University of Alaska

Coastal Marine Institute

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OCS Study MMS 2002-001

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OCS Study MMS 2002-001

University of Alaska Coastal Marine Institute

IN COOPERATION
Minerals Management Service
University of Alaska
State of Alaska

Annual Report No. 8
Federal Fiscal Year 2001

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TO
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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 2001 Annual Report, our eighth annual report. Of the 15 research projects covered, one has been completed and the principal investigator is preparing the final report. Only the abstract and study products are included for this project. Abstracts for the three proposals funded in FY2001 are in the New Projects section.

The Minerals Management Service administers the outer continental shelf (OCS) natural gas, oil, and marine minerals program in which it oversees 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 activities?

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. Under this program, MMS takes advantage of highly-qualified scientific expertise at local levels in order to:

1. Collect and disseminate environmental information needed for OCS oil & gas and marine minerals decisions;

2. Address local and regional OCS-related environmental and resource issues of mutual interest; and

3. Strengthen the partnership between MMS and the state in addressing OCS oil & gas and marine minerals information needs.

CMI is administered by the University of Alaska Fairbanks School of Fisheries and Ocean Sciences to address some of these mutual concerns and share the cost of research. 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:

1. Scientific studies for better understanding marine, coastal, or human environments affected or potentially affected by offshore oil and gas or other mineral exploration and extraction on the outer continental shelf;
2. Modeling studies of environmental, social, economic, or cultural processes related to OCS gas and oil activities in order to improve scientific predictive capabilities;
3. Experimental studies for better understanding of environmental processes or the causes and effects of OCS activities;
4. 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 and gas and marine mineral resources; and
5. Synthesis studies of scientific environmental or socioeconomic information relevant to the OCS gas and oil program.

Projects funded through CMI are directed towards providing information which can be used by MMS and the state for management decisions specifically relevant to MMS mission responsibilities. 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. However, a strong interest in Cook Inlet and Shelikof Strait remains.

The proposal process is initiated each summer with a request for letters of intent to address one or more of the Framework Issues. This request is publicized and sent to researchers at the University of Alaska and to various state agencies, and to relevant profit and non-profit corporations. The CMI technical steering committee then decides which of the proposed letters of intent should be developed into proposals for more detailed evaluation and possible 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.

Correction Factor for Ringed Seal Surveys in Northern Alaska

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Task Order 15162

Abstract

The proportion of radio-tagged ringed seals visible on the ice surface from April to June in 1999 and 2000 was used to estimate correction factors for aerial surveys. Eight and ten ringed seals were live-captured in 1999 and 2000, respectively, and their time resting on the ice was monitored by radio telemetry. The transition period, defined as the period during which the majority (75%) of the tagged seals began resting outside of lairs, was longer in 2000 (24 days) than it was in 1999 (7 days). The midpoint of the transition period, the day by which 50% of the tagged seals began resting in the open, was 31 May in both years. Only once each year was a lair used subsequent to each seal's first appearance outside of a lair. Changes in the number of seals counted during ground-based, visual surveys of seals resting on the ice corresponded to changes in the number of radio-tagged seals basking. Tagged seals spent approximately 20% of the time out of the water before appearing outside of lairs and approximately 30% of the time out of the water after they began to abandon lairs. The transition from lair use to resting in the open appeared to be related to measurable characteristics of the snow.

Introduction

Aerial surveys have been widely used to estimate local densities and, by extrapolation, population size, of ringed seals (*Phoca hispida*) and other pinnipeds [Chapman et al. 1977; Stirling et al. 1977; Harwood and Stirling 1992; Rogers and Bryden 1997; Garner et al. 1999]. Spatial and temporal comparisons typically rest on the assumption (often implicit) that the proportion of animals visible is constant from survey to survey [Caughley 1977; Drummer 1999]. In a few instances, that assumption has been tested in harbor seal (*Phoca vitulina richardsi*) populations using radio telemetry [Withrow and Loughlin 1995, 1996; Huber et al. 2001]. Another recent approach to harbor seal surveys ignored the unseen fraction and analyzed population trends by adjusting counts to standardized conditions based on environmental and temporal co-variates [Frost et al. 1999]. The latter approach assumes that the appropriate co-variates have been identified to predict the peak number of animals potentially visible. Further complications are that seasonal peaks in the number of seals out of the water vary by demographic class, and the timing of those peaks may vary from year to year depending on food availability [Green et al. 1995; Daniel et al. 1999; Jemison and Kelly 2001].

Pinnipeds occupying sea ice are especially difficult to count, because they are broadly distributed on a moving substrate [Green et al. 1995]. Ringed seals, for example, are found in all seasonally ice-covered seas of the northern hemisphere [Scheffer 1958; King 1983]. They likely are the most numerous phocid in the hemisphere [Scheffer 1958; Smith 1987; Kelly 1988], but a reliable worldwide population estimate is lacking due to the difficulties of surveying such an expansive habitat [Kelly 1988]. Nonetheless, regional and local aerial surveys have been used for temporal and spatial comparisons of densities. Assessing the impacts of harvests, ship traffic, and offshore industrial activities on ringed seal populations has depended heavily on analyses of temporal trends in local densities as estimated by aerial surveys. An inherent assumption of that approach is that the proportion of seals visible is constant over time. Surveys of visible seals have been used to test for inter-annual changes in density within local areas and to compare densities over areas that required several days to weeks to survey. For example, since 1970, the Alaska Department of Fish and Game (ADF&G) contrasted densities in several sectors along the Chukchi and Beaufort sea coasts of Alaska and related the observed differences to habitat features and human activities including industrial activities [Burns and Harbo 1972; Burns and Kelly 1982; Frost and Lowry 1988, 1999; Frost et al. 1988, 1997, 1998]. More recently LGL Limited environmental research associates (LGL) used aerial surveys to contrast densities at a much finer scale to assess potential impacts of oil developments on ringed seals [Green and Johnson 1983; Link et al. 1999; Moulton and Elliott 1999; Moulton et al. 2000].

In the case of ringed seals, the proportion of the population that is visible during a survey is not only a function of the proportion of seals in vs. out of water (as in other pinnipeds) but also of the proportion under vs. on top of the snow. During winter and much of the spring, ringed seals come out of the water to rest primarily in subnivean lairs excavated above breathing holes in the sea ice [Chapskii 1940; McLaren 1958; Smith and Stirling 1975]. Surveys of ringed seals have been concentrated in late May and early June when some of the seals are visible resting on the surface of the ice. Adult seals are molting then and regeneration of the epidermis requires that they bask in the sun to elevate skin temperatures [Feltz and Fay 1966; King 1983]. At that time of year, seals partition their time between diving under the ice, where they are not visible, and resting on top of the ice, where they may or may not be visible.

Comparisons of local densities of seals visible on the ice have been used to assess the effects of human activities on ringed seals [Frost and Lowry 1988; Kelly et al. 1988; Richardson and Williams 2000]. Frequently, the human activities of concern occurred some months before the surveys were conducted, and the assumption was made that local seal densities had not changed in the interim. Radio tracking and intensive aerial survey efforts, however, indicated that some ringed seals may move away from their winter range when they emerge from their lairs to bask on top of the ice. At least four of thirteen seals tracked telemetrically near Prudhoe Bay in the 1980s "hauled out at new sites ... several kilometers" from those occupied prior to the beginning of snow melt [Kelly and Quakenbush 1990]. Two of ten seals tracked in the Canadian Arctic basked at sites several kilometers from lairs they occupied earlier in the spring [Kelly, unpublished]. The density of seals visible nearshore decreased while the density offshore increased near Prudhoe Bay during intensive aerial surveys conducted over eight days in 1999 [Moulton et al. 2000]. The changes in densities in 1999 were interpreted as a large-scale movement of seals, but no such shift was evident in similar surveys conducted in 2000 or 2001 [M. Williams, pers. comm.]. We do not know what determines whether ringed seals bask at the same breathing holes they used during their months under the ice and snow.

We used radio telemetry to determine where and when in April, May, and early June ringed seals were concealed under the ice, concealed in subnivean lairs, or visible on top of the snow and ice. We simultaneously monitored weather and snow conditions to determine the relationships between environmental variables and the availability of seals for counting. Our objectives were to determine (1) if there is a predictable period when the proportion of seals visible is constant, (2) the correction factor(s) necessary to adjust counts of seals visible to yield estimates of population size, (3) the environmental conditions that influence the proportion of seals visible, and (4) whether the distribution of seals basking in May and June reflects the distribution of seals during winter months.

Methods

We monitored the use of subnivean lairs by ringed seals in the nearshore Alaskan Beaufort Sea seaward from Prudhoe Bay (70° 22.0′N, 148° 22.0′W) to just beyond Reindeer Island (70° 29.1′N, 148° 21.4′W). Shorefast ice covers the area from October to July in most years [Wise and Searby 1977]. Water depths are mostly less than 9 m with a maximum of 15 m. Most of the snowfall occurs during September and October when there is open water on the Beaufort Sea providing moisture [Dingman et al. 1980; Walker et al. 1980]. Snow is redistributed by winds throughout the winter [Benson et al. 1975] forming areas of shallow snow over smooth ice and drifts on the windward and leeward sides of irregularities in the ice surface (e.g., pressure ridges). Wind-packed snow, in which ringed seals excavate subnivean lairs, reaches maximal depth in May, averaging 30–40 cm [Benson et al. 1975].

Dogs, trained to indicate sources of ringed seal odor, located subnivean breathing holes and lairs [Smith and Stirling 1975; Kelly and Quakenbush 1987], and we marked those sites with numbered wooden stakes and recorded the locations with Global Positioning Systems.

We captured seals in nets that pursed below them when they entered breathing holes [Kelly 1996], and we glued VHF radio transmitters with unique frequencies to the hair on each seal's back. We monitored radio signals hourly from stations equipped with 8-element Yagi antennas on a 35-ft high mast and within 5 km of the seal capture sites. We rotated the antenna through 360° while monitoring and recorded the direction from which each signal was received. Each time a seal came out of the water, as indicated by the presence of its radio signal, we determined its location using a mobile receiver and hand-held directional antenna array. The directional antenna array consisted of two H-antennas communicating with the acoustic receiver by way of a null combiner. Thus, the bearing from the array to a transmitter was indicated by a null surrounded by high amplitude signals. Typically, five or more bearings (with an accuracy of approximately ±3°) from points surrounding a tagged seal were obtained and the seal's position read as the intersection of those bearings. Once the seal's position was determined, we recorded whether each seal was concealed within a lair or visible on the snow surface.

We used the delta method to calculate the correction factor (and its uncertainty), by which counts of seals should be multiplied to account for unseen seals based on the proportion of tagged seals visible.

We counted all seals visible on the ice in an area of approximately 25 km^2 daily (ca. 16:00 Alaska daylight time) from 29 May to 10 June 2000. We used binoculars (Leica and Zeiss 10×42) to make the counts from the roof of a building 62 m above the ice at the southern edge of the study area.

We recorded air temperature, snow temperature (from ice surface to snow surface at 5 cm intervals), wind speed, and wind direction within the study area every 30 minutes from 21 April to 8 June 2000. The data were stored on a CR10 data logger and SM192 storage module (Campbell Scientific). We examined changes in the distribution of liquid water in the snow pack, snow depth, the size and morphology of snow grains, and the overall snow landscape to monitor the transformation of the snow pack during snowmelt. We also obtained reports of satellite-borne Ku-band backscatter data for our study area from the Jet Propulsion Laboratory in California.

Data from the aerial surveys were acquired from LGL (1999 and 2000) and the Alaska Department of Fish and Game (1999).

Results

The trained dogs located 86 breathing holes and lairs in 1999 and 202 in 2000. An additional 19 and 8 breathing holes and lairs were located by tracking radio-tagged seals in 1999 and 2000, respectively. The overall distribution and density of breathing holes and lairs were similar between years, although there was a greater concentration of breathing holes in the southeastern portion of the study area in 2000. Most of those holes were on an active crack.

We set nets in breathing holes 27 times in 1999 and captured 8 seals 9 times (1 recaptured). In 2000, we set nets 41 times and captured 10 seals 15 times (5 recaptured). We tagged and tracked 2 male and 6 female seals in 1999 and 7 male and 3 female seals in 2000.

Temporal patterns in the proportion of seals visible

Aerial surveys of ringed seals in the Alaskan Beaufort Sea have spanned nearly one month, with surveys conducted as early as 25 May and as late as 21 June. In the 1970s, surveys were always conducted in June, but in the 1980s and 1990s, surveys were conducted increasingly earlier (Figure 1).

The first radio-tagged seals appeared on the ice outside of lairs on 21 May 1999 and on 3 May 2000. The latter, an adult male (EL00) was captured on 3 May 2000 at a hole already open to the surface and, apparently, began basking there as early as 26 April when a seal was visually observed resting next to that hole.

Seals spent more time out of the water once they began emerging outside of lairs. The probability of a tagged seal being out of the water increased from 0.18 when seals were using lairs to 0.30 when seals were basking in 1999 and from 0.14 when using lairs to 0.37 when basking in 2000. When basking, the tagged seals showed a strong diel pattern in the proportion of time spent on the ice. Less than 20% of the tagged seals were visible on the ice between 0000 h and 0800 h (Alaska daylight time), after which the proportion increased rapidly until about 1200 h (Figure 2). The proportion continued to increase slowly until 1600 h, after which it declined slowly until about 1900 h and then rapidly until about 0300 h. More than 45% of the tagged seals were visible on the ice between 1200 h and 1900 h.

Correction factors

To determine if our sample of radio-tagged seals represented the behavior of the population as a whole, we compared, in 2000, the proportion of tagged seals visible with the total number of seals visible in a 25 km^2 area expressed as a fraction of the maximal count of visible seals (Figure 3). The cumulative proportion of tagged seals visible corresponded well with the total number of seals visible.

In both 1999 and 2000, the proportions of tagged seals visible on the ice increased in late May early June (Figure 4). Tagged seals began emerging later in 1999 than in 2000, and the proportion visible on the ice increased more slowly in 2000. We observed maximal proportions of 0.41 on 3 and 7 June 1999 and 0.64 on 9 June 2000, but we do not know if those proportions increased after our observations ended on 7 June (1999) and 11 June (2000). Thus, calculated correction factors varied widely from day to day and inter-annually during the typical aerial survey period in the Alaskan Beaufort Sea (Table 1).

Discussion

Seasonal changes in proportions of time spent basking affect the interpretation of aerial survey data. For example, surveys flown on 6 June 1999 would count, on average, 40% of the population; however, surveys flown on 29 May 1999 would count, on average, 12% of the population. Inter-annual variability in the duration and timing of the transition period further complicates between-year interpretations of aerial survey data.

Previous investigations have found inconsistent relationships between the density of visible ringed seals and air temperature, wind speed, and cloud cover [Kingsley et al. 1985; Stirling et al. 1977; Burns and Harbo 1972; Burns and Kelly 1982; Frost et al. 1988]. We are exploring the use of temperature of the snow pack (which integrates air temperature, wind speed, and cloud cover) to predict when seals are visible. We observed a longer transition period in 2000 (24 days) than in 1999 (7 days), but the periods were centered on nearly the same date. In both years, the transition periods corresponded to changes in the temperature of the snow near the snow–ice interface. Most of the radio-tagged seals were basking as the temperature of the snow reached 0 °C.

It may be possible to use historical records of snow conditions to estimate the transition period for previous years and to correct past surveys for the proportion of ringed seals not visible. Records of snow temperature on the ice are lacking, but it may be possible to use snow temperature records from the tundra as a proxy.

The transition from dry, insulating snow to wet, conductive snow is visible in Ku-band radar backscatter signatures. In collaboration with S.V. Nghiem at the Jet Propulsion Laboratory in California, we obtained Ku-band backscatter images of our study area in spring 2000 and were able to correlate the transition of radio-tagged seals from lair use to basking with the changes in the radar backscatter. The use of the Ku- band radar data as an early indicator of snowmelt conditions and as a means to determine (remotely and in real time) when to fly aerial surveys of ringed seals is worthy of further investigation.

