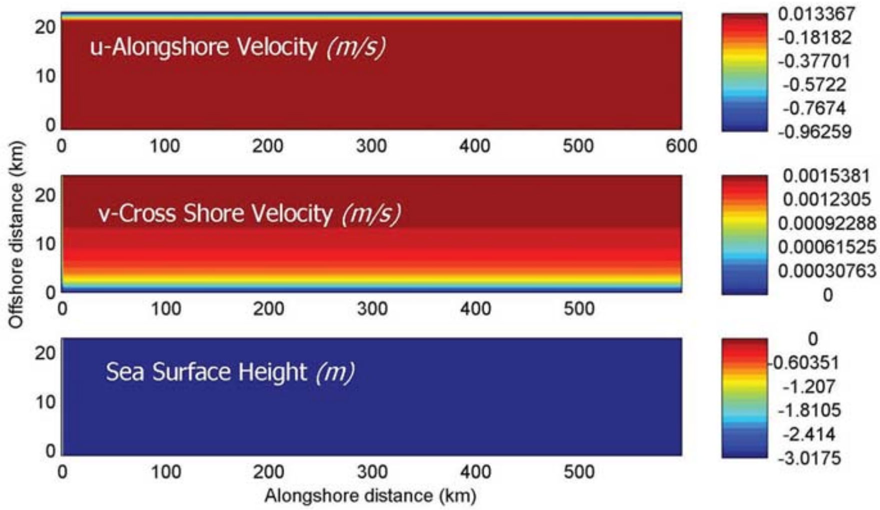


Figure 7. Steady state, ice covered ROMS result. No inflow is present. The ice edge is indicated by the black dotted line ~20 km offshore. Inshore of the dotted line fast ice is present and is modeled as a constant surface friction coefficient: r~O(10-4) m/s. Offshore of the ice edge a spatially and temporally constant wind blows from east to west at 14 knots. Under the ice edge the alongshore velocity is small but positive—in opposition to the wind direction. Cross shore velocities are negligible.

Figure 8. Same as Figure 7 except only the portion of the domain beneath the landfast ice is shown.



shown in Figure 5.

Despite the differences in scale, the bottom pane of Figure 5 (Sea Surface Height) shows good agreement with the ATW solution (Figure 3). The physics are the same and the analytic model does a good job capturing the nature of the flow. More interesting is the case that includes landfast ice, Figure 6. Again the pattern is similar to the analytic model (Figure 4) in that the sea surface height is diffused more offshore with increasing alongshore distance.

Further ROMS experiments were conducted to examine the effect of a spatially varying surface friction coefficient on the under ice flow. The magnitude of the surface friction coefficient was also varied. The same conclusions were reached for the numerical experiments as the analogous analytic experiments.

Perhaps the most interesting set of experiments so far have been a set of vertically averaged ROMS experiments where a wind was blown offshore of the ice edge until steady state was reached. Figures 7, 8 and 9 show a few results from this set of experiments. The model domain is as in Figure 2 except there is no inflow. Ice is included and is spatially uniform ($r=10^{-4}$ m/s). The wind is spatially and temporally uniform and blows from East to West at 14 knots, a reasonable value for the Beaufort Shelf in winter.

Figure 8 is simply a close up of the area beneath the landfast ice. Clearly, the flow is to the east beneath the ice counter to the wind direction. In all cases the cross shore velocity is negligible. Figure 9 shows a profile of the sea surface height from the shore to the edge of the ice. The sea surface height slope towards the ice edge is driven perhaps by the large surface stress curl present at the transition from a relatively small surface stress beneath the ice to a large surface stress due to wind off shore of the ice. The dynamics of this are being investigated but the exciting conclusion is that wind offshore of fast ice may induce a counterflow beneath the ice.

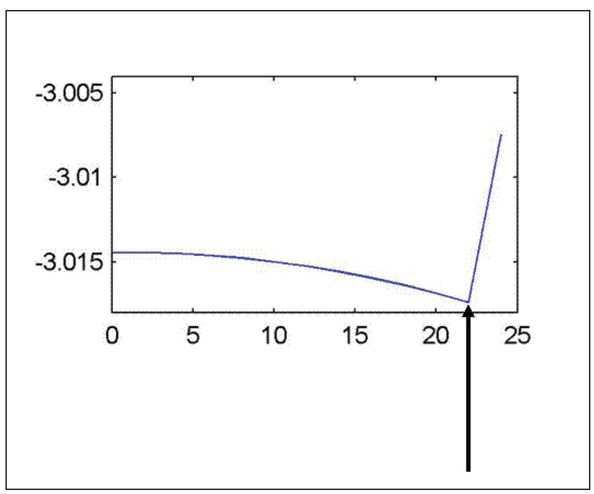


Figure 9. Same ROMS model as Figures 7 and 8. A profile of the sea surface height from the shore to just past the edge of the landfast ice.

Discussion, Ongoing and Future Work

The general agreement between ROMS results and analytical models is good. These models provide important fundamental insights into the physics of landfast ice covered seas. However, given the nature of landfast ice covered seas, the ongoing three dimensional models are critical to understanding areas such as the Beaufort Sea shelf. Current efforts include modeling simple situations similar to those of the vertically averaged models above but utilizing the full three dimensional capabilities of ROMS to provide further insight into such phenomena as the sheared ice edge flow produced by the 2-d models, boundary layer phenomena and vertically sheared flows including especially the influence of river discharge on under ice flows.

Literature Cited

Csanady, G.T., The arrested topographic wave, Journal of Physical Oceanography, 8, 47-62, 1978.

Mellor, G.L., and T. Yamada, Development of a turbulence closure model for geophysical applications, Rev. Geophys. and Space Phys., 20(4), 851-875, 1982.

Shchepetkin, A.F., and J.C. McWilliams, The Regional Ocean Modeling System (ROMS): A split-explicit, free-surface, topography-following coordinates oceanic model, Ocean Modeling, 9, 347-404, 2005.

Song, Y.T. and D.B. Haidvogel, A semi-implicit ocean circulation model using a generalized topography-following coordinate system, J. of Comput. Phys., 115, 228-244, 1994.

Song, Y.T. and D.G. Wright, A general pressure gradient formulation for ocean models. Part II: Energy, momentum and bottom torque consistency, Mon. Wea. Rev., 126, 3231-3247, 1998

Weingartner, T.J., S. R. Okkonen, and S. L. Danielson, Circulation and Water Property Variations in the Nearshore Alaskan Beaufort Sea, Final Report, OCS Study MMS 2005-028, 2005.

Yankovsky, A. E. and D. C. Chapman, A simple theory for the fate of buoyant coastal discharges, J. Phys. Oceanogr., 27, 1386-1401, 1997.

Presentations and publications

Poster presentation, 2006 American Geophysical Union, Fall Meeting, San Francisco. Poster Title: Modeling circulation in the landfast ice zone.

Poster presentation, 2007 Alaska Marine Science Symposium, Anchorage. Poster Title: Modeling circulation in the landfast ice zone

Seminar, Institute of Marine Science Seminar Series, April 25, 2007. Title: Modeling circulation in the landfast ice zone

Acknowledgements

Funding for this study has been provided by the following: the Coastal Marine Institute, Minerals Management Service, the Oil Spill Recovery Institute, Sea Grant in cooperation with the Center for Global Change and the University of Alaska Fairbanks Graduate School. Computer modeling experiments were carried out using Arctic Region Supercomputing Center facilities.