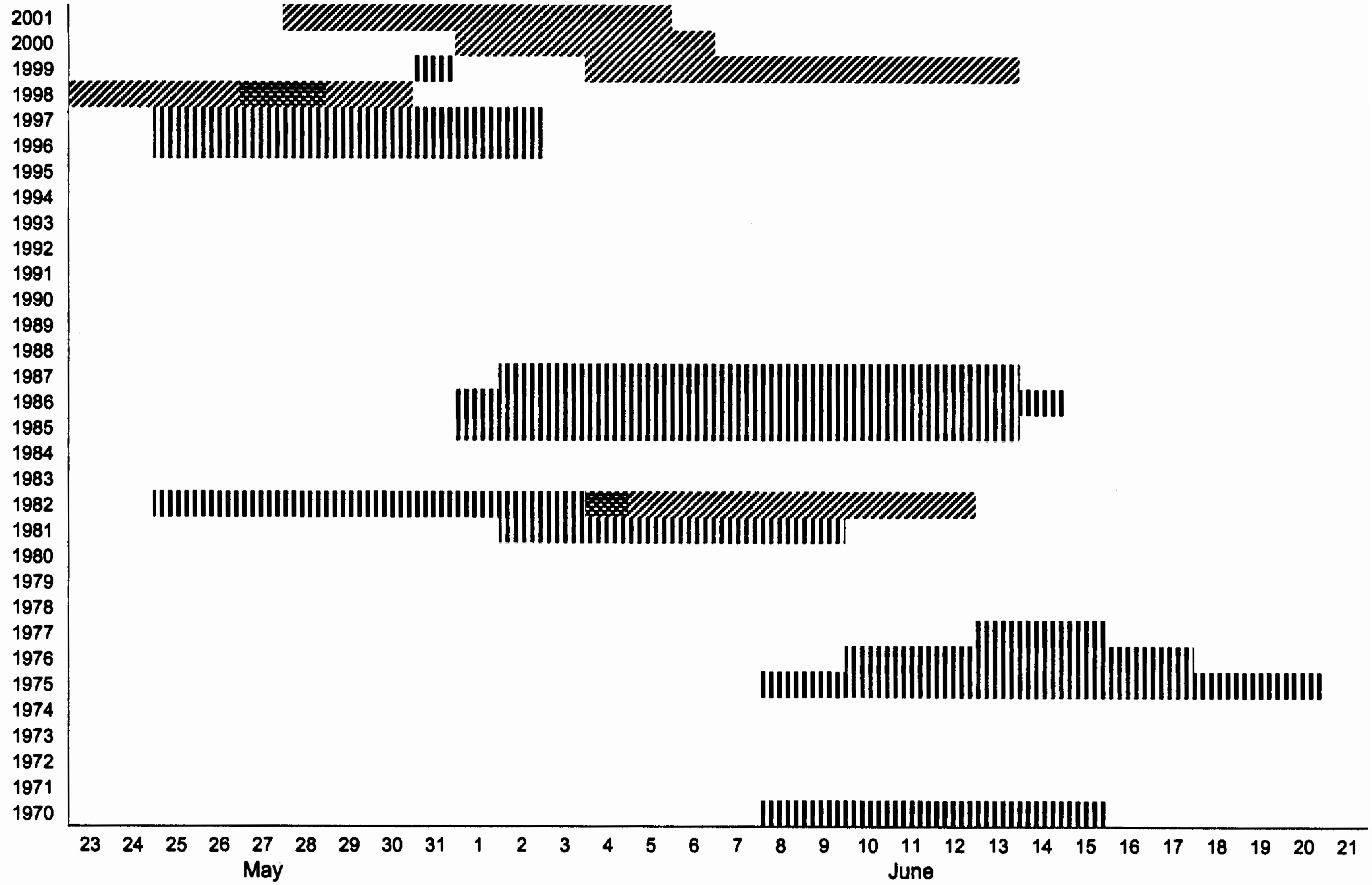

Figure 1. Dates of aerial surveys of ringed seals conducted along the Beaufort Sea coast of Alaska by LGL Limited (▨) and the Alaska Department of Fish and Game (▥).

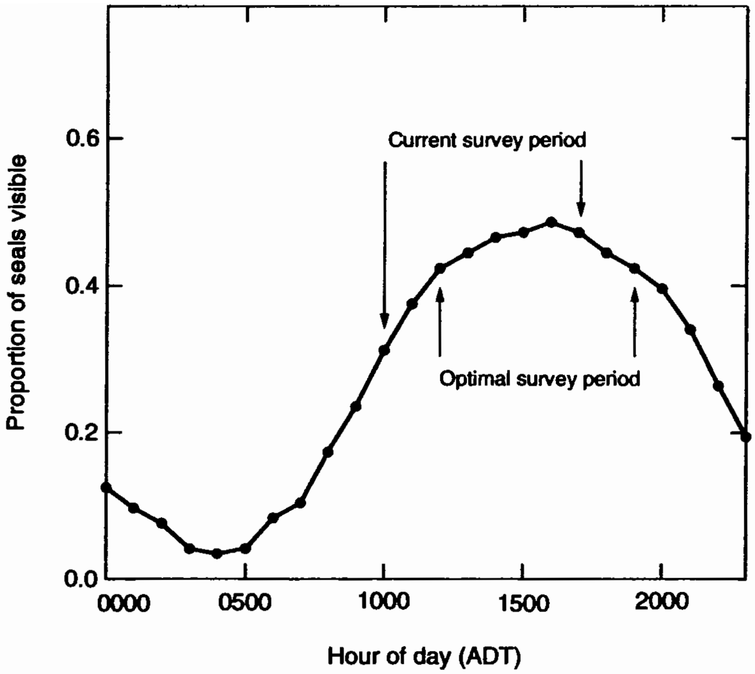

Figure 2. Diel pattern in the proportion of radio-tagged seals out of the water, and potentially visible to observers in aircraft, after the abandonment of lairs.

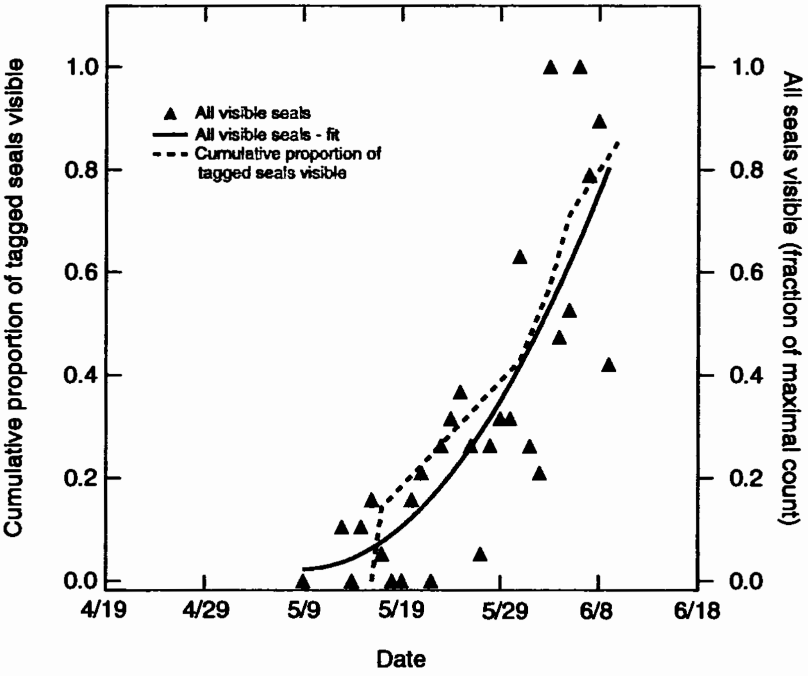

Figure 3. The cumulative proportion of radio-tagged seals visible on the surface of the ice and the total number of seals visible, expressed as a fraction of the maximal count of visible seals.

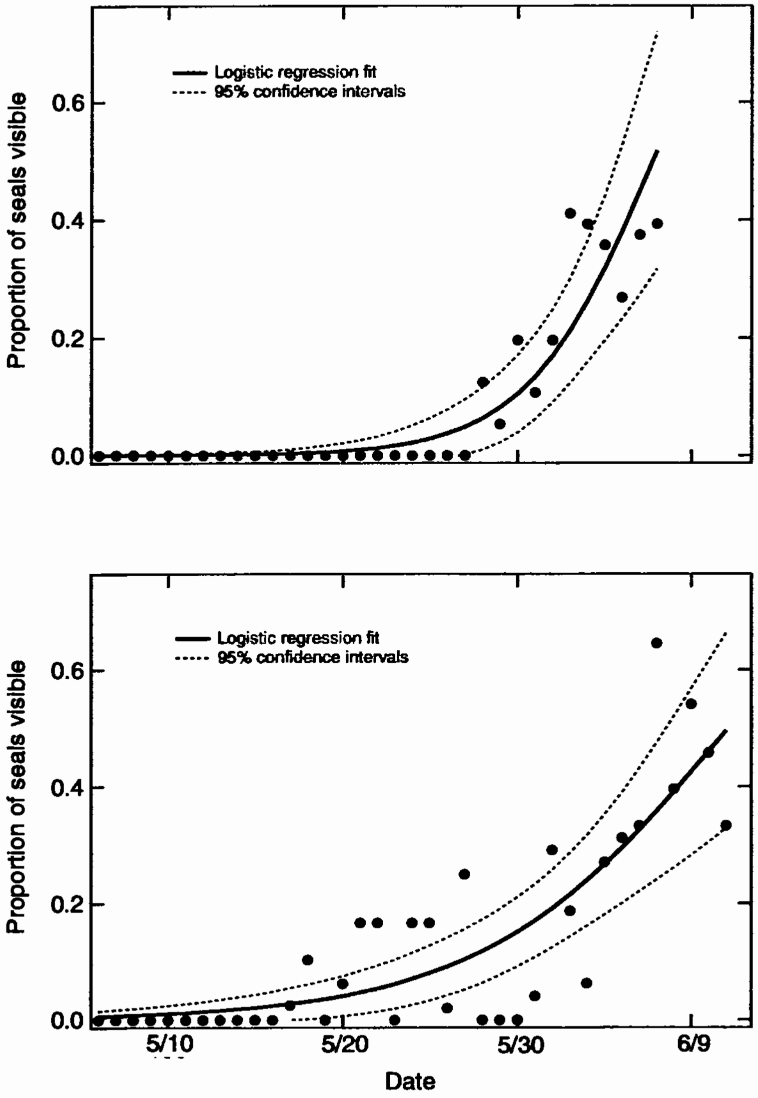

Figure 4. The proportion of radio-tagged seals visible on the ice from 9 May through 9 June in 1999 (upper panel) and 2000 (lower panel).

Table 1. Daily correction factors (CF) and coefficients of variation (CV) for counts of ringed seals during usual survey dates in the Alaskan Beaufort Sea. CF's were calculated based on telemetric observations of 8 seals in 1999 and 10 seals in 2000. Also indicated are dates of aerial surveys conducted in our study area by the Alaska Department of Fish and Game (ADF&G) and LGL Limited (LGL).

	1999			2000		
Date	CF	(CV)	Aerial survey	CF	(CV)	Aerial survey
24 May	>11[a]			11.00	(0.50)	
25 May	>13[a]			>11[a]		
26 May	>13[a]			11.00	(0.50)	
27 May	>13[a]			>11[a]		
28 May	13.00	(0.50)		>11[a]		
29 May	>13[a]			>11[a]		
30 May	4.75	(0.44)		11.00	(0.50)	
31 May	13.00	(0.50)	ADF&G	4.00	(0.43)	LGL
1 June	4.75	(0.44)		11.00	(0.50)	LGL
2 June	2.78	(0.37)		>11[a]		LGL
3 June	2.78	(0.37)		4.00	(0.43)	LGL
4 June	2.78	(0.37)	LGL	4.00	(0.43)	LGL
5 June	4.75	(0.44)	LGL	4.00	(0.43)	LGL
6 June	2.78	(0.37)	LGL	1.63	(0.27)	LGL
7 June	2.78	(0.37)	LGL	4.00	(0.43)	LGL
8 June	No data	—	LGL	2.33	(0.35)	
9 June	No data	—	LGL	2.33	(0.35)	
10 June	No data	—	LGL	4.00	(0.43)	

[a] No tagged seals visible, and CF estimated as greater than the CF calculated when one seal was visible.

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Study Products

Presentations on this project were delivered in several venues in 2001. In February 2001, Oriana Harding presented a poster at the American Society of Limnology and Oceanography [Harding et al. 2001], Lori Quakenbush presented an update to the Coastal Marine Institute, and Brendan Kelly presented a paper at an international conference in Switzerland [Kelly 2001]. In April 2001, Brendan Kelly presented on the project at the Minerals Management Service Information Transfer Meeting in Anchorage and at the 16th meeting of the U.S.–Russia Marine Mammal Project Meeting in Santa Cruz, California. In May 2001, he also presented aspects of the work at the MountainFilm Festival in Telluride, Colorado. A report on the work will be presented orally at the 14th Biennial Conference on the Biology of Marine Mammals to be held next winter in Vancouver, British Columbia [Kelly et al. 2001].

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Circulation, Thermohaline Structure, and Cross-Shelf Transport in the Alaskan Beaufort Sea

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The Canadian and Japanese partners are providing in-kind (matching) support to this project through shiptime (Japan and Canada) and instrumented moorings (Japan).

Task Order 15163

Abstract

This program has collected hourly time series of ocean velocity, temperature, and salinity properties from moored instruments deployed along the outer shelf and slope of the Alaskan Beaufort Sea for a period of one year. The goals are to: 1) quantify the vertical and cross-shore spatial and temporal scales of variability in the circulation and the density (thermohaline) field in this region and 2) estimate the transport within the eastward flowing subsurface undercurrent. The flow and the density structure on the outer shelf and slope affect the cross-shelf transfer of momentum, water properties (heat, salt, nutrients, etc.), contaminants, and pollutants. The region is also an important migratory corridor for marine mammals, particularly bowhead whales that feed here during part of the year. Previous measurements showed that the near surface flow (< ~50 m depth) here, and over the inner shelf, is westward and forced by the winds. However, flow reversals are common and often a result of upwelling of the undercurrent. Further, the pressure field responsible for the undercurrent must influence the dynamics of the inner shelf. The undercurrent originates in the eastern Arctic as a result of inflow through Fram Strait and is fed by outflows from the Eurasian shelf seas and the Chukchi Sea. Hence it is circumpolar in extent and carries with it a variety of water masses. The flow could thus transport pollutants from these regions to the Alaskan shelf. The proposed observations will provide information crucial in guiding model development and evaluating the performance of pollution transport models. The study site is practical (from the resource manager's perspective and for logistical reasons) and optimal from a scientific perspective, for measurements here will capture the integrated effects of the circumpolar forcing which we believe force the undercurrent.

Background and Framework Issues

Flow along the Alaskan Beaufort Sea shelf is influenced by the flow adjoining the slope and shelfbreak. This is a complicated flow field consisting of a surface (upper 50 m), westward flow and a subsurface, eastward flow. The surface flow is wind driven and forced by the prevailing northeasterly wind field and comprises the southern limb of the clockwise Beaufort Sea Gyre. The kinematic properties (vertical and horizontal motion scales, speeds, transports, and temporal and spatial scales of variability) are poorly described. The dynamics of the subsurface flow (also know as the Beaufort Undercurrent [Aagaard 1989]) are not understood but include a number of influences—local and far-field along-shore winds, inflows from the continental shelves bordering the Arctic Ocean to the west of the Beaufort Sea, and inflows from the Atlantic and Pacific oceans.

We believe that regional (Beaufort Sea shelf) oil spill trajectory models will need to include the influence of the circulation along the shelfbreak and slope in order to correctly assess the fate and transport of contaminants into the local marine environment. Our observations will guide model development and evaluation.

Objectives

The overall purpose of this program is to provide a kinematical and, where possible, dynamical description of the circulation, thermohaline structure, and cross-shelf transport along the Beaufort Sea shelfbreak and slope. To achieve this goal the field and data analysis portion of the program is designed to address the following questions and objectives:

1. What is the mean transport over the outer shelf and slope and what are the cross-shore and vertical scales of the mean flow field?
2. What are the magnitudes of transport variability and what are the dominant temporal and spatial scales associated with this variability?
2. What is the relation between variations in temperature and salinity and variations in the flow field at time scales from the synoptic to the seasonal? Are changes in the baroclinic flow consistent with changes in the cross-shore density structure?
4. What are the cross-shore fluxes of heat, salt, and momentum? Do these appear to be related to instabilities (eddy generation mechanisms) of the along-shore flow?
5. How are these variations related to changes in the surface wind field?
6. Compare the results obtained from the proposed field program with those collected in 1987/88 by Aagaard [1989], to determine whether recent large changes in the Arctic Ocean are also reflected in conditions in the Beaufort Sea.
7. Combine this data set with other measurements recently acquired from around the Arctic Ocean to provide an updated synthesis that relates the Beaufort Sea to the large-scale circulation of the Arctic Ocean.

Methods

We have completed the field program, which included the deployment of six instrumented moorings at the locations shown in Figure 1 and listed in Table 1. Mooring deployments (fall 1998) and recoveries (fall 1999) were conducted from the CCGS *Sir Wilfred Laurier*, which was provided as non-federal match to this program. All of the moorings were recovered in fall 1999 except for B4. The acoustic releases did not appear to be responding when we attempted recovery. However, persistently bad weather (high winds, freezing spray) limited the amount of effort that could be expended in the search for this mooring to only a few hours. This program was extended for an additional year so that a more intensive effort could be applied to recovering this mooring. The CCGS *Sir Wilfred Laurier* attempted a second recovery in September–October 2000 in the Beaufort Sea. This included a prolonged (3-day) search over 20 km cross-shore and 40 km along-shore around the deployment site attempting to interrogate and range on the acoustic releases. (We theorized that the mooring might have been dragged by sea ice and was therefore no longer at its original site.) We received no responses from the mooring releases. Failure to respond could mean that the releases were damaged (unlikely because we used two releases on the mooring and it is unlikely that both would have malfunctioned) or that the release batteries ran down (again we felt that this was unlikely given that we provided sufficient power for more than two years). We then searched the same area with a side-scan hoping to find the mooring, but there was no indication that the mooring was present in this area. We believe that the subsurface float (at a depth of about 40 m) on the mooring was caught in drifting ice and that the mooring was dragged far afield. We are now analyzing data from the remaining moorings in conjunction with the surface wind field computed from sea level pressure fields prepared by the European Center for Medium Range Weather Forecasting (ECMWF). We obtained these pressure fields from the National Oceanic and Atmospheric Administration's National Center for Atmospheric Research (NOAA, NCAR).

Table 1. 1998 Beaufort Sea mooring deployments.

Mooring ID	Isobath (m)	Current Meter Depth (m) RCM = Default; F = FSI	T/C Depth (m) (M-Cats at 60 m; S-Cats elsewhere)	Latitude (N)	Longitude (W)
MAIN ARRAY					
B1-98	80	50, 70	none	70° 54.30′	146° 41.15′
BF-S-98 (JAMSTEC)	500	50, 90, 180, 240, 400 (S4+CT)	60, 90, 120, 150, 180, 210, 240	70° 56.94′	146° 35.48′
B3-98	1200	50, 150, 250, 400, 900	60, 125, 200, 300	71° 00.78′	146° 36.58′
B4-98	1700	50, 250, 500, 800 (F), 1200	60, 125, 200, 300	71° 07.46′	146° 31.27′
B5a-98	1000	50, 250, 500, 1000 (F), 1500	60, 125, 200, 300	70° 35.62′	139° 57.54′
WESTERN MOORING (JAMSTEC)					
BF-K-98	120	60, 65 (600 kHz ADCP), 95, 108, 115	none	71° 23.00′	152° 04.72′

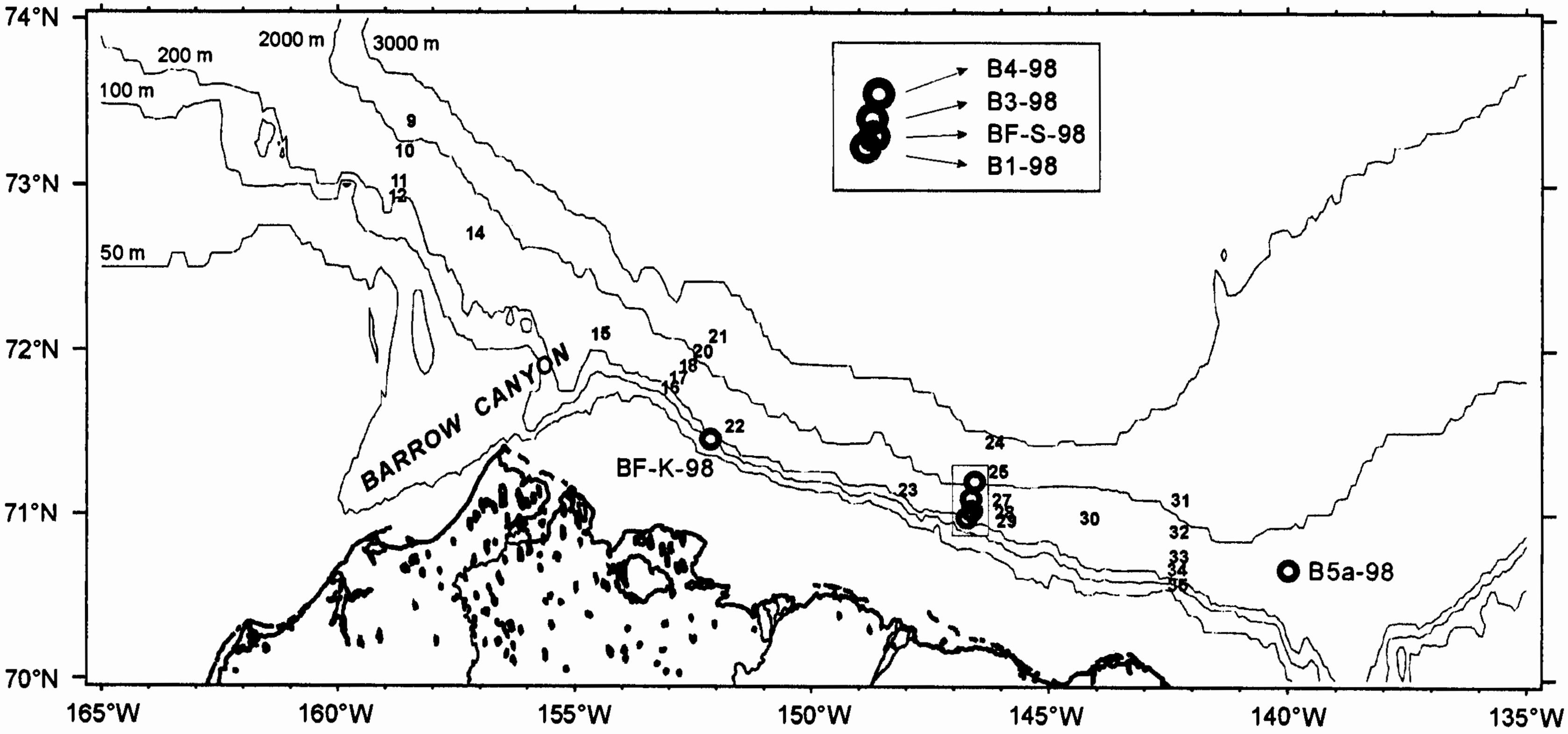

Figure 1. Bathymetric map of the Alaskan Beaufort Sea region showing locations of the moorings listed in Table 1. The numbered locations indicate positions where submarine launched expendable conductivity–temperature–depth probes (SSXCTDs) were launched from the SSN *Hawkbill* in April 1999.

Ancillary Programs

This mooring program complements two additional programs being undertaken simultaneously by the principal investigators. The first is sponsored by the Office of Naval Research (ONR) and is an investigation of the circulation and thermohaline structure of the Chukchi–Beaufort continental slope. It employed the unique sampling capabilities of a U.S. Navy nuclear submarine (*Hawkbill*) operating beneath the ice pack. The sampling included underway measurements of temperature and salinity at a depth of ~130 m from a sail-mounted CTD and submarine-launched expendable CTDs (SSXCTD). Such data are helping to determine the decorrelation length scale of the along-slope density field, the magnitude and structure of the along-shore baroclinic pressure gradient, and along-slope variations in the cross-slope baroclinic pressure gradient. These measurements are directly related to the scales of cross-slope exchanges and forcing mechanisms for the eastward-flowing undercurrent. The second program, sponsored by NOAA, supported moorings in Bering Strait. The purpose of this program is to monitor transport and water mass variations in the strait. Since the flow through Bering Strait eventually feeds the flows along the Beaufort slope, these data are relevant to this CMI program. The strait measurement program results in a nearly 10-year long time series of direct transport measurements in Bering Strait. This time series will allow us to discuss the data from the Beaufort slope mooring program in the context of interannual and seasonal variability of the flow through Bering Strait.

Preliminary Results

We briefly outline two results that illustrate the data that we have gathered. Figure 2 shows time series of the north–south (V) and east–west (U) velocity components, temperature, and salinity from mooring B3-98 at 150-m depth. The data have been smoothed with a 3-day running mean to focus on the low-frequency features. Note that most of the flow is in the east–west component, indicating that it approximately parallels the local isobaths. The along-slope flow varies throughout the year, being weak and variable from July through October 1998, strongly eastward from November 1998 through March 1999, and weak but generally westward from May through September 1999. By contrast, the north–south velocity component is comparatively weak, suggesting that there is little onshore-offshore flow. Temperature and salinity variations are closely correlated throughout the record, indicating water masses from within and below the Arctic Ocean's halocline. Indeed, over most of the record the temperature range is between –0.4 and 0.2 °C and the salinities are between 34.5 and 34.8. These water mass characteristics are of Atlantic Ocean waters that entered the Arctic Ocean through Fram Strait and flowed counter-clockwise around this basin.

Figure 3 shows the along-shore dynamic height obtained from the SSXCTDs collected by the USS *Hawkbill* in April 1999. These data show a trough in the dynamic height at about 150° W (longitude 210). The dynamic height slopes upward to the east and west of the trough. The structure of the along-slope dynamic height field (in conjunction with the cross-shore dynamic height which is not shown) implies a flow with eastward velocity shear (eastward velocities increase or westward velocities decrease with decreasing depth) to the west of 150° W and westward velocity shear (westward velocities increase or eastward velocities decrease with decreasing depth) to the west of 150° W. The dynamic height picture is consistent with the velocity time series from Figure 3 that shows that the eastward flow at 150-m depth decreased from early winter 1998–99 to April 1999. The joint analyses of these data are ongoing.

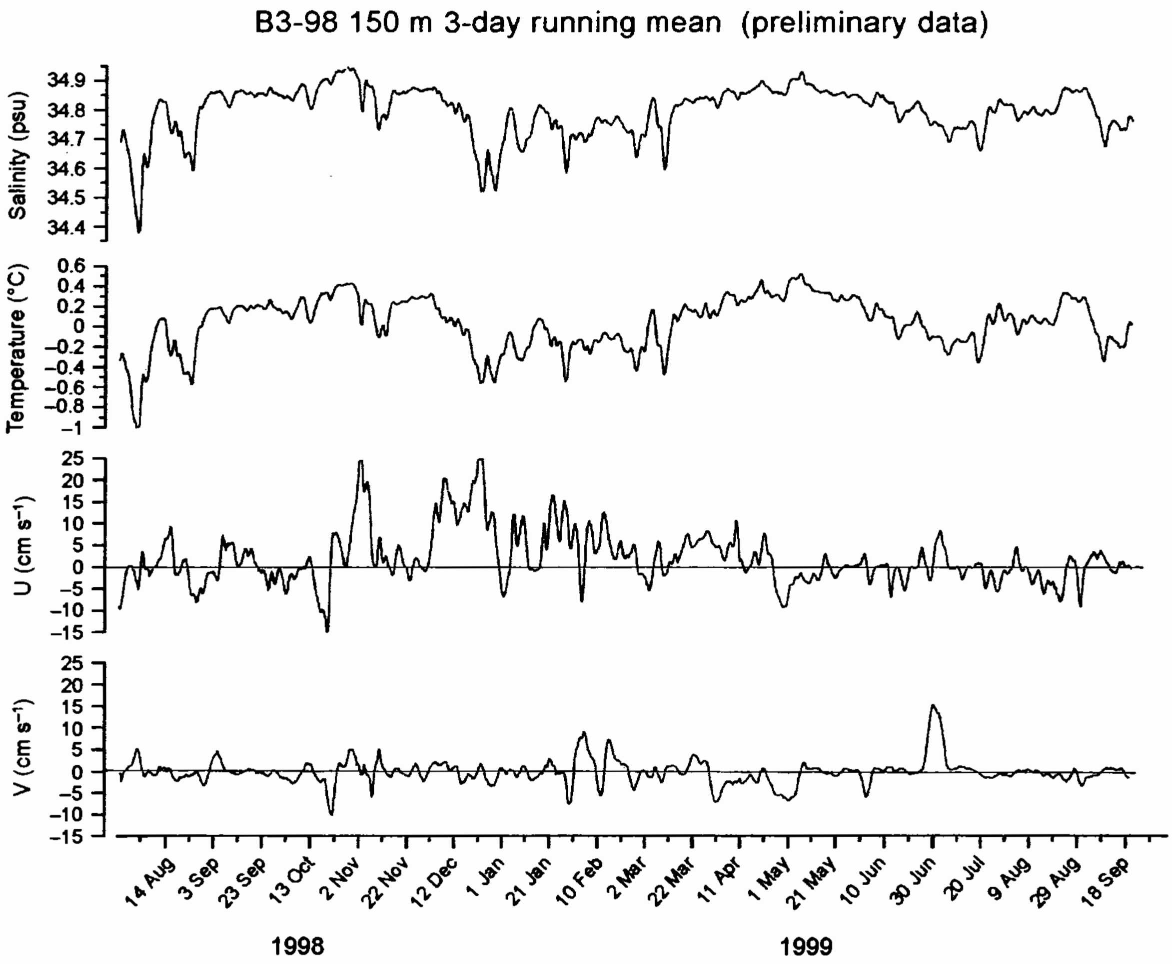

Figure 2. From top to bottom are time series of the salinity, temperature, east–west (U), and north–south (V) velocity components from mooring B3-98 at the 150-m depth. Each time series was smoothed with a 3-day running mean to highlight longer period fluctuations.

Study Products

Weingartner, T.J. 2001. Circulation, thermohaline structure, and cross-shelf transport in the Alaskan Beaufort Sea. University of Alaska Coastal Marine Institute Annual Research Review, February 2001, Fairbanks.

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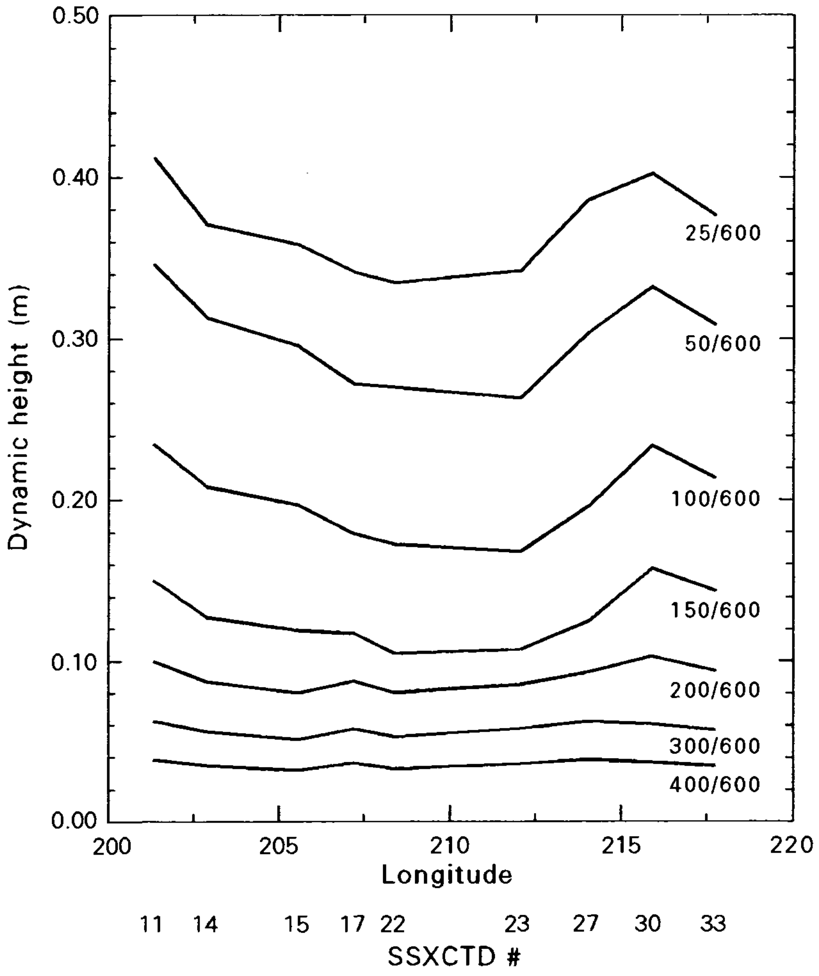

Figure 3. The variation in dynamic height at selected depths (and all referenced to 600 db) from west to east along the Beaufort Sea slope in April 1999.