Foraging Ecology of Common Ravens (*Corvus corax*) on Alaska's Coastal Plain

Abby N. Powell
ffanp@uaf.edu
Institute of Arctic Biology and
U. S. Geological Survey, Alaska
Fish and Wildlife Research Unit
University of Alaska Fairbanks
P. O. Box 757020
Fairbanks, AK 99775-7020

Stacia Backensto
ftsab@uaf.edu
Department of Biology and
Wildlife
University of Alaska Fairbanks
Fairbanks, AK 99775

Cooperators/Collaborators:

Louisa N. Smith
louisa_smith@fws.gov
Fish and Wildlife Biologist
U. S. Fish and Wildlife Service,
Fairbanks Fish and Wildlife
Office
Fairbanks, AK

Robert Suydam
Robert.Suydam@north-slope.org
Wildlife Biologist
North Slope Borough
Barrow, AK

Caryn Rea
clrea@ppco.com
Environmental Studies Coord.
ConocoPhillips Alaska, Inc.
Anchorage, AK

Bill Streever
Bill.Streever@bp.com
Environmental Studies Leader
BP Exploration (Alaska), Inc.
Anchorage, AK

Mark Pavelka
mark_pavelka@fws.gov
Fish and Wildlife Biologist
U. S. Fish and Wildlife Service,
Carlsbad Fish and Wildlife Office
Carlsbad, CA

Task Order: 73026

Abstract

Populations of common ravens (Corvus corax) on the North Slope of Alaska appear to be increasing where anthropogenic resources are available, including numbers of ravens at the North Slope Borough's Prudhoe Bay Landfill during winter. The oil fields provide abundant anthropogenic resources in terms of infrastructure and food sources. Ravens use infrastructure for nesting and forage on anthropogenic foods. In 2007 we documented nest locations and collected sightings of marked ravens from the public across Alaska. We also summarized nest and nest site characteristics, movements of breeding ravens, juvenile survival, and the diet of breeding ravens. Our preliminary findings indicated production facilities were used as nest sites consistently each year, and nests on drill sites and other types of infrastructure were oriented primarily to the south. Breeding adults maintained 1.8 ± 2.7 km² territories (n = 12) around nest sites until late in the nestling stage; after chicks fledged their ranges increased (10.3 ± 16.6 km², n = 13). When all data from all observations (n = 31) were included, average home range during post-fledging decreased to 8.2 ± 12.5 km² and there was high variability among family groups. Of juveniles marked in 2004 (n = 33), 18% were seen again their first year, 21% the second year, and 15% in the third year. Of juveniles marked in 2006 (n = 50), 24% were observed in 2007. Diet of breeding ravens was characterized primarily by small mammals and to lesser degree avian and other taxa. Collared lemmings (Dicrostonyx groenlandicus) and brown lemmings (Lemmus trimucronatus) composed

almost half of the small mammals in their diet. We conclude the oil fields subsidize raven nesting activity, and to some extent, food items during the breeding season. Breeding ravens are foraging generalists in this area and their potential impact as predators increases throughout the summer.

Introduction and Background

Common raven (*Corvus corax*) populations have increased in many parts of their geographic range (Boarman and Heinrich 1999). In some areas of the U.S. it is common for large numbers of ravens to be found in areas where anthropogenic resources (structures and food) are abundant. These subsidies, often localized, are where spatial patterns of hyper-predation are seen and spill-over predation by ravens on local prey species can occur (Kristan and Boarman 2003). In addition, anthropogenic subsidies influence raven demography (Restani et al. 2001, Roth et al. 2004, Webb et al. 2004, Boarman et al. 2006). In some areas outside of Alaska, breeding ravens establish core areas of use around their nest sites near food subsidies (Roth et al. 2004). Juvenile survival may also be enhanced by proximity of nests to anthropogenic resources (Webb et al. 2004). Breeding ravens are known to be foraging generalists (Engel and Young 1989, Boarman and Heinrich 1999, Kristan et al. 2004) throughout their range but in some instances may be selective predators (Sara and Busalacchi 2003) even when other food items are available.

Raven numbers on Alaska's North Slope have increased over the last 30 years where human activities are concentrated, such as the active oil fields, herein referred to as Kuparuk and Prudhoe Bay (Day 1998, National Audubon Society 2004). The role of ravens as scavengers and predators in this arctic region is not well understood; information on diets and ecology of breeding ravens is minimal. There is a great deal of speculation that ravens exert significant predation pressure on tundra-nesting birds on the North Slope. To understand their role as subsidized predators in areas where human development occurs, it is important to evaluate how ravens use the anthropogenic resources available at various spatial levels of human activity.

Objectives

The original objectives of this study were to quantify the summer foraging ecology of ravens in areas where human activity is spread over a large area (e.g. Kuparuk and Prudhoe Bay oil fields), where human activity is more concentrated (e.g. villages of Barrow and Nuiqsut) and where human activity is relatively lower overall (NPR-A Colville River Unit and Pt Lonely). Due to the scope of this study and the logistical constraints of working on Alaska's North Slope, we confined our concentration to ravens breeding within the oil fields. The specific objectives are as follows:

1) Assessment of the raven breeding population in the oil fields of Alaska's North Slope,
2) Assessment of productivity and nest success of ravens nesting in the oil fields,
3) Examination of the movements of ravens from nesting sites to foraging areas, and between breeding and non-breeding seasons on Alaska's North Slope,
4) Quantitative assessment of the summer diet composition.

In 2007, we located nests in the Kuparuk and Prudhoe Bay oil fields and summarized nest and nest site characteristics for 2004-2007, movement of breeding adults and juveniles for 2004-2006, and diets for 2004-2005.

Study Area

Our study included the two largest producing oil fields on the Alaska's North Slope: Kuparuk (103,396 ha, operated primarily by ConocoPhillips Alaska Inc. and BP Alaska Inc.) and Prudhoe Bay's (operated by BP Alaska Inc.) operating areas: eastern (EOA, 52,246 ha), western (WOA, 48,347 ha), and Milne Pt. (22,002 ha). These oil fields are characterized by extensive wetlands and tundra and are flanked by the Colville and Sagavanirktok rivers. Temperatures ranged between -90^{o} C and 25^{o} C with an annual range of 13-18 cm of precipitation; the ground remained frozen and snow covered for 8-9 months each year (Truett and Johnson 2000). Kuparuk and Prudhoe Bay oil fields were a mosaic of buildings and pipelines connected by a gravel road network across the tundra. In general, building density was higher in Prudhoe Bay than Kuparuk. Adjacent to the southern portion of EOA was the service area of Deadhorse, often referred to as an industrial town, covering approximately 400 ha.

Two main types of oil production facilities characterized the oil fields: processing facilities and drill sites. Processing facilities were large buildings 40-60 m tall, had numerous protruding features on their exteriors, and occured in low abundance (n = 18). Drill sites, by contrast, were smaller buildings, 8-20 m tall, had relatively fewer exterior features, and were more abundant (n = 117). Other infrastructure (herein referred to as other infrastructure) included inactive drill rigs, bridges, and U.S. Air Force Alaska Radar System radar towers and were variable in height (5-60 m) and lowest in abundance (n = 11).

Human activity levels varied spatially and temporally throughout the study area and during our study (2004-2007). During times of peak activity, roughly 3000 people (ConocoPhillips Environmental Dept., pers comm.) lived and worked in the oil field on a daily basis, residing in five main camps and three satellite camps (two on the road system and one offshore) that were part of remote processing facilities or camps in Deadhorse. Activity at processing facilities was generally higher than at drill sites, yet increased at drill sites during temporary large-scale projects (construction, drilling, and oil well projects).

Anthropogenic food sources occurred as point subsidies (landfills and dumpsters) and ephemeral subsidies (food items unintentionally discarded on the ground or in personnel work vehicles (e.g. pick up trucks). There were two North Slope Borough operated landfills in and near the oil fields: Prudhoe Bay Landfill in the western portion of EOA, and a landfill in the village of Nuiqsut 50 km southwest of central Kuparuk (Figure 1). Both oil companies managed food wastes to reduce accessibility to wildlife; food wastes from camps and facilities were stored in covered dumpsters until incinerated or buried daily at the Prudhoe Bay Landfill. Ephemeral subsidies were more difficult to quantify or locate, but were considered dynamic low-level subsidies relative to landfills; we assumed they were associated with human activity such as drilling rig activity.