Reference

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The Alaskan Frozen Tissue Collection and Associated Electronic Database: A Resource for Marine Biotechnology

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Task Order 15164

Abstract

The Alaska Frozen Tissue Collection (AFTC) is the primary regional archive for frozen zoological samples and a major contributor to biotechnology studies of the North Pacific and Arctic oceans. It has become the world's third largest frozen tissue collection for wild mammals. These specimens span five decades of field work, and include samples from throughout Alaska's waters. This is the largest collection of these species worldwide and it is heavily used by marine scientists.

The major accomplishment for the project this year has been the development of the database, adapted from a University of California Berkeley program. Data entry is web based and platform independent. We have started expanding the system to include other University of Alaska Museum collections. The Alaska Frozen Tissue Collection continues to grow and is becoming one of the largest resources of its type. Agreements have been made with Native commissions, and subsistence hunters are actively contributing samples to the collection.

Database

Development of the database was a major activity this year. We moved data on mammals into the Oracle database management system running on Arctos, a Sun Enterprise 250 server dedicated to our collections. The data model has been adapted from the National Science Foundation–funded "Collections Re-engineering Project" at the University of California Berkeley's Museum of Vertebrate Zoology, and this allows us to collaborate with Berkeley on programming and the development of data standards. We are no longer operating the database on personal computers, although we do almost all data entry and editing with platform-independent applications run over the web.

Migration of the data necessitated standardization that is more rigorous. Now, both the power of the relational information architecture, and the increased visibility of the data have revealed many inconsistencies and inaccuracies, most which are remedied quickly. For example, inaccurate geographic coordinates are often obvious when mapped, and now web clients can map queries that return fifty or fewer records by displaying the query on the Xerox Corporation's map server. This system gives users access to most of the data that we have and, unlike its predecessor, it includes specific tissue types in the data returned.

The system is well suited to incorporate data from all of the Museum's biological collections and some geological collections. We also expect to modify it to incorporate several categories of "environmental samples", i.e., samples without formal taxonomic attributes such as soil samples, oceanographic samples, and taxonomically unsorted lots. We have already made a crucial step from one collection to more than one by incorporating the Museum's small collection of amphibians into the Arctos database; additional collections will be primarily a data migration issue.

For the benefit of the Alaska Native Harbor Seal Commission, we have implemented features that hide the names of collectors from the web for specifically flagged specimens. This will probably be desirable for other citizen hunters.

In addition to the specimen data, the Arctos database contains structures to describe specimen usage and summarize results from specimen usage. For example, projects that provide specimens are linked to the projects that have used those specimens and vice versa. Projects are also linked to resultant publications. Web users can search by project name, project-participant name, and year. Some data have been entered into these structures, but in order to be fully functional, we still need to integrate data on loans. This will be completed soon.

The web interface is evolving rapidly as we attempt to make it reflect the depth and range of specimen holdings, and the range of specimen-based activities.

URL: http://arctos.museum.uaf.edu:8080/uam_db

Collection Growth

The AFTC continues to grow, establishing itself as a default repository for samples from regional management agencies, and becoming one of the largest resources of its kind.

Formal agreements for specimen deposition were reached with two Alaska Native marine mammal co-management commissions: the Alaska Native Harbor Seal Commission, and the Alaska Sea Otter and Steller Sea Lion Commission. Both organizations were established under the Native co-management mandate of the Marine Mammal Protection Act, and give Native subsistence hunters substantial control over scientific sampling and the disposition of scientific samples. Both commissions have agreed to deposit samples collected by their members in the AFTC.

The AFTC has cemented its relationship with the Alaska Native Sea Otter and Sea Lion Commission by accepting tissue samples from 299 sea otters taken by subsistence hunters over the past several years. Linda Comerci of the U.S. Fish and Wildlife Service, who works with this co-management commission, provided access to the specimens in Anchorage and assisted with the sub-sampling.

No formal agreement exists with the Alaska Eskimo Whaling Commission, but the Department of Wildlife Management at the North Slope Borough regularly contributes samples from harvested bowhead whales and many other marine mammals. Such long-term arrangements will steadily build chronological samples relevant to environmental change and to parameters that may be changing naturally over time.

Gay Sheffield (Alaska Department of Fish and Game, Fairbanks), working on a contract with the National Marine Mammal Laboratory of the National Oceanic and Atmospheric Administration, provided tissue samples from 38 ice seals (bearded, spotted and ringed) and one belukha whale. Most of this material was from Shishmaref.

Alan Springer (Institute of Marine Science, University of Alaska Fairbanks) provided ten Steller sea lion heads from subsistence hunters in Tatitlek, Alaska. Laura Litzky (School of Fisheries, University of Washington) provided tissues from eight Steller sea lions from Alaska and Washington.

Collection Use

Edward Miller from the Memorial University of Newfoundland spent ten days at the Museum working with bacula from sea otters and seals. He took measurements of 287 specimens.

Personnel

Amy Runck, who was supported as the AFTC coordinator, completed her M.S. degree on the genetics of an interspecific hybrid zone in red-backed voles. She is beginning a doctoral program at Idaho State University this fall.

John Chythlook, who was supported as AFTC subsistence coordinator, completed his M.S. degree on the molecular phylogeography of stickleback fishes. Since finishing he has worked as a fisheries technician for Alaska Department of Fish aand Game, and as a wildlife specialist for the Bristol Bay Native Corporation.

Joseph Cook accepted a professorship at Idaho State University in Pocatello where he is serving as permanent chairman of the Department of Biological Sciences. His research continues to be largely based in Alaska. The Museum and the UAF Department of Biology and Wildlife have formed a search committee for the new curator of mammals.

Gordon Jarrell is serving as acting curator of mammals and coordinator of the AFTC. We are in the final stages of recruiting a replacement for him as mammal collection manager. This eventual separation from the Mammal Collection will allow Dr. Jarrell to concentrate on bringing other marine taxa into the Frozen Tissue Collection.

Gordon Haas has just started at the Museum as curator of fishes. This is a joint appointment with the UAF School of Fisheries and Ocean Sciences. A tenure-track curator for this collection will certainly result in expansion of the AFTC's ichthyological holdings.

Beaufort Sea Nearshore Under-Ice Currents: Science, Analysis and Logistics

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Task Order 15169

Abstract

We measured velocity, temperature, salinity, and transmissivity (a proxy for suspended sediment load) hourly for one year within the landfast ice zone of the Beaufort Sea near Prudhoe Bay, Alaska. The purpose was to measure under-ice and open water currents for evaluating oil-spill trajectories and sedimentation risk in this nearshore environment. The measurements were made from an array of three instrumented moorings spanning an along-shore distance of ~28 km within the western portion of Stefansson Sound. The circulation dynamics vary seasonally and in response to the formation and disappearance of the landfast ice. The landfast ice formed in mid-October 1999 and remained intact until the end of June 2000. Current speeds were typically about 3 cm s^{-1} *and most of the current variability was at subtidal periods. Current speeds greater than 10 cm* s^{-1} *were observed less than 5% of the time at two locations and about 10% of the time at one location. During the open water season, current speeds typically exceeded 10 cm* s^{-1} *and the maximum currents were greater than 10 cm* s^{-1}*. Winds and currents were strongly correlated during the open water season but uncorrelated once the landfast ice was established. The highest transmissivity signals were observed in early October 1999 during a strong gale and in early June, when the landfast ice was still intact and winds were weak. We believe that the June turbidity signal was associated with the summer freshet from the Sagavanirktok River, which flows beneath the landfast ice and (at least) 10 km offshore of the river mouth.*

These data represent the first year-round (including the freeze-up and ice melt seasons) current measurements for this area. This information is critical for designing oil spill response protocols for offshore drilling operations specifically at the nearby Northstar and Liberty fields and generally for similar landfast ice regions of the Alaskan Beaufort Sea. The data should also be useful in evaluating regional numerical circulation models that would be used for oil spill trajectory predictions. While these were the principal reasons for this study, the data will have broader scientific applications relevant to other arctic shelves. For example, the low current energy beneath the landfast ice zone implies little vertical mixing, which has important implications for the fate of river waters entering the shelf in early summer. Consequently, this data will lead to a better understanding of mixing processes and circulation on the innermost portion of arctic shelves.

Study Products

Portions of data collected and analyzed in this project were presented as follows:

Weingartner T.J. 2000. Beaufort Sea nearshore under-ice currents: Science, analysis and logistics, p. 75. *In* University of Alaska Coastal Marine Institute Annual Report No. 6. OCS Study MMS 2000-046, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region.

Weingartner T.J. 2000. Beaufort Sea nearshore under-ice currents: Science, analysis and logistics, p. 37–41. *In* University of Alaska Coastal Marine Institute Annual Report No. 7. OCS Study MMS 2000-070, University of Alaska Fairbanks and USDOI, MMS, Alaska OCS Region.

Weingartner T.J. 2001. Beaufort Sea nearshore under-ice currents: Science, analysis and logistics. University of Alaska Coastal Marine Institute Annual Research Review, February 2001, Fairbanks.

Weingartner, T.J. 2001. Beaufort Sea nearshore under-ice currents: Science, analysis and logistics. MMS Information Transfer Meeting, April 2001, Anchorage.

Weingartner, T.J. 2001. Going to extremes: Buoyancy forcing on arctic continental shelves. Gordon Conference on Coastal Ocean Circulation, June 2001, New London, NH.

Dr. Weingartner was an invited speaker at this conference and presented some of the results from this project at the meeting.

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 OCS Region, 22 p.

Kinetics and Mechanisms of Slow PAH Desorption from Lower Cook Inlet and Beaufort Sea Sediments

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Abstract

The role of humic acid in the adsorption and desorption of organic pollutants in coastal sediments was examined. Humic acids were extracted from intertidal and subtidal Alaska coastal marine sediments, representing a variety of organic matter sources. Melanoidins, used as model humic acids, were synthesized from glucose and bovine casein. The natural and synthetic humic acids were characterized by elemental and isotopic analyses, as well as by Fourier transform infrared and carbon-13 nuclear magnetic resonance spectroscopy. Adsorption and desorption of phenanthrene from the humic substances was investigated using a radiotracer. Partition coefficients (K_p) were not related to concentrations of humic materials on clay. The percent nonpolar carbon of humic material, but not aromaticity alone, was weakly correlated to the organic carbon normalized K_p (K_{oc}). However, K_{oc} had a stronger, negative correlation with the humic acid N/C ratio and with the sum of amide and carboxylic carbons, a measure of the polarity of the humic acids. Desorption of phenanthrene was inversely related to the concentration of organic matter coating mineral particles, indicative of slow diffusion of polycyclic aromatic hydrocarbons from the organic matrix.

Introduction

Aromatic hydrocarbons make up only about 10% of the complex mixture of compounds in petroleum, but are a special concern as environmental contaminants, because they are among the most toxic, mutagenic, and carcinogenic constituents [Black et al. 1983; White 1986]. They are also the most soluble constituents, and thus the most likely to be transported in solution, to affect organisms from the dissolved phase, and to be affected by adsorption–desorption reactions in the marine environment. However, in absolute terms, aromatic hydrocarbons have low to very low aqueous solubilites and high affinities for surfaces in aquatic ecosystems [Farrington and Westall 1986]. Their adsorption is usually not rapidly or completely reversible, indicating that this process is probably a factor in polycyclic aromatic hydrocarbon (PAH) retention by contaminated sediments [Brusseau and Rao 1991; Hatzinger et al. 1995]. Adsorption may decrease the availability of contaminants to microbial degraders [Carmichael et al. 1997; Braddock and Richter 1998]. Weissenfels et al. [1992] concluded that biodegradability and biotoxicity of PAH were decreased by adsorption and migration into an organic matter matrix.

For all hydrophobic organic pollutants, organic matter is considered the primary adsorbent in sediments [Karickhoff and Morris 1985]. The adsorption partition coefficient increases with increasing organic content of sediments and soils [Means et al. 1980; Shaw and Terschak 1998]. Organic matter properties also influence adsorption. Aromatic hydrocarbon adsorption has correlated positively with the nonpolar–polar functional group ratio [Rutherford et al. 1992; Garbarini and Lion 1986] and aromaticity [Gauthier et al. 1987; Chin et al. 1994] of organic matter.

The overall goal of the CMI-funded research is to examine the role that humic acids play in the adsorption and desorption of phenanthrene by the sediments of coastal marine environments. This annual report addresses the effects of humic acid structure and other characteristics on the extent and rate of phenanthrene adsorption and desorption. Both natural humic substances and an artificial analog, melanoidins [Ertel and Hedges 1983], were investigated. These organic substances represent a wide range of properties potentially affecting associations with phenanthrene.

Methods

Samples were taken from three separate coastal locations in Alaska (Table 1). For sediment organic carbon and nitrogen determination and stable isotopic composition, dry sediment was acidified with 1 N HCl and homogenized, then redried and ground to a powder. The analyses of Port Valdez and lower Cook Inlet sediments were performed by the analytical lab at the Marine Science Institute, University of California, Santa Barbara. Total organic carbon (TOC) and nitrogen analyses of the Beaufort Sea sediments and all humic acids were performed using a Finnigan MAT Delta Plus mass spectrometer with a Conflo II interface and a Carlo Erba elemental analyzer.

Table 1. Sampling locations, elemental, and isotopic compositions of sediment organic material used in this study. N/A= not applicable, as lower Cook Inlet samples were intertidal. N/D=not determined.

Location	**Station**	**Latitude (W)**	**Longitude (N)**	**Depth (m)**	**Humic Acid $\delta^{13}C$**	**Humic Acid $\delta^{15}N$**	**Humic Acid N/C**	**Sediment N/C**
Port Valdez	25	61° 05.5′	146° 23.3′	73	–27.57	1.27	0.0657	0.1036
Port Valdez	82	61° 05.4′	146° 22.3′	79	–24.37	4.35	0.0878	0.0987
Lower Cook Inlet	HBH	59° 36.3′	151° 25.0′	N/A	–21.04	8.56	0.0879	0.0966
Lower Cook Inlet	JB2	59° 27.1′	151° 29.3′	N/A	–17.38	6.95	0.1067	0.1142
Lower Cook Inlet	TB2	59° 24.8′	151° 17.0′	N/A	–18.21	5.72	0.1297	0.1497
Beaufort Sea	5A	70° 29.7′	148° 46.0′	11.4	–25.94	7.34	0.1109	N/D
Beaufort Sea	6G	70° 31.3′	149° 53.9′	2.1	N/D	N/D	N/D	N/D

Humic acid was obtained by 0.5 M NaOH extraction of the sediment [Anderson and Schoenau 1983]. After extraction, the humic acid was precipitated by addition of 6M HCl until a pH of 1.5 was obtained, and recovered by centrifugation for 30 min at 12,000 rpm. The precipitated humic acid was lyophilized at –85 °C for 24 h. The resulting dry humic acid was stored at room temperature in a glass vial under nitrogen.

Artificial humic acids were prepared in the laboratory by refluxing various ratios of glucose and bovine casein in buffered solutions for 24 to 48 h as described by Yamamoto and Ishiwatari [1989]. The buffer was composed of 125 mL 0.1 M KH_2PO_4, 75 mL 0.1 M NaOH and 50 mL of glass distilled water to give a final pH of 7.0. After reaction the mixture was allowed to cool, and then the artificial humic acid was isolated using the extraction procedure above.

Fourier transform infrared (FTIR) spectra were obtained using a Nicolet Magna 560 FT-IR spectrometer, KBr beam splitter, and a MCT/B detector. Sixty milligrams of a ground mixture of 0.200 g KBr and 0.005 g humic acid were made into a pellet. Signals were averaged from 200 scans at a resolution of 0.121 cm^{-1}. Spectra were obtained between 4000 cm^{-1} and 400 cm^{-1} and processed against a background of KBr.

Cross-polarized magic-angle spinning ^{13}C nuclear magnetic resonance (CPMAS/^{13}CNMR) spectroscopic data were obtained from the NMR Laboratory at Florida State University in Tallahassee using the methods described by Hatcher et al. [1981]. The NMR spectrometer was a Bruker/IBM WP200SY with a 7-mm standard Doty Scientific multifrequency CPMAS probe. Five major regions of chemical shifts between 0 ppm and 300 ppm were assigned: aliphatic (0–50 ppm), aromatic (110–160 ppm), oxygen bound alkyl (50–110 ppm), carboxylic and amide (160–190 ppm), and carbonyl (190–240 ppm) functional groups [Malcolm 1990]. Carboxyl-free aromaticities were calculated by subtracting the integrated area of carboxylic and amide carbon peaks from those assigned to the aromatic carbons. The nonpolar fraction was calculated by adding the fractions of aliphatic and aromatic carbons.