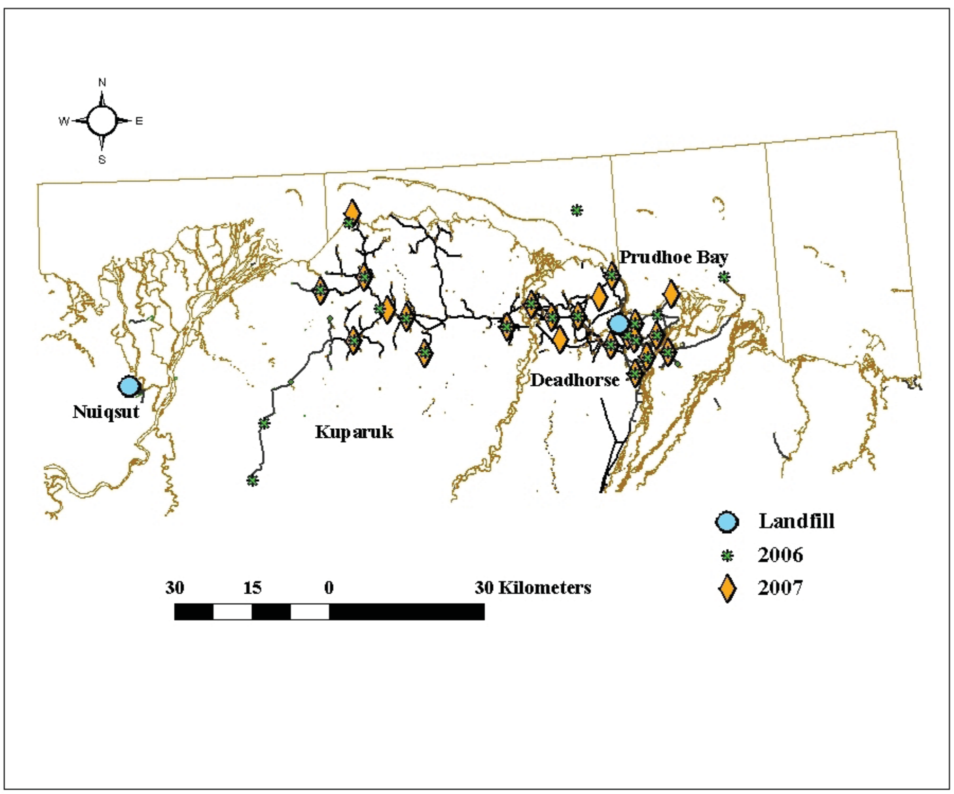


Figure 1. Locations of common raven nests in 2007 in the Kuparuk and Prudhoe Bay oil fields, Alaska.

Methods

Assessment of Breeding Population

We located active raven nests from 30 April - 7 May 2007 by conducting road surveys to search for breeding activity. We surveyed roughly 90% of the facilities and pads on the road system in Prudhoe Bay and all of Kuparuk. A few locations of Prudhoe Bay could not be accessed due to inclement weather and road restrictions.

Nest and Nest Site Characteristics

We summarized nest characteristics for all nests where we observed raven activity in 2004-2007, including height above ground, aspect, and substrate. We excluded nests reused in subsequent years unless the nest had changed location on the structure. We summarized proximity of nests to the following topographic features: nesting neighbor, worker camps, landfills, and drill rig activity in February and March. We measured distances in ArcView GIS 3.3 (Hooge and Eichenlaub 2000) for all known nest attempts in 2004-2006 including sites that were reused in subsequent years. North Star Island was included in this assessment based on oil field worker reports of nesting activity during all three years of our study.

Movements of Adult and Juvenile Ravens

In 2004 we fit nine (one died during handling) adult ravens, eight of which were breeding adults (4 males, 4 females) with 22-g, VHF transmitters and patagial-wing tags with two alpha codes. We radio tracked eight of these adults in 2004, two in 2005 (one of which abandoned nesting early in the season), and one in 2006. In addition to the individuals we radio tracked in 2005-2006, we resighted wing-tagged adults who had removed their transmitters; two in 2005 and three in 2006. Over the course of the study we marked 91 juveniles with wing tags, which allowed to us to identify individual family groups in addition to families with marked adults. We resighted five families in 2005 and 17 in 2006. We also resighted adults and families at the landfill and opportunistically during travel throughout the study area.

We resighted marked juveniles at the Prudhoe Bay Landfill from 2004-2007. In addition to our observations, we collected sightings from the oil field community and general public outside of the oil fields in Alaska from 2004-2007 via phone calls, emails, and our website (www.rap.uaf.edu/raven). We also documented reports of juvenile electrocutions in 2005 and 2006, and subsequently investigated locations where they occurred immediately after they were reported.

Movement Assessment

Movement data were summarized for locations collected April-August 2004-2006, from radio-tracking, family resightings, landfill sightings, and opportunistic sightings, using Animal Movement Extension in ArcView 3.3 (Hooge and Eichenlaub 2000). We created minimum convex polygon (MCP) home range estimates for marked adults that reared young, and for family groups after fledging, with locations collected during pre-fledge and post-fledge stages. Each individual's or family's nest location was included in the polygon calculation. We were missing data for marked adults in Kuparuk in 2005 because both ravens abandoned their nests early in the season and were not seen thereafter. We describe juvenile survival for each cohort we banded in 2004 and 2006 as the percentage of individuals sighted in their second, third, and fourth summers both in the oilfields and elsewhere in Alaska.

Diet Composition Assessment

We separated and identified animal remains from pellets collected in 2004 (n = 149) and 2005 (n = 198). We identified these remains to species level when possible or to higher taxonomic levels when species could not be determined. In addition to pellets, we identified prey remains (n = 33) near pellets collected in 2004 and 2005 and eggshells (n = 38) from 2004. Eggshells were collected only at Prudhoe Bay in 2004 because additional field assistance allowed us to discover caches near some nests sites. We summarized diet contents as occurrence of items in the pellet (percent of pellets that contained ≥ 1 food item in the pellet). Anthropogenic materials (trash and domestic animal remains) found in pellets were included in this summary.

Results

Assessment of Breeding Population

In 2007, 17 nests were initiated in Prudhoe Bay including Deadhorse, and seven nests were initiated in Kuparuk (Figure 1). Of all sites used in 2006 (n = 25), 68% were used in 2007; 75% of Prudhoe Bay sites were reused in contrast to 55%

of Kuparuk sites. Of five marked adults nesting across the oil fields in 2006 (n = 2 in Kuparuk, n = 3 in Prudhoe Bay), only two Prudhoe Bay individuals returned to their former nest site. Interestingly, one nest site used in 2006 by a marked individual in 2006 was occupied in 2007 by an unmarked pair, even though the known individual was within the area.

Nest and Nest Site Characteristics

We found a total of 88 nests from 2004-2007: 18 in 2004, 21 in 2005, 25 in 2006, and 24 in 2007. Nests occurred primarily on processing facilities (n = 41) and drill sites (n = 31) and to a lesser extent (n = 16) on other types of infrastructure (bridges, inactive drill rigs, radar tower). Of the nests used in all four years (n = 9), 77% were on processing facilities in contrast to 11% on drill sites and 11% on other infrastructure.

Ravens built nests primarily on pipes and structural support beams of buildings, bridges, and large tanks (Table 1). Nests on structural beams were most common at processing facilities and other infrastructure. Nests were placed on pipes only at processing facilities and drill sites, while nests on exhaust vents were found only at drill sites. Both processing facilities and drill sites had nests on heated substrates (e.g. pipes, exhaust vents, and cable trays). Nest height ranged from 3-30 m and half of all nests were oriented to the south (Table 1). South-facing nests were most common at drill sites and other infrastructure.

Proximity of nests (2004-2006) to topographic features varied by nest site type and between Kuparuk and Prudhoe (Table 2). Distance to nearest neighbor for all nests ranged from 1.8-27.6 km and was similar between Kuparuk and Prudhoe. Nests at drill sites were closer to each other than at processing facilities or other infrastructure. Nests ranged from 2.4 -53.1 km to either Prudhoe or Nuiqsut landfills and were closer to a landfill in Prudhoe than Kuparuk. Likewise, all nests were closer to camps in Prudhoe than Kuparuk, ranging from 0.9-37.0 km; nests on processing facilities were closest to camps. Nests in Kuparuk were closer to drill rig activity in February than in March (Table 2).

Table 1. Nest characteristics of common raven breeding in Alaska's North Slope oil fields 2004-2007. Nest height is mean ± s.d., all others are percents within each infrastructure type.

Nest Characteristics	Facility n= 21	Drill site n = 23	Other n = 11	Total Nest Sites n = 55
Height	13.6 ± 6.8	7.9 ± 3.9	12.5 ± 11.2	11.0 ± 7.3
Aspect				
North	19.0	4.3	9.1	10.9
South	38.1	65.2	45.5	50.9
East	23.8	8.7	0	12.7
West	4.8	13.0	9.1	9.1
Other	14.3	8.7	36.4	16.4
Substrate types				
Heated Substrate	33.3	43.5	0	29.8
Exhaust vent	0	21.7	0	9.1
Structural beam	38.1	8.7	100	41.8
Cable tray	19.0	13.0	0	12.7
Communication Tower	0	8.7	0	3.6
Pipe	28.6	26.1	0	21.8
Platform ladder	14.3	0	0	5.5
Tank platform/beams	0	21.7	0	9.1

Table 2. Distance (mean ± s.e.) of common ravens nests to neighboring nests and potential food sources in Alaska's North Slope oilfields, 2004-2007.

Distance (km)	Infrastructure Type				Site		
	Facility	Drill Site	Other	*P*	Kuparuk	Prudhoe	*P*
Nearest Neighbor	13.2 ± 5.3	7.1 ± 5.2	8.4 ± 7.3	ns	9.0 ± 5.1	10.2 ± 4.7	ns
Landfill	28.4 ± 1.6	25.4 ± 1.6	23.5 ± 2.2	ns	40.8 ± 1.6	10.7 ± 1.4	< 0.001
Camp	5.6 ± 1.8	11.7 ± 1.8	10.1 ± 2.3	0.06	14.7 ± 1.7	3.6 ± 1.6	< 0.001
Rig Activity, February	4.7 ± 1.2	7.8 ± 1.2	7.1 ± 1.6	ns	8.9 ± 1.2	4.2 ± 1.1	<0.01
Rig Activity, March	9.0 ± 1.4	11.1 ± 1.3	8.0 ± 1.9	ns	14.5 ± 1.3	4.2 ± 1.2	< 0.001

Movements of Adults

Breeding territory sizes, as determined by minimum convex polygons (MCP) for VHF-transmittered adults (n = 8) in 2004 and 2006, differed between Kuparuk and Prudhoe for pre-fledge and post-fledge periods (Table 3). We were unable to make statistical comparisons among years and between breeding stage and sex due to small sample sizes (Tables 3 & 4). However, pre-fledge territories at Kuparuk appeared larger in 2004 than post-fledge territories at Prudhoe in both 2005 and 2006. Pre-fledge territories (n = 12) for marked adults in all years were smaller (1.8 ± 2.7 km^2) than during post-fledge (10.3 ± 16.6 km^2, n = 13). When families without marked adults were combined with marked adults in the post-fledge assessment, average home range (n = 31) decreased to 8.2 ± 12.5 km^2, yet remained larger than pre-fledge home ranges. There was no clear pattern of territory size between males and females annually and by nesting stage given the small sample sizes and high variation in ranges (Table 4). Pre-fledge territories of females were smaller (1.0 ± 1.4 km^2, n = 7) in all years than post-fledge (14.6 ± 21.4 km^2, n = 8), whereas males were more similar between pre-fledge (2.8 ± 3.9 km^2, n = 5) and post-fledge (4.0 ± 2.5 km^2, n = 6).

Table 3. Territory sizes (km^2; mean ± s.d.) during the nestling and post-fledge periods for common ravens nesting in Alaska's North Slope oil fields, 2004-2006.

Period	Kuparuk			Prudhoe		
	Field Observations	All Observations	n	Field Observations	All Observations	n
Nestling						
2004	5.2 ± 4.0	-	3	0.9 ± 0.6	1.0 ± 0.7	5
2005	-	-	0	0.4	-	1
2006	0.1	10.2	1	0.2 ± 0.1	-	2
Post-fledge						
2004	11.2 ± 9.7	11.5 ± 10.3	3	15.9 ± 27.9	16.7 ± 27.4	5
2005	10.3	-	1	4.1 ± 4.1	4.8 ± 5.5	5
2006	6.7 ± 11.3	18.7 ± 20.6	5	6.5 ± 4.9	10.2 ± 10.1	12

Table 4. Territory sizes (km2) of breeding male and female marked common ravens during pre-fledge and post-fledge periods in Kuparuk and Prudhoe Bay, Alaska 2004-2006

	Male			Female		
	mean ± s.d	range	*n*	mean ± s.d.	range	*n*
Pre-fledge						
2004	3.5 ± 4.2	1.2 - 9.8	4	1.6 ± 1.6	0.1 - 3.6	4
2005	-	-	0	0.3	-	1
2006	0.2	-	1	0.2 ± 0.1	0.1 - 0.3	2
Post-fledge						
2004	3.5 ± 2.1	2.2 - 5.9	3	22.8 ± 29.4	3.2 - 65.7	4
2005	0.1	-	1	10.1	-	1
2006	3.5 ± 4.0	0.7 - 6.3	2	4.9 ± 4.3	0.4 - 8.9	3

Table 5. Territory sizes (km2) of all common raven families observed during post-fledge in Kuparuk and Prudhoe Bay, Alaska, 2005-2006.

	Kuparuk			Prudhoe		
	mean ± s.d	range	*n*	mean ± s.d	range	*n*
2005	10.3	-	1	2.6 ± 2.7	0.03 - 6.5	4
2006	6.7 ± 11.3	0.2 - 26.5	5	6.3 ± 4.7	0.2 - 17.0	12

Movements of Juveniles

Of juveniles marked in 2004 (n = 33), 18% were observed again during their first year, 21% in the second year, and 15% in the third year. Juveniles marked in 2005 (n = 8) were not resighted in any subsequent years. We observed 24% of juveniles marked in 2006 (n = 50) in the oil fields up to early May 2007. Juveniles (n = 9) from both 2004 and 2006 cohorts were observed outside of the oil fields in 2004-2006; five of those individuals were observed outside of the North Slope. One individual returned to the oil fields in summer 2005 after being sighted during the previous winter in Fairbanks. Dead juveniles were recovered in July-August in 2005 (n = 1) and 2006 (n = 5) at the base of or on power transformers in Prudhoe Bay. Electrocution was identified as the cause of mortality either by witnesses who reported the event, or the presence of singed feathers.

Diet Composition

Small mammal jaws were found in more than half of the pellets collected in 2004 and 2005. Northern collared lemming (*Dicrostonyx groenlandicus)* occurred most frequently, followed by brown lemming (*Lemmus trimucronatus)*, tundra vole

Table 6. Contents of pellets (n = 347) collected from under and around raven nests in Alaska's North Slope oil fields 2004-2005. Number of pellets is the count of pellets containing one or more of that item, percent is proportion of total pellets containing that item. Unidentified bones were believe to be chicken and pork (anthropogenic sources).

Class	Contents	Number of Pellets	% Pellets
Aves			
	Total remains (feathers, bones)	66	19.0
	Eggshell fragments	29	8.3
	Duck remains	4	1.1
Mammalia			
	Total remains (hair, feet, bones)	192	55.3
	Total small mammal jaws	174	50.1
	Dicrostonyx groenlandicus	106	30.3
	Lemmus trimucronatus	35	10.0
	Microtus miurus	5	1.4
	Microtus oeconomous	15	4.3
	Cleithronomus rutilus	1	0.2
	Sorex spp.	2	0.5
Insecta	*Coleoptera spp.*	2	0.5
Osteichythes		2	0.5
Unidentified Bones		88	25.2
Anthropogenic		40	11.5
Unclassified remains		113	32.4

(*Microtus oeconomous)*, and singing vole (*M. miurus)* respectively (Table 6). Avian remains occurred in 19 % (n = 66) of the pellets (Table 6). Of the prey remains collected with pellets (n = 33), 15 % were avian, 12 % mammalian, and 66 % unidentified bones. Eggshells (n = 38) were primarily goose (57%) followed by duck (32%), and to a lesser extent ptarmigan (5%) and unidentified species (5%).