A montmorillonite standard (A.P.I. # 26, 49 E 2600 from Clay Spur, Wyoming; Ward's Natural Science Establishment, Inc.) was ground for 2 min using a shatter box equipped with carbide rings. The resulting powder was sieved through a 270 mesh (53 µm) sieve using a Roto-Tap apparatus. Organic material was removed from the clay by oxidation with 30% hydrogen peroxide.

Humic acids were coated onto the inorganic substrate for use in the adsorption/desorption experiments. Approximately 1 g lyophilized humic acid was dissolved in 100 mL organic-free water and maintained at a pH of 10 with sodium hydroxide by mixing under an atmosphere of ultra high purity nitrogen for 3–7 d. The humic acid solution was then added to the washed clay and mixed for 24 h. The suspension was transferred to a centrifuge bottle containing the salts resulting from the evaporation of an equal volume of artificial seawater and mixed for 48 h, then centrifuged at 12,000 rpm for 2 h and the supernatant discarded. A sample of the humic acid coated clay was dried and submitted for TOC analysis. The remaining humic acid coated clay was stored in a refrigerator at 5–10 °C in a container flushed with ultra high purity nitrogen.

Radiolabeled phenanthrene was used to examine adsorption and desorption [Henrichs et al. 1997]. All glassware and Teflon® liners used were cleaned to remove any hydrocarbon contamination before use. A stock solution was prepared by dissolving [9-^{14}C] phenanthrene (5–15 mCi $mmol^{-1}$, Sigma Chemical Co.) and non-radiolabeled phenanthrene in acetonitrile. After evaporation of the acetonitrile, artificial seawater was added to aliquots of the stock solution to produce 50, 300, and 700 µg L^{-1} phenanthrene solutions. The artificial seawater [Lyman and Fleming 1940] was prepared from reagent grade salts and water that had been glass distilled over a saturated solution of potassium permanganate. Mercuric chloride (0.500 g) was added as an antimicrobial agent.

Adsorption experiments were begun by weighing 0.1 g of wet, humic-coated clay into vials with Teflon® lined caps and mixing with 5 mL of a radiolabeled phenanthrene/seawater solution. Control experiments were done with vials containing no sediment and with vials containing organic free clay. After 14 d on a table shaker, the vials were centrifuged at 5000 rpm for 30 min and a 1.0 mL aliquot of each of the radiolabeled reaction solutions was removed and scintillation counted. Reported partition coefficients, K_{oc}, are the ratio of adsorbed phenanthrene to dissolved phenanthrene, normalized to organic carbon content of the sediment.

After adsorption, the remaining supernatant was discarded and replaced with 300 $\mu g\ L^{-1}$ non-radiolabeled phenanthrene solution. After up to 90 d on a table shaker, the vials were centrifuged at 5000 rpm for 30 min and a 1.0 mL aliquot of each solution was removed and scintillation counted. The supernatant was discarded and the sediments were dried, then weighed. The percent of adsorbed phenanthrene from the prior adsorption experiment that was desorbed was calculated for comparison to the desorption expected based on the partition coefficient.

The statistical significance of correlations was determined using a two-tailed t-test with $(n-2)$ degrees of freedom at both the 5% and 10% significance levels ($p=0.05$ and $p=0.10$, respectively) [Mendenhall and Sincich 1996]. All correlations are reported at the $p=0.05$ significance level unless otherwise noted.

Results

The $\delta^{13}C$ (PDB standard) of the extracted sediment humic acids averaged –24.00±0.99‰ in Port Valdez, –19.82±1.36‰ in lower Cook Inlet, and –26.01±0.72‰ in the Beaufort Sea. The $\delta^{15}N$ (air standard) of the extracted sediment humic acids averaged 6.46±1.99‰ in Port Valdez, 7.71±1.37‰ in lower Cook Inlet, and 5.42±2.21‰ in the Beaufort Sea. The nitrogen/carbon ratio (N/C) of natural humic acids ranged from 0.026 to 0.14 with a mean of 0.088±0.027; it was correlated with, but consistently lower than, that of the total sediment organic matter. The synthetic humic acids had greater N/C, ranging from 0.16 to 0.27 with a mean of 0.22±0.041.

As indicated by ^{13}CNMR data, the carboxyl-free aromaticities ranged from 15 to 34% for natural humic acids and 10 to 18% for the synthetic humic acids. Aliphaticity ranged from 31 to 44% for the natural humics and 37–44% for the synthetics. The percentage of carbon atoms involved in carboxyl and amide bonds ranged from 10 to 14% for natural humic acids and 16 to 22% for the synthetic humic acids. As expected, increasing nitrogen/carbon ratios corresponded to an increase in the relative proportions of carbon atoms associated with amide bonds ($r^2=0.90$, $t=10.091$). The trend was similar for natural and synthetic humic acids, although the natural humic acids were consistently lower in amide carbon and N/C. A negative correlation existed between aromaticity and polarity, as measured by N/C ($r^2=0.55$, $t=3.649$) and fraction carboxyl and amide C ($r^2=0.44$, $t=2.914$), but aromaticity did not correlate with the aliphatic fraction ($r^2=0.05$, $t=1.718$).

Fourier transform infrared spectra of the natural and synthetic humic acids were similar but not identical, as found in earlier studies [Ertel and Hedges 1983; Rubinsztain et al. 1984]. All had absorbance bands for hydrogen-bonded OH at about 3400 cm^{-1}; aromatic C–H stretch as a shoulder between 3100 and 3000 cm^{-1}; aliphatic C–H stretch between 3000 and 2850 cm^{-1}; C=O stretch of aldehydes, ketones, and acids as a shoulder at 1710 cm^{-1}; amide linkages of proteins at 1650 cm^{-1}; C–O stretch of ethers, esters, and phenols at 1230 cm^{-1}; COO– stretching at 1532 and 1386 cm^{-1}; C–O stretch of carbohydrates at 1040 cm^{-1}; and possible NH_3^+ torsional vibrations at 530 and 470 cm^{-1}. The Beaufort Sea 5A humic acid showed stronger absorption bands associated with ethers, esters, and phenols than the other natural and synthetic humic acids, including a sharp phenolic and alcoholic OH stretch at 3622 cm^{-1}. The lower Cook

Inlet samples all showed pronounced absorption bands associated with amide linkages, while the same bands in the other humic acids were less prominent. The synthetic 1:10–24 produced a more defined peak in the aromatic C–H stretching band than any of the other humic acids. Both natural and synthetic humic acids had major ^{13}CNMR peaks corresponding to terminal methyl groups (~24 ppm), methylene carbon (~31 ppm), aliphatic esters and ethers, methoxyl and ethoxyl carbons (~55 ppm), ring carbons of polysaccharides and ether bonded aliphatic carbons (~70 ppm), carbon singly bonded to two oxygen atoms and anomeric carbon in polysaccharides, acetal or ketal groups (~100 ppm), unsubstituted and alkyl substituted aromatic carbons (~129 ppm), and carboxyl, esters and amide carbon (~173 ppm).

While all of the humic acids investigated in our study showed strong adsorption of phenanthrene, the synthetic humic acids' partition coefficients averaged about 50% less than those for the natural humic acids. The montmorillonite clay alone adsorbed phenanthrene much less (K_{HA}/K_{clay}=~3) than the humic acid coated clay. Neither aromaticity (r^2=0.15, t=1.121) nor aliphaticity (r^2=0.03, t=0.456) of the humic acids appeared to control measured partition coefficients. Humic acid nonpolar carbon (the sum of aliphatic and aromatic carbon) weakly correlated with the partition coefficient (r^2=0.38, t=2.091, p=0.10). Partition coefficients decreased as N/C increased (Figure 1); this trend was mainly due to the difference between natural and synthetic humic acid properties. The combined effects of increased nitrogen and oxygen, measured as the percent carboxyl and amide carbon, correlated with a decrease in the partition coefficient (r^2=0.78, t=4.982) (Figure 2). The natural humic acids show this trend clearly, and it is also seen in the comparison of natural and synthetic humic acids.

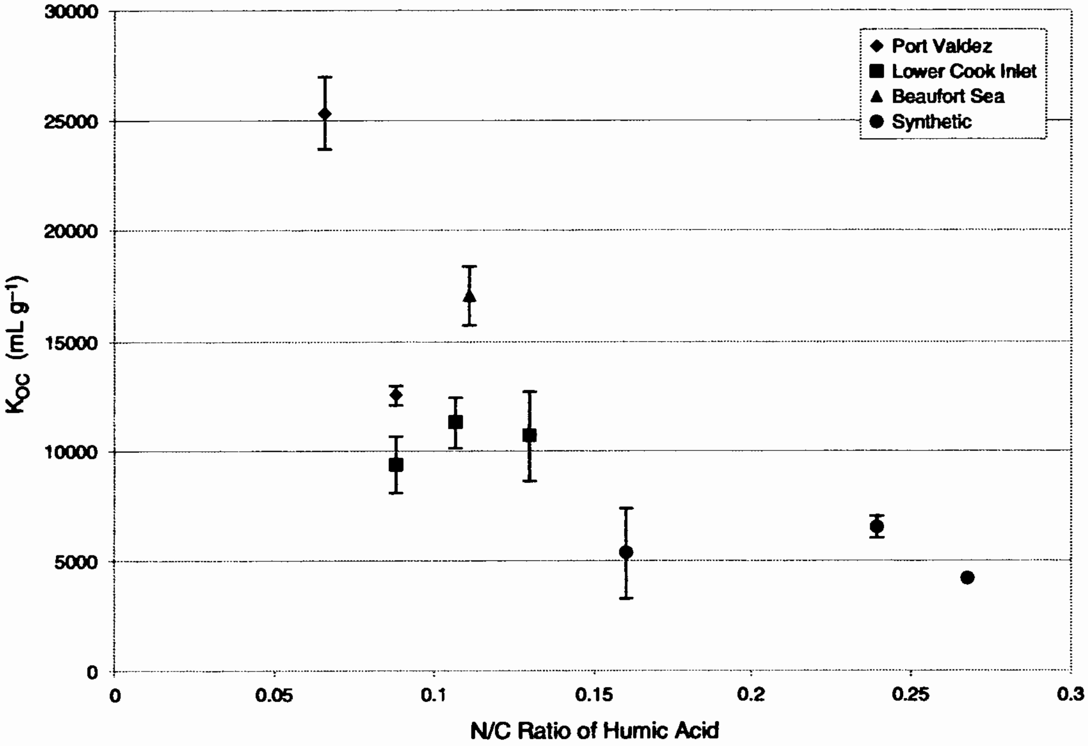

Figure 1. Phenanthrene partition coefficients (K_{OC}) decrease with increasing nitrogen to carbon (N/C) ratios of humic acids.

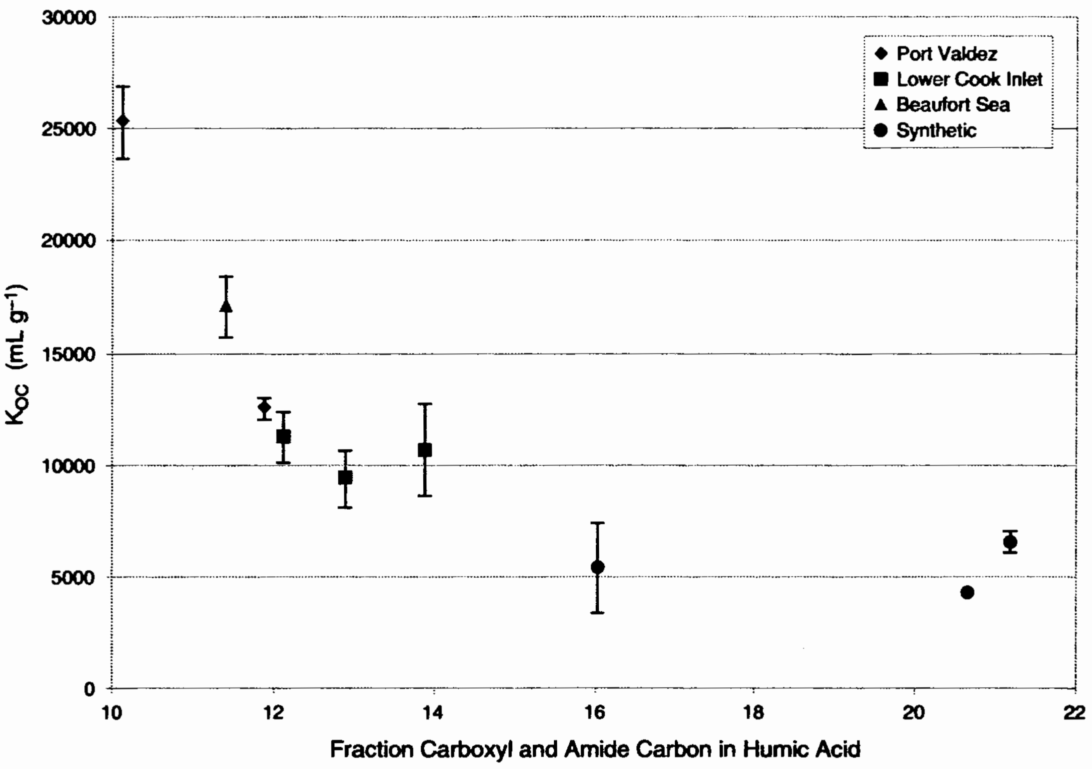

Figure 2. Phenanthrene partition coefficients (K_{OC}) decrease as the fraction of carboxyl and amide carbon in humic acids increases.

Phenanthrene desorption was incomplete in most experiments and increased with time for at least 14 d. Phenanthrene desorption at 3 d and beyond was negatively correlated with the proportion of extractable humic acid from the organic matter of marine sediments (HA/OM). Before 3 d of desorption, no correlation was found. Values of desorption were found to decrease from 53.6% to 12.1% as the ratio of extractable humic acid to total organic matter of sediment increased from 10.6 to 53.1 (r^2=0.85, t=6.211). No significant correlation was found between desorption and the percent of nonpolar carbon (r^2=0.06, t=0.683).

Partition coefficients (K_p; not normalized to organic carbon content) did not correlate with the amount of organic carbon coated on the clay particles (mg OC g^{-1} clay) used in the laboratory experiments (r^2=0.03, t=0.429). However, the extent of phenanthrene desorption, as the ratio of observed to expected percent desorption, was weakly negatively correlated with the amount of organic carbon coated onto the clay particles (mg OC g^{-1} clay) (r^2=0.37, t=2.037, p=0.10).

Discussion

Organic matter properties

Sediment isotopic ratios tend to reflect the sources of organic carbon, namely photosynthetic organisms [Ikan et al. 1990]. Biomolecules formed in the marine environment usually have isotopic signatures of about –20 to –23‰. Terrestrially derived biomolecules from C_3 plants have $\delta^{13}C$ values around –25 to –27‰. Nitrogen isotopic signatures in the marine environment are usually in the range of 6–10‰, reflecting the sources of inorganic nitrogen in the form of ammonium and nitrate in the ocean, while terrestrial plant $\delta^{15}N$ values are closer to that of atmospheric nitrogen (0‰). N/C ratios can be used in conjunction with isotopic studies to make a clearer distinction between marine and terrestrial humic acids. Terrestrial plants contain nitrogen deficient lignin and cellulose, and have low N/C [Goodell 1972] while marine phytoplankton is richer in protein, tending to higher N/C (~0.167) [Muller 1977]. The values of $\delta^{13}C$, $\delta^{15}N$ and N/C shown in Table 1 indicate that lower Cook Inlet sediment humic acids are mostly of marine origin, despite the surrounding steeply sloping, forested coast. Like lower Cook Inlet, Port Valdez is also a fjordal environment. Port Valdez humic acids, however, show greater terrestrial input. Beaufort Sea humic acids have more negative $\delta^{13}C$ and lower $\delta^{15}N$ values, reflecting a strong influence from the tundra peat [Yunker et al. 1991].