Discussion

Ravens used many of the same nests in 2007 as 2006, and nest-site fidelity by marked adults at Prudhoe suggested these sites were important. The high proportion of processing facilities used repeatedly over the course of the study suggests they may be preferred over drill sites and other types of infrastructure. Processing facilities have more opportunities for nest placement at various heights and on various substrates, some of which are heated or in close proximity to heat. Average nest height in our study (11.0 ± 7.3 m) was at the low end of the range for ravens nesting on trees and cliffs elsewhere in North America (3-30 m, Boarman and Heinrich 1999). Processing facilities rarely exceed 30 m and their tallest portions did not appear to provide features for nest placement. In addition, higher human activity at processing facilities may be beneficial because of increased food opportunities. Fidelity to drill sites may be lower than processing facilities because they have fewer nest substrates, fewer heated substrates, and lower human activity overall. Drill site features were also more exposed to the elements than those on processing facilities and other infrastructure. It was more common for drill site nests to be on heated substrates and facing south than processing facilities (other infrastructure does not produce heat).

Ravens appeared to have similar spacing requirements between Kuparuk and Prudhoe. Territorial spacing for ravens varies throughout their North American range (1.6-8.2 km/nearest neighbor) but factors that affect these densities are not well documented (Boarman and Heinrich 1999). Territoriality is likely more important in comparison to food point subsidies and human activity patterns in how ravens select nest sites in the oil fields. Proximity to anthropogenic food point subsidies (landfill, worker camps) was more variable between Kuparuk and Prudhoe in part because the layout of infrastructure varied. Anthropogenic foods associated with human activity (e.g. drilling rig activity) may not be a useful measure to understand nest use patterns given the variability we observed between Kuparuk and Prudhoe types of nest sites.

Breeding adults foraged close to their nests during the nestling stage, and moved greater distances away from nest sites once fledging occurred; a pattern observed for breeding ravens in central California (Roth et al. 2004). Common ravens in California used areas less than 5 km^2 around their nests during all stages of the breeding cycle when human food subsidies were included in their territories (Linz et al. 1992, Roth et al. 2004). In our study, average territory size after fledging was, in most years, larger than the territories observed in California. It is difficult to make conclusions about movements of oil field ravens relative to other studies because of our limited sample size, combined with the fact that we relied on methods other than telemetry after the first year. Methodological constraints in some instances may have contributed to the large variation in home ranges. Locating individuals and families in Prudhoe Bay was easier than Kuparuk because there were more roads.

Our observations of juveniles, in addition to reported sightings from the public, suggested they might have lower survival than juveniles in southern California (Webb et al. 2004). However, our estimates were not a robust approximation of juvenile survival. It is possible that in the oil fields, industrial infrastructure and activities posed more dangers to juvenile ravens; power transformers were common near nests and we documented electrocutions of juveniles in 2005 and 2006. Finally, our estimates only accounted for those juveniles that remained on or returned to the oil fields in a given year. Locations of juveniles we documented during this study, suggest some juveniles leave the North Slope and return to the oil fields in subsequent years.

Ravens in the oil fields appeared to be generalist foragers. Based on our collections and occurrence of food items we identified in the pellets, small mammals were an important component of the diet. Temple (1974) found similar species in the pellets of winter roosting ravens in Umiat, AK, although in his sample brown lemmings were almost as common as collared lemmings. Avian remains present in both pellets and whole remains near nests suggested ravens were predators and/or scavengers of birds as well. Many items more digestible than small mammal bones were likely to be underrepresented in the pellets (Redpath et al. 2001). It was also difficult to assess the importance of anthropogenic foods for oil fields ravens because these foods (excluding bones and packing material) were digestible. Kristan et al. (2004) showed the frequency of trash in pellets of southern California ravens nesting near anthropogenic food subsidies was higher than those far from subsidies. The nests in our study area were all associated with human infrastructure and human activity.

Future Directions

We continue to analyze data from all years of this study. Work on the final report will be completed this year. The final report will include summaries and maps of adult and juvenile locations during the non breeding season, maps of breeding territories, summer landfill counts of ravens and marked adults and juveniles, and summaries of breeding raven foraging observations.

Study Products

Presentations

Backensto, S., A. Powell, G. Kofinas, C. Gerlach, and E. Follmann. The Common Raven (*Corvus corax*) on the North Slope of Alaska. 28 March 2007, Alaska Cooperative Research Unit Review Fairbanks, AK.

Backensto, S., A. Powell, G. Kofinas, C. Gerlach, and E. Follmann. The Common Raven (*Corvus corax*) on the North Slope of Alaska. 6 February 2007, Coastal Marine Institute Annual Research Review, University of Alaska , Fairbanks, AK.

Backensto S. A. Powell, G. Kofinas, C. Gerlach, and E. Follmann. The Common Raven (*Corvus corax*) through the eyes of oil field workers: Local knowledge in Alaska's North Slope Oil fields. 7-9 February, 2006 11th Annual Alaska Bird Conference Juneau, AK.

Backensto, S., A. Powell, G. Kofinas, C. Gerlach, and E. Follmann. The Common Raven (*Corvus corax*) on the North Slope of Alaska. 30 March 2005, Alaska Cooperative Research Unit Review Fairbanks, AK.

Morse, J. and S. Backensto. Don't Mess with Black Birds: Ravens, Oystercatchers, and Resilience. 10 March 2005, Alaska Bird Observatory Seminar Series Fairbanks AK.

Backensto, S., A. Powell, G. Kofinas, C. Gerlach, E. Follmann. The Common Raven (*Corvus corax*) on the North Slope of Alaska. 14-16 March, 2005, Minerals Management Service (MMS) – Alaska Outer Continental Shelf (OCS) Region 10th Information Transfer Meeting (ITM), Anchorage, AK.

Backensto, S., A. Powell, G. Kofinas, C. Gerlach, and E. Follmann. The Common Raven (*Corvus corax*) on the North Slope of Alaska. 8 March 2005, Coastal Marine Institute Annual Research Review, University of Alaska , Fairbanks, AK.

Backensto, S., A. Powell, G. Kofinas, C. Gerlach, and E. Follmann. Industrial Opportunivores. Alaska Public Lands Saturday Seminar Series 26 March 2005, Fairbanks, AK.

Backensto, S., A. Powell, G. Kofinas, C. Gerlach, and E. Follmann . The Common Raven (*Corvus corax*) on the North Slope of Alaska. 9 February 2005, National Park Service Brown Bag Lunch, Fairbanks, AK.

Backensto, S., A. Powell, G. Kofinas, C. Gerlach, and E. Follmann. The Common Raven (*Corvus corax*) on the North Slope of Alaska. 28 October 2004, FWS Brown Bag Lunch. Fairbanks, AK.

Backensto, S., A. Powell, G. Kofinas, and C. Gerlach. The Common Raven (*Corvus corax*) on the North Slope of Alaska: Wildlife Management and the Human Dimension (poster). 10 March 2004, Tenth Alaska Bird Conference and Workshops, Anchorage, AK.

Backensto, S., A. Powell, G. Kofinas, and C. Gerlach. The Common Raven (*Corvus corax*) on the North Slope of Alaska: Wildlife Management and the Human Dimension (poster). 25 February 2004, Alaska Cooperative Research Unit Review, Fairbanks,AK.

Backensto, S. and A. Powell. The Common Raven (*Corvus corax*) on the North Slope of Alaska: Wildlife Management and the Human Dimension (poster). 27 October 2003, HARC Patterns, Connections, and Methods Workshop, Seattle, WA.

Backensto, S. and A. Powell. The Common Raven (*Corvus corax*) on the North Slope of Alaska: Wildlife Management and the Human Dimension (poster). 27 October 2003, SEARCH Open Science Meeting. Seattle, WA.

Backensto, S. and A. Powell. The Common Raven (*Corvus corax*) on the North Slope of Alaska: Wildlife Management and the Human Dimension (poster). 30 April 2003, Cooper Ornithological Society Meeting Annual Meeting Flagstaff, AZ.

Press Releases

Foraging ecology of common ravens on Alaska's North Slope – this study gets considerable press and stories have appeared in newspapers throughout the world:

"Ravens interactions with oil rigs studied", by Dan Joling, Associated Press (http://www.enn.com/today.html?id=6946)

"Study says ravens thriving in Alaska oil fields", Reuters News Service, (http://www.planetark.com/dailynewsstory.cfm/newsid/29993/newsDate/18-Mar2005/story.htm)

"UAF's most wanted birds", by Jennifer Miller, UAF Sun Star (http://www.uaf.edu/sunstar/rchives/20050412/birds.htm)

Radio – "Alaska's oil field ravens", Arctic Science Journeys (http://www.ualedu/seagrant/NewsMedia/05ASJ/04.01.05oil-ravens.html)

"North Slope ravens force researcher to go incognito", by Ned Rozell, (www.gi.alaska.edu/ScienceForum/ASF18/ 1808.html)

"Her fat suit fools some wild ravens", by Ned Rozell (http://www.adn.com/life/story/9289910p-9204374c.html)

Acknowledgments

We would like to thank the following research institutes, industries, and agencies for financial support and/or collaboration: Coastal Marine Institute, NSF Regional Resilience and Adaptation Program, Center for Global Change, U.S. Geological Survey Alaska Cooperative Fish and Wildlife Research Unit, ConocoPhillips Alaska, Inc., BP Exploration (Alaska), Inc., Minerals Management Service, Bureau of Land Management, U.S. Fish and Wildlife Service, and North Slope Borough. We would also like to thank personnel at the North Slope Borough Prudhoe Bay Landfill and the communities of Kuparuk and Prudhoe Bay. Philip Martin, Ted Swem, and Debbie Nigro also provided valuable contributions to this study.

Literature Cited

Boarman, W. I. and B. Heinrich. 1999. Common raven (*Corvus corax*). *In* the Birds of North America, No. 476 (A. Poole and F. Gill, eds.). The Birds of North America, Inc. Philadelphia, PA.

Boarman, W. I., M.A. Patten, R.J. Camp, and S.J Collis. 2006. Ecology of a population of subsidized predators: Common ravens in the central Mojave Desert, California. Journal of Arid Environments 67:248-261.

Day, R. H. 1998. Predator populations and predation intensity on tundra-nesting birds in relation to human development. Unpubl. Report, prepared for U.S. Fish and Wildlife Service, Fairbanks, AK, by ABR, Inc., Fairbanks, AK. 106 pp.

Engel, K. A. and L. S. Young. 1989. Spatial and temporal patterns in the diet of common ravens in southwestern Idaho. Condor 91:372-378.

Hooge, P. N. and B. Eichenlaub. 2000. Animal Movement extension to ArcView, Version 1.1. U.S. Geological Survey, Alaska Biological Science Center, Anchorage, AK.

Kristan, W. and W. Boarman. 2003. Spatial pattern of risk of common raven predation on desert tortoises. Ecology 84(9):2432-2443

Kristan, W. B. B. Boarman, and J. Crayon. 2004. Diet composition of common ravens across the urban-wildland interface of the west Mojave Desert. Wildlife Society Bulletin 32:244-253.

Linz, G. M., E. Knittle, and R.E. Johnson. 1992. Home range of breeding common ravens in coastal Southern California. Southwestern Naturalist 37:199-202.

National Audubon Society. 2004. www.audubon.org/bird/cbc/

Neatherlin, E. A. and J. M. Marzluff. 2004. Responses of American crow populations to campgrounds in remote native forest landscapes. Journal Wildlife Management 68:708-718.

Redpath, S. M., R. Clarke, M. Madders, and S. J. Thirgood. 2001. Assessing raptor diet: comparing pellets, prey remains, and observational data at hen harrier nests. Condor 103:184-188.

Restani, M., J. M. Marzluff, and R. E. Yates. 2001. Effects of anthropogenic food sources on movements, survivorship, and sociality of common ravens in the Arctic. Condor 103:399-404.

Roth, J., J. Kelly, W. Sydeman, and M. Colwell. 2004.

Sex differences in space use of breeding common ravens in western Marin County, California. Condor 106:529-539.
Sara, M. and B. Busalacchi. 2003. Diet and feeding habits of nesting and non-nesting ravens (*Corvus corax*) on a Mediterranean island (Vulcano, Eolian archipelago). Ethology, Ecology, and Evolution 15:119-131.
Temple, S. A. 1974. Winter food habits of ravens on the arctic slope of Alaska. Arctic 27:41-46.
Truett, J. C. and S. R. Johnson. 2000. The natural history of an arctic oil field: development and the biota. Academic Press, San Diego, CA.
Webb, W. C., W. I. Boarman, and J. T. Rotenberry. 2004. Common raven juvenile survival in a human-augmented landscape. Condor 106:517-528

Final Reports Pending

TO	Title	Authors	Status
15177	**Alaska Sea Ice Atlas**	**Orson P. Smith** *afops@uaa.alaska.edu* School of Engineering University of Alaska Anchorage 3211 Providence Drive Anchorage, AK 99508-8054 **William J. Lee** *afwjl3@uaa.alaska.edu*	**SFOS Dean is working with the PI to obtain an acceptable final report.**
15178	**A Nowcast/Forecast Model for the Beaufort Sea Ice – Ocean – Oil Spill System (NFM-BSIOS)**	**Jia Wang** *jwang@iarc.uaf.edu* International Arctic Research Center Frontier Research System for Global Change University of Alaska Fairbanks Fairbanks, AK 99775-7340 **Meibing Jin** *ffjm@uaf.edu* Institute of Marine Science University of Alaska Fairbanks Fairbanks, AK 99775-7220	**This report will be integrated into Wang's report for TO 35407, "Sea Ice–Ocean–Oilspill Modeling System".**
37628	**Seasonability of Boundary Conditions for Cook Inlet, Alaska**	**Stephen Okkonen** *okkonen@alaska.net* Institute of Marine Science University of Alaska Fairbanks Fairbanks, AK 99775 **W. Scott Pegau** *afwjl3@uaa.alaska.edu* Oil Spill Recovery Institute P.O. Box 705 Cordova, AK 99574 **Susan Saupe** *Saupe@circac.org* Cook Inlet RCAC 910 Highland Ave. Kenai, AK 99611	**This report has been submitted to MMS for editing.**
73070	**High-Resolution Numerical Modeling of Near-Surface Weather Conditions over Alaska's Cook Inlet and Shelikof Strait**	**Peter Q. Olsson** *auclima@uaa.alaska.edu* University of Alaska Anchorage 3211 Providence Drive Anchorage, Alaska 99508	**This report has been submitted to CMI for final edit.**
85308	**Water and Ice Dynamics in Cook Inlet**	**Mark Johnson** *johnson@ims.uaf.edu* Institute of Marine Science University of Alaska Fairbanks Fairbanks, AK 99775	**This report has been submitted to CMI for final edit.**

CMI Program Funding Summary

Student Support

The cooperative agreement that formed the University of Alaska Coastal Marine Institute stressed the need to support education, as well as research. The following student support information is summarized from proposals and may not accurately reflect actual expenditures.

Fiscal Year 1994		Students	MMS Funds	Matching Funds
	PhD	1	$22,558	$9,220
	M.S.	6	$65,107	$37,411
	Undergrad	1	$4,270	$0
Source Total			**$91,935**	**$46,631**

Fiscal Year 1995		Students	MMS Funds	Matching Funds
	PhD	4	$53,061	$9,523
	M.S.	8	$90,367	$64,380
	Undergrad	5	$4,297	$13,933
Source Total			**$147,725**	**$87,836**

Fiscal Year 1996		Students	MMS Funds	Matching Funds
	PhD	5	$75,499	$8,499
	M.S.	5	$80,245	$18,661
	Undergrad	2	$4,644	$0
Source Total			**$160,388**	**$27,160**

Fiscal Year 1997		Students	MMS Funds	Matching Funds
	PhD	2	$37,714	$0
	M.S.	2	$22,798	$0
	Undergrad	2	$2,610	$0
Source Total			**$63,122**	**$0**

Fiscal Year 1998		Students	MMS Funds	Matching Funds
	PhD	2	$17,109	$17,109
	M.S.	2	$26,012	$7,200
	Undergrad	2	$0	$2,548
Source Total			**$43,121**	**$26,857**

Fiscal Year 1999		Students	MMS Funds	Matching Funds
	PhD	6	$66,750	$38,073
	M.S.	4	$31,650	$8,730
	Undergrad	4	$0	$10,704
Source Total			**$98,400**	**$57,507**