Interpretation of FTIR spectra is limited to qualitative identification of functional groups, and the natural and synthetic humic acids had qualitatively similar spectra. The natural humic acids from all sites showed strong absorption bands characteristic of marine derived humic acids [Ertel and Hedges 1983]; these bands were especially prominent for the lower Cook Inlet humic acids, consistent with other indicators of their predominantly marine origin. Similar to the humic acids of our study, Hatcher et al. [1980] reported major ^{13}CNMR peaks in marine sediment extracted humic acids at 30 ppm, 130 ppm and 175 ppm, and weak or absent peaks (compared to terrestrial humic acids) at 75 ppm and 150 ppm. No statistically significant differences in ^{13}CNMR spectra could be found when comparing the integrated peak areas of the humic acids from Port Valdez, lower Cook Inlet, or the Beaufort Sea when examined as separate geographical groups, but the Beaufort spectra were of very low resolution. The synthetic humic acids displayed a larger and sharper ^{13}CNMR peak in the carboxylic region, but their ranges of aliphatic and aromatic carbon overlapped those of the natural humics. Overall, the spectroscopic and elemental composition data indicated that the synthetic humics had more polar nitrogen and oxygen containing functional groups than the natural humic acids, but otherwise had many structural similarities to the natural substances.

Phenanthrene adsorption and desorption

The mechanism of adsorption of neutral hydrophobic organic compounds to organic matter is not fully understood, but is thought to involve rapid van der Waals type interactions [Brusseau and Rao 1991]. Sediment organic matter, of which humic acid is a part, is a flexible, cross-linked, branched, amorphous, polyelectrolytic, polymeric substance within which organic pollutants can diffuse [Brusseau et al. 1991]. Humic acids appear to have an open structure with hydrophobic cavities that are dynamic and ephemeral [Schlautman and Morgan 1993]. It has been proposed that humic acids, being amphiphilic, form regions similar to detergent micelles. These "pseudomicelles" are considered to have a hydrophobic interior into which nonpolar compounds can partition [Ragle et al. 1997].

Partition coefficients of phenanthrene determined by our research (14,000±6000 mL g^{-1} C) are within the range found by others. For example, Karickhoff et al. [1979] found K_{oc} to be 23,000 mL g^{-1} C for course silt fractions of two ponds of northern Georgia. Partition coefficients of 19,800±954 mL g^{-1} C were measured for Boston Harbor sediments by Chin and Gschwend [1992]. Partition coefficients (K_{oc}) for intact Jakolof Bay sediments were about 50,000±20,000 mL g^{-1} C [Henrichs et al. 1997]; these are larger but of similar magnitude to the values for the extracted humic substances reported here.

Although a positive correlation between sediment organic matter concentration and partition coefficients for hydrophobic organic compounds was found in several earlier studies [Karickhoff et al. 1979; Means et al. 1980; Gundersen et al. 1997; Maruya et al. 1996], it was absent here, probably because of the wide range of organic matter properties. This correlation is more likely where organic matter properties are fairly uniform over the range of organic matter concentrations. Except for those of Means et al. [1980], samples used in previous studies were usually from small geographical regions. Characterization of the organic matter in the earlier studies was limited, so the extent of variation in organic matter properties is not clear. The results of the present study show that sediment total organic carbon alone is not necessarily the best indicator of adsorptive properties.

A number of laboratory studies have shown a positive correlation between humic substance aromaticities and PAH adsorption [Gauthier et al. 1987; Maruya et al. 1996: Chin et al. 1997], PAH solubility [Uhle et al. 1999], and Freundlich exponents [Xing 2001]. Aromaticity, however, did not predict partition coefficients in our study. Partition coefficients for phenanthrene decreased with increasing polarity of the humic acid and increased with increasing nonpolar fractions. Humic acid polarity was inferred from increasing N/C, increasing fraction of carboxyl and amide carbon, and decreasing fraction of nonpolar carbon (the sum of aliphatic and aromatic carbons by ^{13}CNMR). Similar to the results of our study, Rutherford et al. [1992] showed a correlation between partition coefficients and the polar-to-nonpolar group ratios (quantified as (O+N)/C) of soil organic matter. More recently, Kile et al. [1999] demonstrated that polarity (determined by ^{13}CNMR) was a significant factor in the binding of carbon tetrachloride to soil and sediment organic matter. This is not surprising, following the concept that "like dissolves like".

The sum of both the aromatic and aliphatic carbon fractions (as the nonpolar fraction) predicted partition coefficients much better than either property alone. This suggests that phenanthrene adsorbs well to both the aliphatic and aromatic parts of the humic molecule. However, the relationship between K_{oc} and the fraction of carboxyl and amide carbon is tighter than the relationship of K_{oc} and nonpolar carbon. Carboxyl and amidic carbons constitute only 10–20% of the carbon, and it is not obvious why small changes in this fraction have such a strong effect on K_{oc}. One possibility is that when adsorbed on the clay, the polar functional groups of the humic acid are positioned outward, so that they have an especially great influence on the particle surface properties.

The strongest adsorption was found for humic substances from areas of mixed terrestrial and marine organic matter input (PV25, PV82, and 5A). It has been proposed that terrestrial humic acids bind better due to their lignin precursors, and therefore greater aromaticity [Chin et al. 1994, 1997], but aromaticity was not a predictor of adsorption in our study. Rather, the data indicated that humic acids in these mixed environments were less polar, i.e., had fewer carboxylic and amide carbons, and that these properties were related to their greater adsorption of phenanthrene.

The slow and incomplete desorption of phenanthrene observed in our study has been reported for a wide variety of other organic compounds [Brusseau and Rao 1991; Kan et al. 1994; Hatzinger et al. 1995] as well as PAH [Carmichael et al. 1997]. Slow intraorganic matter diffusion is thought to be the most likely mechanism for hydrophobic organic compounds [Brusseau et al. 1991]. Phenanthrene desorption did not show any patterns based on geographical location or sources of organic matter. Desorption decreased as the amount of humic acid that could be extracted from the organic matter of the parent sediments (HA/OM) increased. This might be a function of the humic acid's polarity; the more base extractable humic acids are likely to be more polar. However, no direct relationship was found between HA/OM and any of the measures for polarity of the humic acids. HA/OM was correlated (r^2=0.69, t=3.937) to the amount of organic carbon that coated the mineral particles in the laboratory experiments (mg OC g^{-1} clay), but desorption itself was only weakly correlated (r^2=0.37, t=2.037, p=0.10) with mg OC g^{-1} clay. Although not measured in our study, the molecular weight of the humic acids is another possible reason for these patterns [Chin et al. 1994]. The decrease of desorption with increasing organic content of the clay (mg OC g^{-1} clay) is consistent with the idea that desorption is incomplete at shorter reaction times because of slow diffusion within the organic matrix of particles. It was expected that this effect would increase with the amount of coating, as was observed.

In our data set, both N/C (r^2=0.37, t=2.037, p=0.10) and fraction of carboxyl and amide carbon (r^2=0.34, t=1.884, p=0.10) were weakly correlated with the amount of organic carbon coating the clay (mg OC g^{-1} clay). Hence, the more polar humic substances adsorbed to the mineral particles to a greater extent, and the higher organic matter concentration led to less desorption of phenanthrene at 30 d. This could have interesting implications for the environmental fate of PAH. That is, although initial phenanthrene adsorption was least for more polar humic substances, the phenanthrene desorption was slower or less complete, since greater amounts of the polar humic substances associated with mineral particles. In the environment, polar organic matter might have greater importance in persistent contamination of sediments than its relatively low adsorption coefficient (K_{oc}) would suggest.

The results of our work indicate that particle organic content alone does not predict phenanthrene adsorption (r^2=0.03, t=0.429) when a broad range of sediment organic matter types are examined, although it does influence desorption. The differences in adsorption appear to be best explained by a measure of polar functional group content (fraction carboxyl and amidic carbon), but the ^{13}CNMR data required for this parameter are costly and not readily available in many laboratories. A simple N/C ratio captures much of the variability in humic acid properties in our sample set, and may be a better candidate for routine assessments of sediment adsorptive properties.

Future Research

All data collection for the project has been completed, and we are in the process of writing the final report. This annual report is an abridged version of the nearly completed first section, which is also a manuscript that will soon be submitted for journal publication. Two other manuscripts, now in preparation, will comprise the remainder of the final report. One describes phenanthrene adsorption and its kinetics, the other the rate and extent of phenanthrene desorption from humic acids.

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An Experimental Approach to Investigate Seasonal Differences in the Role of Zooplankton in the Distribution of Hydrocarbons

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Abstract

Copepods bioaccumulate polyaromatic compounds (PAC) from the water soluble fraction of weathered crude oil. They may form an important and yet unrecognized ecological compartment in the transfer of PAC from aqueous solutions into marine food webs. Large seasonal and regional variations in lipid content in most dominant high latitude calanoids may influence the extent of PAC uptake. The lipophilic nature of large 3–5 ring aromatics facilitates their passage through biomembranes, and once in the organism PAC adhere to fat tissue. Further, high surface-area-to-volume ratios in copepods result in high uptake rates. The same relative frequencies of PAC were measured in the water and in copepod tissue after 24 h of exposure, which supports the notion of passive PAC uptake. While copepods are relatively insensitive to aqueous petroleum concentrations (sublethal responses for several species were measured at concentrations between 1 and 100 ppm [Capuzzo 1985], oil toxicity is increased by a factor of 1000 in the presence of UV radiation. After exposure of Calanus marshallae *and* Metridia okhotensis *to total PAC (TPAC) concentrations of ~2 ppb and subsequent daylight exposure for 3.3 h on a sunny and 8.2 h on a rainy day, respectively, mortality, immobilization and discoloration of lipid sacs were observed. The interaction effect of PAC exposure and UV exposure was highly significant ($P < 0.005$). Dose–response experiments with* Neocalanus plumchrus *and* N. flemingeri *had high correlations between PAC dose in the exposure water and biological response at equal UV exposure levels. Exclusion of UV-B radiation by the use of Mylar-D reduced observed biological responses only slightly, indicating that the phototoxic component of sunlight is UV-A radiation.*

Objectives

To assess the role of zooplankton in the transport of polyaromatic compounds (PAC) in the environment, the development of a reproducible system for the experimental exposure of plankton organisms to constant concentrations of the water soluble fraction of oil is a prerequisite. A further objective of this study was to determine whether a correlation exists between lipid content of copepods and their PAC accumulation. Passive uptake rates of water soluble PAC, rather than feeding behavior on particulate oil globules, were investigated. Passive PAC accumulation by copepods is important because of their role as primary prey for many higher trophic level consumers, including several economically important species.

If oil toxicity to copepods is increased by a synergistic effect in the presence of ambient daylight, reductions of the secondary production in an impacted area are possible. In this study experimental evidence was collected to test whether a significant interaction between previous oil exposure and exposure to ultraviolet (UV) radiation from sunlight existed. Incorporation of PAC in feces could contribute to their introduction into benthic food chains. An attempt will be made to determine whether PAC are incorporated into fecal pellets and if so, whether their PAC signature is altered by metabolism.

Methods

Oil exposure system

A dilute solution of oil-derived PAC was prepared by passing seawater over 3-mm diameter glass beads coated with weathered Alaska North Slope (ANS) crude oil. The ANS oil was heated and stirred overnight at 80 °C to 20% weight loss, which removed most monocyclic aromatic compounds. It was then added to the glass beads at an application rate of 2.6 g oil kg^{-1} of beads and tumbled for approximately 24 h. The oiled beads were spread to a single layer and left under a hood for 4 d at 25 °C to allow the oil to harden onto the beads, and then were stored at –20 °C until use.

One hundred milliliters of the oiled beads were placed inside a 25-cm long by 2.5-cm ID glass column stoppered at each end by a glass plug and piece of plankton mesh followed by a neoprene stopper penetrated by a 2.8-mm ID glass tube. Natural seawater (30‰, 10 ± 1 °C) was pumped through the columns at 5 ± 0.5 mL min^{-1} flow rate by a peristaltic pump.

For dose–response experiments the volume of oiled glass beads in the column was decreased or several columns were connected to manipulate effluent concentrations. The resulting concentrations were estimated as a proportion of the average 2.2 ppb measured in columns with 100 mL of oiled beads. Water samples were collected at the beginning and end of each exposure, extracted in dichloromethane, and frozen for later processing and analysis to derive PAC concentrations in the exposure water.

Chemical extractions and analysis

All chemical extractions of water and tissue samples were and will be conducted at the Auke Bay Laboratory (National Marine Fisheries Service/NOAA). Procedures for the quantitative determination of PAC in water and in tissues are described by Short and Harris [1996]. Seawater samples (0.9 L) were extracted twice with 100 mL of dichloromethane. Copepods were pulverized in a porcelain grinder with 3 × 1 mL of dichloromethane. Dichloromethane extracts of the PAC were reduced in volume and exchanged with hexane over a steam bath, followed by fractionation and purification by alumina/silica gel chromatography. PAC were measured by gas chromatography/mass spectrometry in the selected ion monitoring mode. PAC analytes were comprised of dibenzothiophenes and PAC containing 2–5 rings, including the alkylated homologues listed in Figure 1.

PAC uptake experiments

In 2001, five oil exposure experiments were conducted with *Neocalanus flemingeri* and *N. plumchrus* at concentrations of ~2 ppb. Copepods were collected at various stations in Prince William Sound and the adjacent Gulf of Alaska. Each experiment consisted of a 24-h oil exposure and immediate freezing of replicate samples of oiled copepods at the end of the exposure. At time of sorting, three replicate samples of copepods were collected and frozen for total lipid analysis. All samples are presently awaiting further processing.

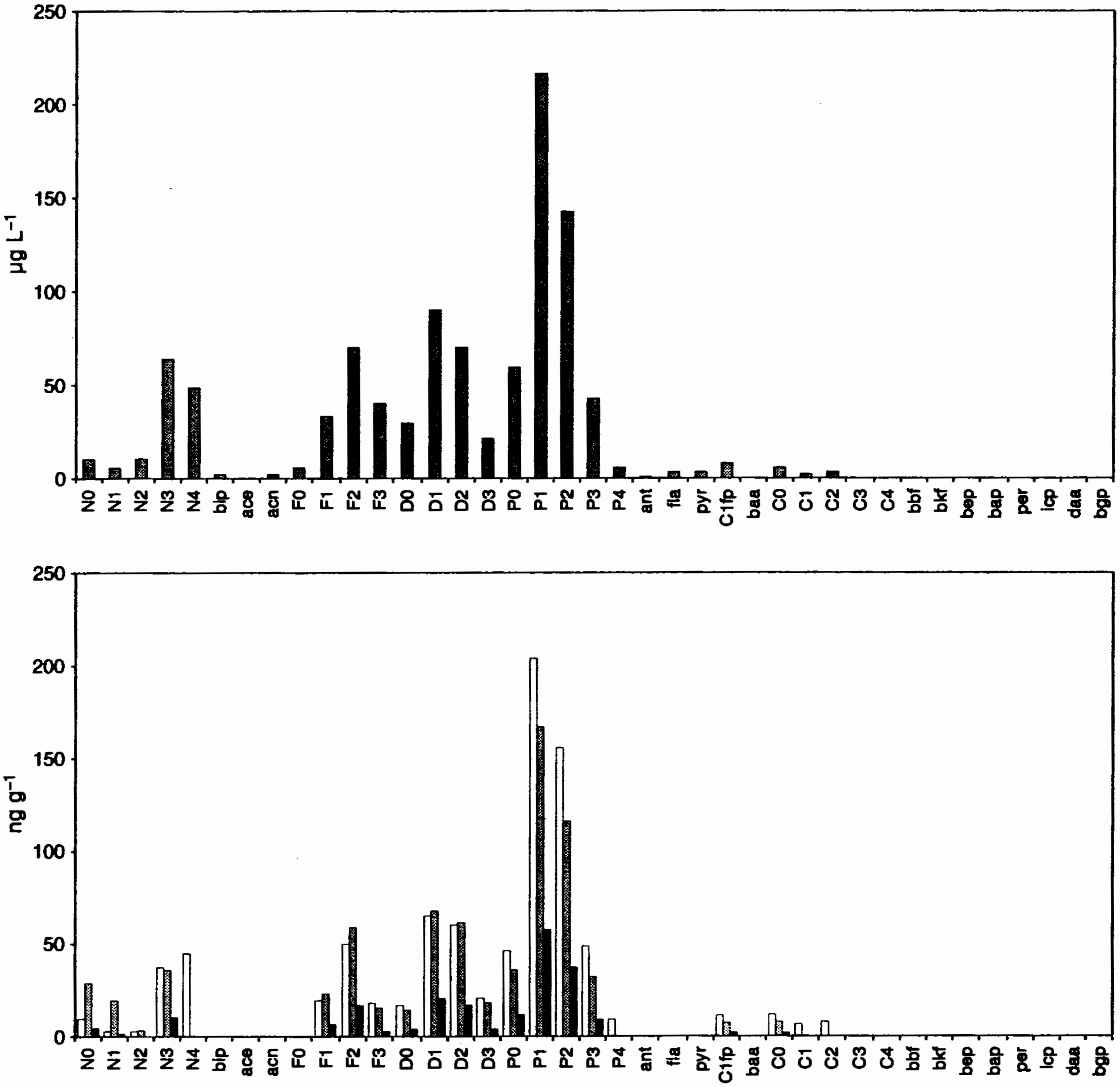

Figure 1. Concentrations of PAC analytes in exposure water (N=6) and copepod tissue; white: *Calanus marshallae* (N=16), grey: *C. marshallae* (N=20), black: *Metridia okhotensis* (N=40).
N0 = napthalene, N1 = C-1 napthalenes, N2 = C-2 napthalenes, N3 = C-3 napthalenes,
N4 = C-4 napthalenes, bip = biphenyl, ace = acenaphthylene, acn = acenapthene,
F0 = flourene, F1 = C-1 flourenes, F2 = C-2 flourenes, F3 = C-3 flourenes,
D0 = dibenzothiophene, D1 = C-1 dibenzothiophenes, D2 = C-2 dibenzothiophenes,
D3 = C-3 dibenzothiophenes, P0 = phenanthrene, P1 = C-1 phenanthrenes,
P2 = C-2 phenanthrenes, P3 = C-3 phenanthrenes, P4 = C-4 phenanthrenes, ant = anthracene,
fla = flouranthene, pyr = pyrene, C1fp = C1 flouranthenes/pyrenes, baa = benz-a-anthracene,
C0 = chrysene, C1 = C-1 chrysenes, C2 = C-2 chrysenes, C3 = C-3 chrysenes,
C4 = C-4 chrysenes, bbf = benzo-b-flouranthene, bkf = benzo-k-flouranthene,
bep = benzo-e-pyrene, bap = benzo-a-pyrene, per = perylene, icp = indeno-1,2,3-c,d-pyrene,
daa = dibenzo-a,h-anthracene, bgp = benzo-g,h,i-perylene.