Fiscal Year 2000		Students	MMS Funds	Matching Funds
	PhD	6	$61,383	$30,551
	M.S.	2	$5,868	$10,135
	Undergrad	7	$0	$21,299
Source Total			**$67,251**	**$61,985**

Fiscal Year 2001		Students	MMS Funds	Matching Funds
	PhD	2	$19,159	$22,019
	M.S.	1	$0	$5,800
	Undergrad	3	$10,983	$5,761
Source Total			**$30,142**	**$33,580**

Fiscal Year 2002		Students	MMS Funds	Matching Funds
	PhD	3	$48,476	$0
	M.S.	5	$66,676	$7,500
	Undergrad	0	$0	$0
Source Total			**$115,152**	**$7,500**

Fiscal Year 2003		Students	MMS Funds	Matching Funds
	PhD	3	$45,032	$12,000
	M.S.	5	$79,448	$7,500
	Undergrad	1	$1,349	$0
Source Total			**$125,829**	**$19,500**

Fiscal Year 2004		Students	MMS Funds	Matching Funds
	PhD	4	$55,365	$15,000
	M.S.	2	$34,715	$0
	Undergrad	0	$0	$0
Source Total			**$90,080**	**$15,000**

Fiscal Year 2005		Students	MMS Funds	Matching Funds
	PhD	2	$30,942	$0
	M.S.	2	$6,385	$0
	Undergrad	1	$1,398	$0
Source Total			**$38,725**	**$0**

Fiscal Year 2006		Students	MMS Funds	Matching Funds
	PhD	2	$21,132	$6,667
	M.S.	1	$0	$0
	Undergrad	2	$0	$0
Source Total			**$21,132**	**$6,667**

Fiscal Year 2007		Students	MMS Funds	Matching Funds
	PhD	0	$0	$0
	M.S.	1	$82,635	$0
	Undergrad	0	$0	$0
Source Total			**$82,635**	**$0**

	MMS	Matching
Totals to Date	$1,175,637	$390,223

Total CMI Funding

The total MMS funding committed to CMI projects through federal fiscal year 2007 is approximately $15 million. Since all CMI-funded projects require a one-to-one match with non-federal monies, total CMI project commitments through fiscal year 2007 have totaled approximately $27 million.

Sources of Matching Funds

Matching for CMI-funded projects has come from a wide variety of sources. Identifying and verifying match remains a major administrative challenge in the development of CMI proposals. In general, match has been available to those investigators who expend the necessary extra effort to locate and secure the support. The following partial list of fund matching participants demonstrates the breadth of support for CMI-funded programs:

- Afognak Native Corporation
- Alaska Beluga Whale Committee
- Alaska Department of Environmental Conservation (ADEC)
- Alaska Department of Fish and Game (ADF&G)
- ADF&G – Kachemak Bay Research Reserve
- Alaska Department of Transportation and Public Facilities
- Alaska Science and Technology Foundation
- Alyeska Pipeline Service Company
- Ben A. Thomas Logging Camp
- BP Amoco
- BP Exploration (Alaska) Inc.
- Canadian Wildlife Service
- CODAR Ocean Sensors
- Cominco Alaska, Inc.
- ConocoPhillips Alaska, Inc.
- Cook Inlet Regional Citizens Advisory Council
- Cook Inlet Spill Prevention & Response, Inc.
- Department of Fisheries and Oceans Canada
- Exxon Valdez Oil Spill Trustee Council
- Frontier Geosciences, Inc.
- Golden Plover Guiding Co.
- Littoral Ecological & Environmental Services
- Japanese Marine Science and Technology Center (JAMSTEC)
- Kodiak Island Borough
- North Slope Borough
- Oil Spill Recovery Institute
- Phillips Alaska, Inc.
- Prince William Sound Aquaculture Corporation
- Simon Frasier University
- University of Alaska Anchorage
- University of Alaska Fairbanks
- College of Science, Engineering & Mathematics
- Frontier Research System for Global Change, IARC
- Institute of Arctic Biology
- Institute of Marine Science
- International Arctic Research Center (IARC)
- School of Agriculture & Land Resources Management
- School of Fisheries and Ocean Sciences
- School of Management
- School of Mineral Engineering
- University of Alaska Museum
- Wadati Fund
- Water Research Center
- University of Alaska Natural Resources Fund
- University of Alaska Southeast
- University of California, Los Angeles
- University of Northern Iowa
- University of Texas
- Woods Hole Oceanographic Institution

CMI Publications

Contact information

e-mail: sharice@sfos.uaf.edu
phone: 907.474.7208
fax: 907.474.7204
Coastal Marine Institute
School of Fisheries and Ocean Sciences
University of Alaska Fairbanks
P.O. Box 757220
Fairbanks, AK 99775-7220

Alexander, V. (Director). 1995. University of Alaska Coastal Marine Institute Annual Report No. 1. University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 16 p.

Alexander, V. (Director). 1996. University of Alaska Coastal Marine Institute Annual Report No. 2. OCS Study MMS 95-0057, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 122 p.

Alexander, V. (Director). 1997. University of Alaska Coastal Marine Institute Annual Report No. 3. OCS Study MMS 97-0001, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 191 p.

Alexander, V. (Director). 1998. University of Alaska Coastal Marine Institute Annual Report No. 4. OCS Study MMS 98-0005, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 81 p.

Alexander, V. (Director). 1998. University of Alaska Coastal Marine Institute Annual Report No. 5. OCS Study MMS 98-0062, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 72 p.

Alexander, V. (Director). 2000. University of Alaska Coastal Marine Institute Annual Report No. 6. OCS Study MMS 2000-0046, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 86 p.

Alexander, V. (Director). 2000. University of Alaska Coastal Marine Institute Annual Report No. 7. OCS Study MMS 2000-0070, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 92 p.

Alexander, V. (Director). 2002. University of Alaska Coastal Marine Institute Annual Report No. 8. OCS Study MMS 2002-001, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 109 p.

Alexander, V. (Director). 2003. University of Alaska Coastal Marine Institute Annual Report No. 9. OCS Study MMS 2003-003, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 108 p.

Alexander, V. (Director). 2004. University of Alaska Coastal Marine Institute Annual Report No. 10. OCS Study MMS 2004-002, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 119 p.

Alexander, V. (Director). 2005. University of Alaska Coastal Marine Institute Annual Report No. 11. OCS Study MMS 2005-055, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 157 p.

Braddock, J.F., and Z. Richter. 1998. Microbial Degradation of Aromatic Hydrocarbons in Marine Sediments. Final Report. OCS Study MMS 97-0041, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 82 p.

Braddock, J.F., K.A. Gannon and B.T. Rasley. 2004. Petroleum hydrocarbon-degrading microbial communities in Beaufort-Chukchi Sea sediments. Final Report. OCS Study MMS 2004-061, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 38 p.

Cook, J.A. and G.H. Jarrell. 2002. The Alaska Frozen Tissue Collection: A Resource for Marine Biotechnology, Phase II. Final Report. OCS Study MMS 2002-027, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 23 p.

Cook, J.A., G.H. Jarrell, A.M. Runck and J.R. Demboski. 1999. The Alaska Frozen Tissue Collection and Associated Electronic Database: A Resource for Marine Biotechnology. Final Report. OCS Study MMS 99-0008, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 23 p.

Duesterloh, S., and T.C. Shirley. 2004. The Role of Copepods in the Distribution of Hydrocarbons: An Experimental Approach. Final Report. OCS Study MMS 2004-034, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 53 p.

Duffy, L.K., R.T. Bowyer, D.D. Roby and J.B. Faro. 1998. Intertidal Effects of Pollution: Assessment of Top Trophic Level Predators as Bioindicators. Final Report. OCS Study MMS 97-0008, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 62 p.

Gradinger, R. and B. Bluhm. 2005. Susceptibility of sea ice biota to disturbances in the shallow Beaufort Sea: Phase 1: Biological coupling of sea ice with the pelagic and benthic realms. Final Report. OCS Study MMS 2005-062, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 87 p.

Henrichs, S.M., M. Luoma and S. Smith. 1997. A study of the Adsorption of Aromatic Hydrocarbons by Marine Sediments. Final Report. OCS Study MMS 97-0002, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS Alaska OCS Region, 47 p.

Herrmann, M., S.T. Lee, C. Hamel, K.R. Criddle, H.T. Geier, J.A. Greenberg and C.E. Lewis. 2001. An Economic Assessment of the Sport Fisheries for Halibut, Chinook and Coho Salmon in Lower and Central Cook Inlet. Final Report. OCS Study MMS 2000-061, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and US DOI, MMS, Alaska OCS Region, 135 p.

Highsmith, R.C., S.M. Saupe and A.L. Blanchard. 2001. Kachemak Bay Experimental and Monitoring Studies: Recruitment, Succession, and Recovery in Seasonally Disturbed Rocky-Intertidal Habitat. Final Report. OCS Study MMS 2001-053, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 66 p.

Holladay, B.A., B.L. Norcross and A. Blanchard. 1999. A Limited Investigation into the Relationship of Diet to the Habitat Preferences of Juvenile Flathead Sole. Final Report. OCS Study MMS 99-0025, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 27 p.

Johnson, M.A., and S.R. Okkonen [eds.]. 2000. Proceedings Cook Inlet Oceanography Workshop. November 1999, Kenai, AK. Final Report. OCS Study MMS 2000-043, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 118 p.

Kelly, B.P., O.P. Harding, M. Kunnasranta, L.T. Quakenbush, and B.D. Taras. 2005. Correction Factor for Ringed Seal Surveys in Northern Alaska. Final Report. OCS Study MMS 2005-006, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 32 p.

Kline, T.C., J.R., and J.J. Goering. 1998. North Slope Amphidromy Assessment. Final Report. OCS Study MMS 98-0006, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska Region, 25 p.

Konar, B. 2006. Role of Grazers on the Recolonization of Hard-Bottom Communities in the Alaska Beaufort Sea. Final Report. OCS Study MMS 2006-015, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska Region, 23 p.

McCracken, K.G., S.A. Sonthagen, S.L. Talbot, R.B. Lanctot, and K.T. Scribner. 2006. Population Genetic Structure of Common Eiders (Somateria mollissima) Nesting on Coastal Barrier Islands Adjacent to Oil Facilities in the Beaufort Sea, Alaska. Final Report. OCS Study MMS 2006-040, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 94 p.

Musgrave, D., and H. Statscewich. 2006. CODAR in Alaska. Final Report. OCS Study MMS 2006-032, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 23 p.

Naidu, A.S., J.J. Goering, J.J. Kelley and M.I. Venkatesan. 2001. Historical Changes in Trace Metals and Hydrocarbons in the Inner

Shelf Sediments, Beaufort Sea: Prior and Subsequent to Petroleum-Related Industrial Developments. Final Report. OCS Study MMS 2001-061, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 80 p.

Naidu, A.S., J.J. Kelley, J.J. Goering and M.I. Venkatesan. 2003. Trace Metals and Hydrocarbons in Sediments of Elson Lagoon (Barrow, Northwest Arctic Alaska) as Related to the Prudhoe Bay Industrial Region. Final Report. OCS Study MMS 2003-057, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 33 p.

Naidu, A.S., J.J. Kelley, D. Misra and M.I. Venkatesan. 2006. Trace Metals and Hydrocarbons in Sediments of the Beaufort Lagoon, Northeast Arctic Alaska, Exposed to Long-term Natural Oil Seepage, Recent Anthropogenic Activities and Pristine Conditions. Final Report. OCS Study MMS 2005-041, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 57p.

Niebauer, H.J. 2000. Physical-Biological Numerical Modeling on Alaskan Arctic Shelves. Final Report. OCS Study MMS 2000-041, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 84 p.

Norcross, B.L., B.A. Holladay, A.A. Abookire and S.C. Dressel. 1998. Defining Habitats for Juvenile Groundfishes in Southcentral Alaska, Vol. I. Final Report. OCS Study MMS 97-0046, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 131 p.

Norcross, B.L., B.A. Holladay, A.A. Abookire and S.C. Dressel. 1998. Defining Habitats for Juvenile Groundfishes in Southcentral Alaska, Vol. II. Final Report, Appendices. OCS Study MMS 97-0046, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 127 p.

Okkonen, S.R., and S.S. Howell. 2003. Measurements of Temperature, Salinity and Circulation in Cook Inlet, Alaska. Final Report. OCS Study MMS 2003-036, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 28p.

Okkonen, S.R. 2005. Observations of hydrography and currents in central Cook Inlet, Alaska during diurnal and semidiurnal tidal cycles. Final Report. OCS Study MMS 2004-058, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 28 p.

Powell, A., L. Phillips, E.A. Rexstad, E.J. Taylor. 2005. Importance of Alaskan Beaufort Sea to King Eiders (Somateria spectabilis). Final Report. OCS Study 2005-057, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 40 p.

Powell, A., R.S. Suydam, and R. Mcguire. 2005. Breeding Biology of King Eiders on the Coastal Plain of Northern Alaska. Final Report. OCS Study 2005-060, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 40 p.

Proshutinsky, A.Y.2000. Wind Field Representations and Their Effect on Shelf Circulation Models: A Case Study in the Chukchi Sea. Final Report. OCS Study MMS 2000-011, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 136 p.

Proshutinsky, A.Y., M.A. Johnson, T.O. Proshutinsky and J.A. Maslanik. 2003. Beaufort and Chukchi Sea Seasonal Variability for Two Arctic Climate States. Final Report. OCS Study MMS 2003-024, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 197 p.

Quakenbush, L. and R. Small. 2005. Satellite Tracking of Bowhead Whales: The Planning Phase 1. Final Report. OCS Study MMS 2005-058, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 24 p.

Shaw, D.G., and J. Terschak. 1998. Interaction Between Marine Humic Matter and Polycyclic Aromatic Hydrocarbons in Lower Cook Inlet and Port Valdez, Alaska.

Final Report. OCS Study MMS 98-0033, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 27 p.

Schell, D.M. 1998. Testing Conceptual Models of Marine Mammal Trophic Dynamics Using Carbon and Nitrogen Stable Isotope Ratios. Final Report. OCS Study MMS 98-0031, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 137 p.

Terschak, J.A., S.M. Henrichs and D.G. Shaw. 2004. Phenanthrene Adsorption and Desorption by Melanoidins and Marine Sediment Humic Acids. Final Report. OCS Study MMS 2004-001, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 65 p.

Tyler, A.V., C.O. Swanton and B.C. Mcintosh. 2001. Feeding Ecology of Maturing Sockeye Salmon (Oncorhynchus nerka) in Nearshore Waters of the Kodiak Archipelago. Final Report. OCS Study MMS 2001-059, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 34 p.

Wang, J. 2006. Proceedings of a Workshop on Hydrological Modeling of Freshwater Discharge from Alaska's Arctic Coast. Final Report. OCS Study MMS 2005-043, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 56 p.

Wang, J. 2003. Proceedings of a Workshop on Small Scale Sea-Ice and Ocean Modeling (SIOM) in the Nearshore Beaufort and Chukchi Seas. Final Report. OCS Study MMS 2003-043, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 56 p.

Weingartner, T.J. 1998. Circulation on the North Central Chukchi Sea Shelf. Final Report. OCS Study MMS 98-0026, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 39 p.

Weingartner, T.J. 2006. Circulation, thermohaline structure, and cross-shelf transport in the Alaskan Beaufort Sea. Final Report. OCS Study MMS 2006-031, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 58 p.

Weingartner, T.J., and S.R. Okkonen. 2001. Beaufort Sea Nearshore Under-Ice Currents: Science, Analysis and Logistics. Final Report. OCS Study MMS 2001-068, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska Region, 22 p.

Weingartner, T.J., and T. Proshutinsky. 1998. Modeling the Circulation on the Chukchi Sea Shelf. Final Report. OCS Study MMS 98-0017, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska Region, 75 p.

Winker, K., and D.A. Rocque. 2004. Seabird Samples as Resources for Marine Environmental Assessment. Final Report. OCS Study MMS 2004-035, University of Alaska Coastal Marine Institute, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region, 26 p.

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 principals 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.