Phytotoxicity experiments

In June 2000,we performed two successive phototoxicity experiments that differed in the species tested and the UV exposure intensities used. Each experiment included three treatments: (1) a PAC assemblage dissolved from crude oil in the absence of UV radiation (denoted as "+Oil–UV"), (2) UV radiation in the absence of the PAC assemblage (denoted as "–Oil+UV"), and (3) the PAC assemblage followed by UV radiation (denoted as "+Oil+UV"). Copepods in the +Oil treatments were exposed for 24 h to about 2.2 µg TPAC L^{-1} (total PAC) in both experiments. Experiment 1 (high UV) involved *C. marshallae* only, and the UV exposure consisted of bright natural sunlight for 3.8 h. Experiment 2 (low UV) involved both *C. marshallae* and *M. okhotensis*, and the UV exposure consisted of cloud-attenuated sunlight for 8.2 h.

Phototoxicity of oil to *Neocalanus flemingeri* and *N. plumchrus* was tested in two dose–response experiments conducted in 2001. In experiment 1, copepods were exposed for 24 h to approximately 0 ppb, 0.5 ppb, 2.5 ppb and 12 ppb, followed by exposure to ambient natural sunlight. In experiment 2 the PAC concentrations in the water were approximately 0 ppb, 2.5 ppb, 6.5 ppb and 12 ppb. The duration of the UV exposure differed between experiment 1 and experiment 2, but was the same for all treatments within an experiment. To determine the phototoxically active component of sunlight, one treatment for each oil dose was wrapped in Mylar-D foil to exclude UV-B radiation; the control treatment was wrapped in aluminum foil to exclude all light. During the UV exposure, flasks containing the copepods were placed in a water bath outside and maintained at 7 °C. Measurements of UV-A, UV-B and visible light were recorded every 10 min, then integrated to estimate total UV dose over the exposure period. All measurements were taken at 9.4 cm depth in the water bath. The exposure was terminated when first signs of immobilization or mortality were observed in the high dose treatment. Copepods were then microscopically evaluated and biological responses were categorized into unaffected, impaired and dead.

Fecal pellet collection

For the collection of fecal pellets, an experiment was designed with three treatments: (1) oil exposure with copepods, (2) oil exposure with no copepods, and (3) no oil with copepods. The rationale for the treatment with no copepods was that a possible correction factor for the contribution of sedimented algae to the PAC content of the copepod feces was to be established. At the start of the experiment and every 24 h thereafter, concentrated algae were added to the experimental flasks. At 48 and 72 h all sediment from the bottom of the flasks was pipetted onto a pre-weighed GF/C filter and frozen for later PAC analysis. Two experiments were initiated with this design. In May 2001, 150 *Neocalanus* spp. copepods were added to each of the treatments "with copepods" and fed concentrated algae from a phytoplankton sample collected from the dock of the Seward Marine Center (Institute of Marine Science/UAF) in Seward, Alaska with a 63-µm mesh size phytoplankton net. During the oil exposure a refrigeration failure in the laboratory occurred and the temperature rose to 15 °C in the exposure water. High mortality began to occur and the experiment was terminated. In August, the experiment was repeated with 120 *Calanus marshallae* per treatment. Copepods were fed once daily with a combination of the diatoms *Chaetoceros-B* and *Phaeodactylum tricornutum* and the flagellate *Nannochloropsis oculata* (algae paste spat formula, Innovative Aquaculture Products, Ltd.) at a concentration of initially 4000–8000 cells mL^{-1}. This resulted in very limited fecal pellet production (addition of algae directly into the exposure flasks). On 3 and 4 August, 2 L of algae solution containing a total of ~5 billion cells, were added to the 72-L flow-through overhead tank. This provided food concentrations in the flasks that followed a bell shaped curve over time. However, fecal pellet production did not increase.

Results

PAC exposure system

The chemical analysis of 12 water samples collected at the beginning and end of a 24-h exposure resulted in an average concentration of 2.2 ± 0.6 ppb TPAC. Relative frequencies of analytes and their ranges are listed in Figure 1. Concentrations in the effluent of two additional columns measured after 96 and 192 h were not significantly different.

Bioaccumulation of PAC

Both *C. marshallae* and *M. okhotensis* accumulated high concentrations of TPAC from the exposure seawater. The TPAC concentrations in *C. marshallae* were 85.4 $\mu g\ g^{-1}$ dry weight and 71.7 $\mu g\ g^{-1}$ dry weight at the end of the oil exposure of two experiments conducted in June 2000, compared to a concentration of 21.3 $\mu g\ g^{-1}$ dry weight in *M. okhotensis*. Approximately 45 tissue samples for PAC analysis and 30 tissue samples for lipid analysis of the copepod species *Neocalanus flemingeri* and *N. plumchrus* are awaiting analysis at this time.

Two oil exposure experiments were conducted with juvenile euphausiids (*Thysanoessa raschii).* High mortality in the first experiment was attributed to starvation effects. However, in a second experiment fed euphausiids had similar high mortalities: after 48 h of exposure at approximately 4.5 ppb TPAC water concentration, 98% of the oiled euphausiids had died, while mortality in the control treatment was <50%.

Phytotoxicity of oil to copepods

Calanus marshallae were very sensitive to the Oil+UV treatment compared with the other treatments in both experiments. More than 90% of the copepods exposed to oil only or the UV only were unaffected in both experiments, contrasting with more than 80% of the copepods affected (i.e., impaired, immobile or dead) by the Oil+UV treatment (Figure 2). Of the copepods impaired or immobile at the end of the UV exposure, two-thirds (six animals) died by the following day in experiment 1, while one other impaired copepod recovered. In experiment 2, only one copepod immobile at the end of the UV exposure died by the following day, while three immobile copepods recovered the ability to move their swimming appendages but not their antennules.

The pattern of results for *M. okhotensis* was similar to that of *C. marshallae*, except a higher UV sensitivity was observed (Figure 2e). While only one copepod died in the oil only treatment (n = 31), 17 died in the UV only treatment (n = 40) with 12 alive and unaffected, and 11 either immobile or impaired in their swimming ability. All copepods in the Oil+UV treatment were dead (n = 31) by the end of the UV exposure.

Calanus marshallae in the Oil+UV treatment that were impaired or immobile had opaque rather than transparent lipid sacs, whereas copepods in the oil only or UV only treatments had transparent lipid sacs.

Preliminary results of the phototoxicity experiments with *Neocalanus flemingeri* and *N. plumchrus* reflected increased toxicity of oil to copepods in the presence of ambient daylight. Toxicity increased with oil concentration and daylight exposure dose (intensity × time). While this reciprocal relationship between oil exposure dose and radiation seemed to hold under the influence of UV-A alone, effects were greater in the full spectrum treatments.

Effects of phototoxicity as reported in Figure 3 include mortality and paralysis. A separate analysis of effects on the species *Neocalanus flemingeri* and *N. plumchrus* in the second experiment revealed no difference between these two very similar species.

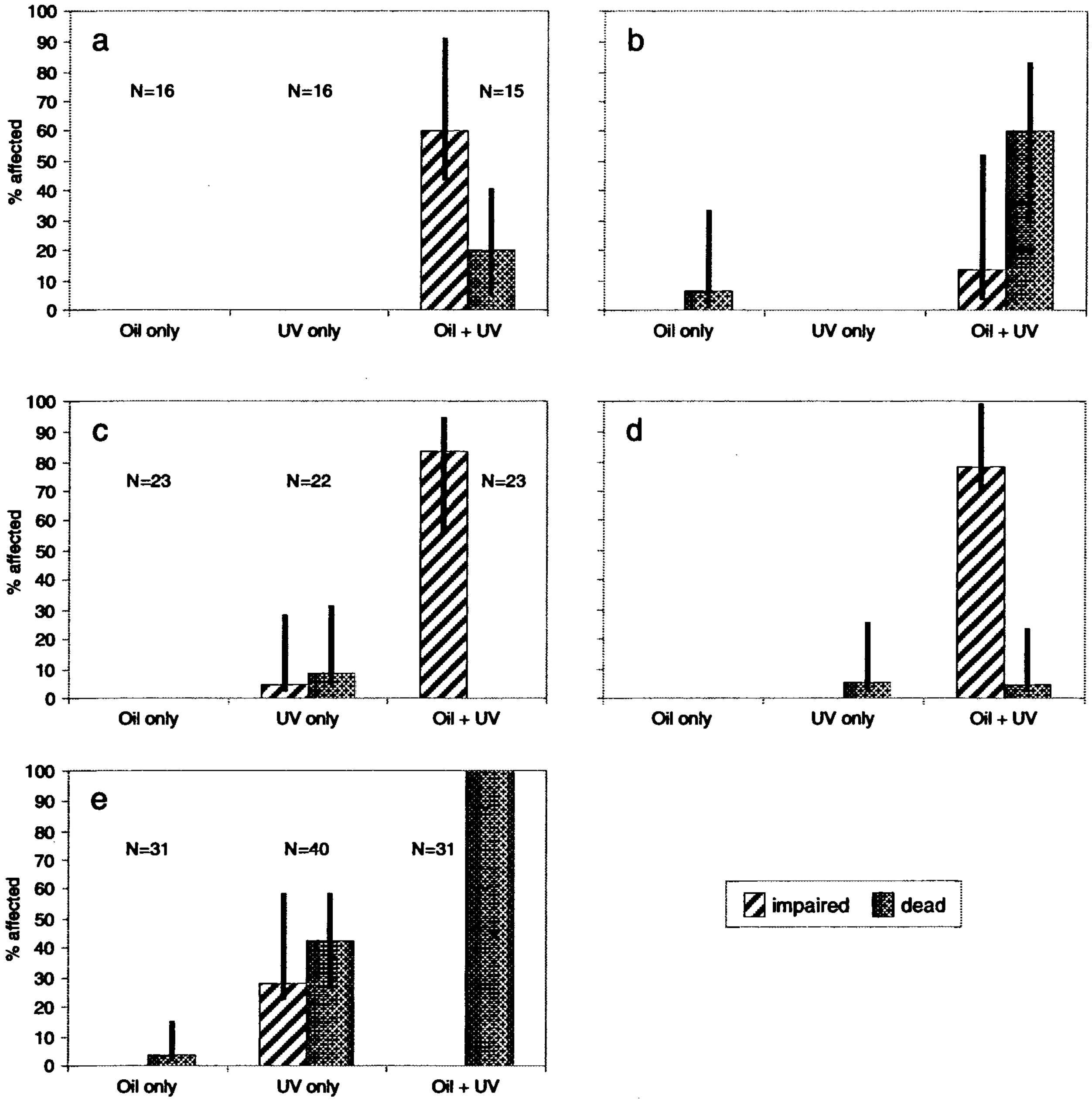

Figure 2. Biological responses in phototoxicity experiments. a) *Calanus marshallae*: 24-h oil exposure followed by 3.8-h UV exposure on a sunny day; b) as in a) but after 17.5-h depuration; c) *Calanus marshallae*: 24-h oil exposure followed by 8.2-h UV exposure on a rainy day; d) as in c) but after 22.5-h depuration; e) *Metridia okhotensis*: 24-h oil exposure followed by 8.2-h UV exposure on a rainy day. Impaired = unable to move posterior appendages.

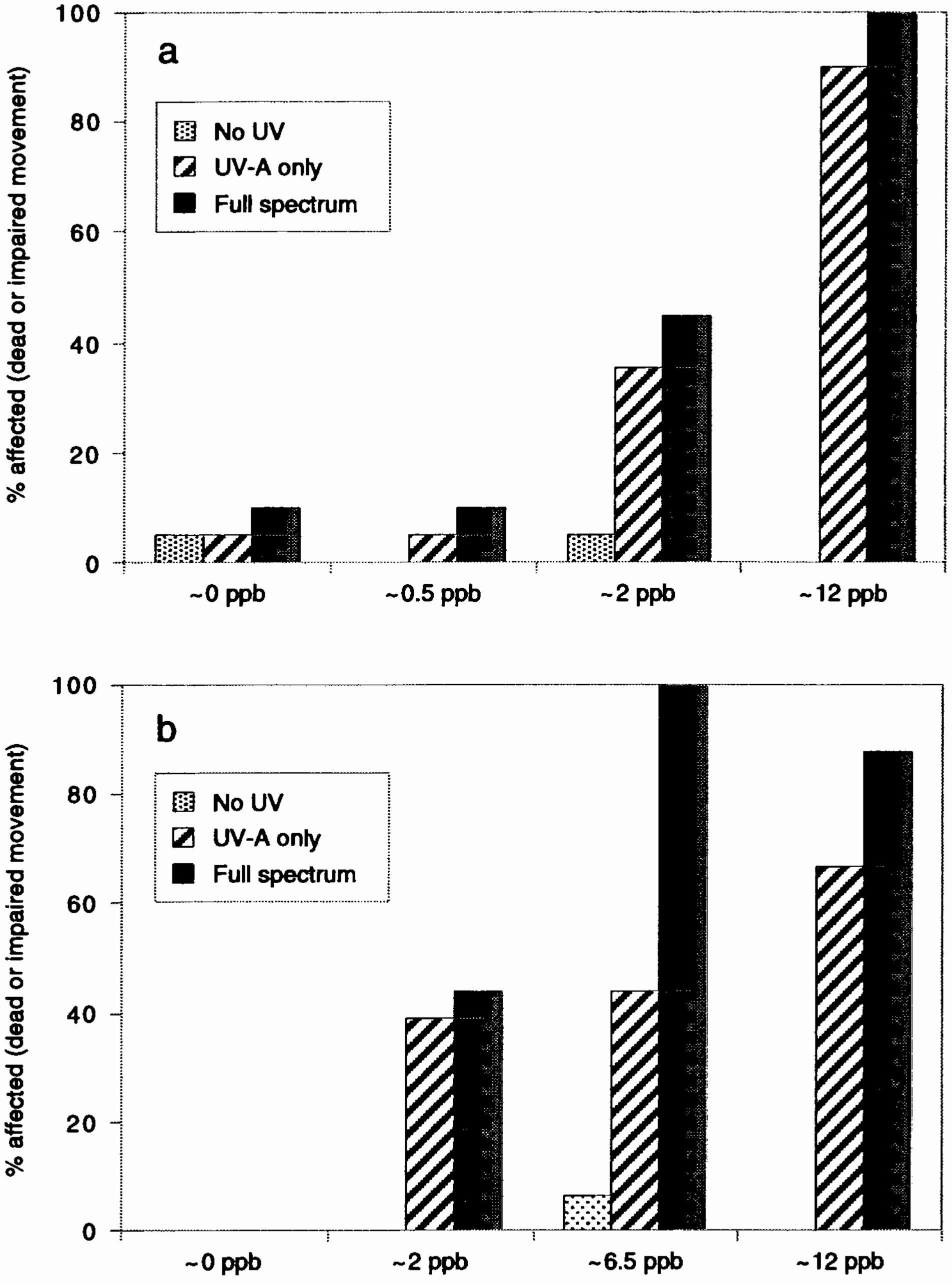

Figure 3. Phototoxicity of oil to a) *Neocalanus flemingeri* and b) *N. flemingeri* and *N. plumchrus* at different concentrations.

Discussion

Copepods rapidly accumulate PAC because of their high ratio of surface area to volume. They may thus form an important and largely unrecognized ecological compartment for the accumulation of PAC from the water and the transfer of PAC to higher trophic level consumers. Bioaccumulation factors of ANS crude measured in this study were 8000 for *C. marshallae* and 2000 for *M. okhotensis*. These are within the range of 100 to 10,000 reported for *Daphnia pulex* in a single compound study [Southworth et al.

1978]. The higher PAC concentrations found in *C. marshallae* compared with *M. okhotensis* may reflect different sizes of lipid pools. Both copepod species have high surface-area-to-volume ratios and approach equilibrium rapidly, as indicated by high values of bioaccumulation within a 24-h exposure period. But *C. marshallae* has a higher bioaccumulation capacity for PAC because it has a higher total lipid content. Also, the similarity of the relative PAC concentrations in the exposure water and in the copepod tissue at the end of the exposure indicates that the PAC were passively accumulated from the water without selective uptake.

Juvenile euphausiids (*Thysanoessa raschii)* are more sensitive to water soluble PAC then copepods. Mortality was observed in oil exposures at concentrations (~4.5 ppb) far below reported lethal doses to copepods (in the order of >10 ppm). This may be caused by different metabolic pathways. While copepods are high in wax esters that are used as energy reserves for later utilization and are thus temporarily biologically inactive, euphausiids have a higher percentage of structural phospholipids [Hagen 1988]. Consequently, PAC that bioaccumulate in fat tissue may be more apt to disrupt essential metabolic reactions and cause immediate mortality in euphausiids. Most toxicity assessments do not take into account delayed toxicity that would occur when PAC accumulated in lipid stores are utilized. Some evidence of this mechanism was provided in a post-oil survival study on *Calanus marshallae* females [Shirley and Duesterloh 2000].

Phototoxic effects on copepods may be of great ecological importance with respect to their role in transferring primary production into an accessible food base for many higher trophic level consumers in nearshore and oceanic environments. While lethal concentrations of PAC to some copepod species are reported in the order of 0.05 to 9.4 mg L^{-1} [Spies 1987], we found phototoxic concentrations to be lower by a factor of 1000 (2.2 µg L^{-1}). Mortality caused by photo-enhanced toxicity may have important adverse ecosystem effects—for example, local depletion of food resources to first-feeding fish larvae (e.g., salmon fry). The observed sublethal response of copepods to phototoxicity was an impairment of the escape response, causing a high vulnerability to predators that likely results in increased predation rates. We believe that copepods play a major role in the transfer of PAC from contamination sources in the environment to higher trophic levels.

Study Products

Duesterloh, S. 2000. Part 1: Copepod reproduction in culture experiments, and Part 2: Synergistic effects of oil and ultraviolet radiation (UV) on copepods. Seminar summarizing research results at the Juneau Center School of Fisheries and Ocean Sciences public seminar series. December 2000, Juneau.

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Seabird Samples as Resources for Marine Environmental Assessment

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Task Order 15173

Abstract

Archived specimens of seabirds are beginning to play critical roles in a host of studies contrasting changes in time and space among things such as genetics, stable isotopes, and contaminants. Seabirds are excellent marine bioindicators, representing multiple trophic levels but being especially rich at higher levels. Preserving and archiving multiple sample types from these animals caters to an increasingly broad variety of researchers. By preserving these samples, we enable present and future analyses for questions ranging from changes in contaminant levels, to the nature of populations and genetic stocks in affected areas, to other issues related to outer continental shelf (OCS) activities. Having the samples to address such retrospective and geographic comparative analyses becomes increasingly important for studying the rates and characteristics of natural and anthropogenic changes.

This project stems from an increasing interest and need for samples of preserved marine bird specimens, particularly for genetic, contaminant, and stable isotope studies. Critical to these studies is the availability of material from time periods and geographic areas of interest. Recent requests for samples of various types have made it clear that demand exceeds supply and that low rates of specimen influx were not meeting this demand, particularly in the documentation of the present. By supporting a graduate assistantship to process marine bird specimens, this project is making such sample preservation both active and less geographically and taxonomically haphazard than in the past. In the first two years of this project, more than 510 seabirds have been prepared and archived as skin, skeleton, and tissue samples at the University of Alaska Museum (UAM). A snowballing effect is apparent, both in the deposition of more specimens and in the level of interest in this new material. Two visiting researchers used some of this preserved material, a request for associated data was filled, and several inquiries were fielded that will probably lead to future uses. Presentations on this project were made at two CMI/MMS meetings.

Introduction

More than 100 species of Alaska birds depend on marine environments. These species occupy three trophic levels and represent a major component of the nation's marine ecosystems. These birds are vulnerable to both natural and anthropogenic changes (e.g., outer continental shelf activities) and are also politically sensitive organisms because they are protected by international treaties with such countries as Russia, Japan, Canada, and Mexico. Also, many are a source of food for humans. Birds have long served as environmental indicators—"canaries in the coal mine"—and specimens representing baseline conditions have been crucial for documenting both natural and anthropogenic changes. Perhaps the most widely recognized example of this was the use of historic museum egg collections to demonstrate the effects of increased concentrations of DDT on the reproduction of birds occupying higher trophic levels (e.g., Peregrine Falcons, *Falco peregrinus*). A more recent example is the use of historic bird specimens to document the effects of runoff contaminants into marine ecosystems in California. The bottom line is that samples that temporally span change events, or at least document conditions in change and non-change areas, are crucial.

Providing samples to support environmental research is an increasingly important function of natural history museums. But with limited resources to apply to broad taxonomic, geographic, and scientific demands, museums do well to cover even a few areas well. Many of the researchers making sample requests to the University of Alaska Museum are engaged in studies directly relevant to the Framework Issues of interest to the Minerals Management Service (MMS), and this project—a partnership with MMS, through CMI—has enabled marine bird samples to be actively brought in and preserved for this research community. Requests for Alaska marine bird samples vary from studies of temporal contrasts of contaminant levels and stable isotope ratios, to comparative systematic studies of population and species-level genetics and morphology, to synoptic studies for the identification of archaeological material. This collection, though limited in its holdings, provides these researchers with a substantial percentage of the samples pertinent to their questions. It has been clear that this science would be substantially strengthened if more samples were available, and this project is beginning to meet this objective through the half-time graduate assistant that it supports to process marine bird samples.

This project is distinct from other sample preservation projects, and it is filling a major gap in other sample archiving efforts. It complements existing projects and addresses an identified weakness in the preservation of samples of higher marine organisms. Our objectives have been to preserve a substantially increased number of marine and coastal bird samples from Alaska for studies ranging from contaminants and stable isotopes to genetics and morphology, and of course to make these samples available to the research community. Alaska seabird samples were not being archived anywhere at levels sufficient to meet the needs of this research community, and the UA Museum is in a unique position to address this need. The archived samples enable the testing of numerous hypotheses, particularly those addressing environmental changes from events such as contaminations and other OCS activities impacting Alaska's marine environments.

One of our most important goals in sample archiving is to maximize the usefulness of each individual bird to the scientific community. When possible, we preserve a combination skin/skeleton prep, two tissue samples, and stomach contents from each bird. We use no chemicals in the preparation process, except when a specimen is particularly fatty; in these cases the fat remaining after fleshing the skin is often removed with a solvent (e.g., mineral spirits). Skin and skeleton preparations are archival in quality and are expected to last for centuries. Tissue samples are archived in two, 2-mL plastic cryovials and archived at –80 °C in the Alaska Frozen Tissue Collection (AFTC). Stomach contents are preserved in isopropyl alcohol.

Results

Following notification of funding approval in 1999, a nationwide search for a graduate assistant resulted in the recruitment of Deborah Rocque, who joined UAF as a Ph.D. student in the fall of 1999. Deb received a Master's degree at the University of Connecticut, where she gained experience studying contaminants in birds. The match between her interests and this project was excellent, and her research on stable isotopes and contaminants in seabirds is being augmented by samples being preserved by this project.

Fully 297 specimens were prepared during this second year of the project. These specimens represent a diverse array of seabird genera, including: *Fratercula, Oceanodroma, Fulmarus, Phoebastria, Clangula, Somateria, Histrionicus, Anas, Uria, Rissa, Puffinus, Brachyramphus,* and *Larus*. Key localities represented are Barrow, the Chukchi Sea, Cook Inlet, and localities in and around the Bering Sea. All of these birds have been catalogued, and the entire bird collection has been rearranged to house the increasing quantity of seabirds in proper taxonomic sequence.

Collection Growth

The graph below, which summarizes 14 seabird genera, shows that this project continues to have a major impact on UAM seabird holdings. It is important to reiterate that these samples, representing unique points in time and geographic space, are not being replicated elsewhere.

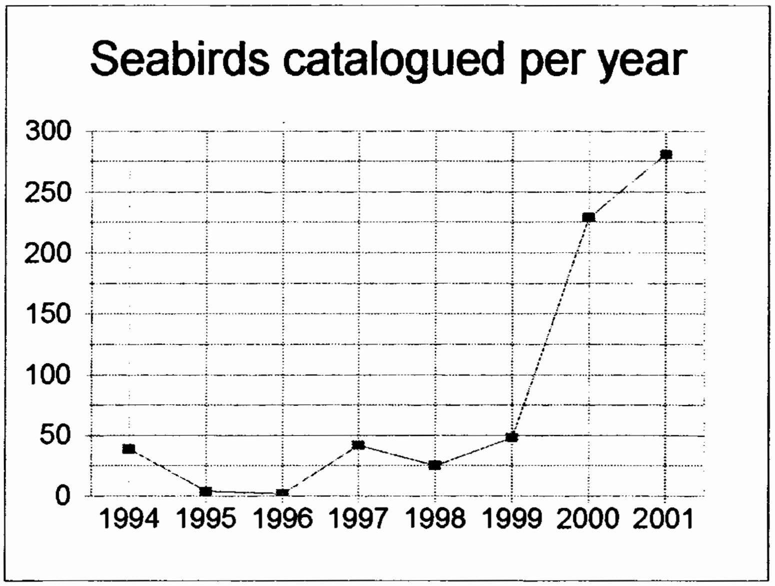

Figure 1. Summary of the number of specimens of 14 seabird genera catalogued into the UAM bird collection annually since 1994. The dramatic increase after 1999 is entirely due to this project.

Collection Use

Two visiting researchers coming to use the UAM bird collection found recent material preserved by this project to be useful in their studies. One was studying Alaska gulls; the other was synthesizing data on the birds of the Pribilofs. We also sent specimen data for North Pacific *Puffinus griseus* to a researcher in New Zealand (where these birds breed; the North Pacific is part of their nonbreeding range). Deb Rocque is using some of this preserved material to augment her dissertation research on stable isotopes and contaminants in Aleutian seabirds. In addition, we have fielded several queries of specimen holdings that will in all likelihood lead to important uses of these specimens in the coming year.

Of growing importance is our archiving of specimens taken for specific research projects. Vouchering this material is particularly good in two ways. First, it preserves specimens already known to be useful for pertinent scientific questions. Secondly, it maximizes the scientific utility of birds already collected by making them available to other researchers for other questions. This project has been important in cementing such partnerships, and the quality of the preserved material is enhanced by being used for research before it is even deposited. We will summarize these project-oriented specimens in next year's report, when the full scope is clearer.

Discussion

The activities surrounding this project are creating a noticeable snowball effect. The influx of seabird specimens has been greater than we had predicted. We are preserving more specimens per year than we outlined in the initial proposal, but even so, under this support alone we cannot preserve all that we could receive. Rather than turn important specimens away, we are instead continuing to encourage people to deposit seabirds with us and are in the process of leveraging additional funds to further increase our preparation capacity. Everything is in accordance with the projected timeline and the project continues to go very well.

Acknowledgments

We remain grateful to all biologists who obtain dead seabirds, label and freeze them, and deposit them with the University of Alaska Museum. Particularly important on this project thus far have been the efforts of Robert Suydam, Alan Springer, Jeff Williams, Vernon Byrd, John Piatt, Shannon Fitzgerald, Ed Melvin, Sharon Davis, and Paula Cullenberg. This work is conducted under a series of permits from the U.S. Fish and Wildlife Service, Convention on the International Trade in Endangered Species (CITES), the Alaska Department of Fish and Game, and U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS). We thank permitting officers for their continued facilitation of permits and related matters.

Beaufort and Chukchi Sea Seasonal Variability for Two Arctic Climate States

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Task Order 15174

Abstract

The major goal of this research is to document the atmospheric, ice, oceanic, and terrestrial signals showing seasonal variability of environmental parameters during cyclonic and anticyclonic climate states in the Beaufort and Chukchi seas. In order to fulfill the third year project objectives, we have developed two high resolution models of the Beaufort and Chukchi seas. The spatial resolutions of these models are 13.89 km and 2.5 km respectively. The bathymetry data were obtained from the International Bathymetric Chart of the Arctic Ocean with a resolution of 2.5 km. To calibrate these models we simulated one of the strongest storm surges observed in the Beaufort and Chukchi seas (August 2000). Simulation results are in relatively good agreement with observations of sea level heights and ice drift. Detailed studies showed that the spatial and temporal resolutions of the NCEP/NCAR sea level pressure data (2.5×2.5 degrees, 6 hours) are too low and do not reproduce well the extreme conditions of the relatively small polar cyclones.

We also simulated trajectories of a non-reactive, conservative soluble tracer originating from the mouth of the Mackenzie River. Results from this research demonstrate realistic potential flow pathlines and we describe how those pathlines change in response to climate forcing. These results can be used to aid current and future scenario risk assessments and may provide MMS with the tools to determine where and when risks from contaminants might exist.

Introduction/Background

The existence of two arctic atmosphere and ocean circulation regimes [Proshutinsky and Johnson 1997; Proshutinsky et al. 1999; Johnson et al. 1999] provides the foundation and motivation for the research done here. Major features of two circulation regimes in the Beaufort and Chukchi seas were described in the last year's CMI annual report [CMI 2000]. Here we extend our research on investigation of the Beaufort and Chukchi sea level variability and storm effects on sea ice conditions and circulation. There is a significant lack of data for the environmental parameters in the Beaufort and Chukchi seas; therefore our goal was to use coupled ice–ocean models and all available data for our research.

Results/Progress

Models/calibration

In Proshutinsky and Johnson [1997], a two-dimensional, barotropic coupled ice–ocean model with horizontal resolution of 55.5 km was forced by winds, river runoff, and an imposed but realistic sea level slope between the Pacific and the Atlantic oceans [see Proshutinsky and Johnson 1997 for details]. We have now developed two high resolution barotropic coupled ice–ocean models of the Beaufort and Chukchi seas. The spatial resolutions of these models are 13.89 km and 2.5 km respectively. The bathymetry data were obtained from the International Bathymetric Chart of the Arctic Ocean with a resolution of 2.5 km.

The models were calibrated and validated using an extreme arctic storm situation that occurred in the Beaufort and Chukchi seas in August 2000. In order to calibrate and to validate our models we ran them from 1 August through 1 September 2000. Figure 1 shows results of a simulation of ice drift and ice concentration. Sea ice concentration was compared with satellite data provided by James Maslanik. Figure 1b shows a sea ice drift pattern for 11 August when wind speed reached its maximum. We calibrated model results based on sea level variability. Figure 2 shows observed and simulated sea level heights at six locations. Five of these locations had tide gauge data available for this period. The best results were obtained for the Prudhoe Bay station where simulation results in the 2.5-km resolution model practically coincide with observations (dashed and dotted lines, respectively). The other station results are not so successful and, in general, the models underestimate observations by about 30%. We carried out several numerical experiments testing different model parameters and forcing factors (wind speed and wind stress, ice concentration and ice thickness, model resolution, and a role of atmospheric pressure gradients). We have concluded that the spatial and temporal resolutions of the NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) sea level pressure data (2.5×2.5 degrees, 6 hours) are insufficient to properly reproduce the extreme conditions in the relatively small polar cyclones.

Storm and sea ice condition statistics

At this stage we are completing our studies of storm statistics and sea ice parameter variability for the cyclonic and anticyclonic circulation regimes.

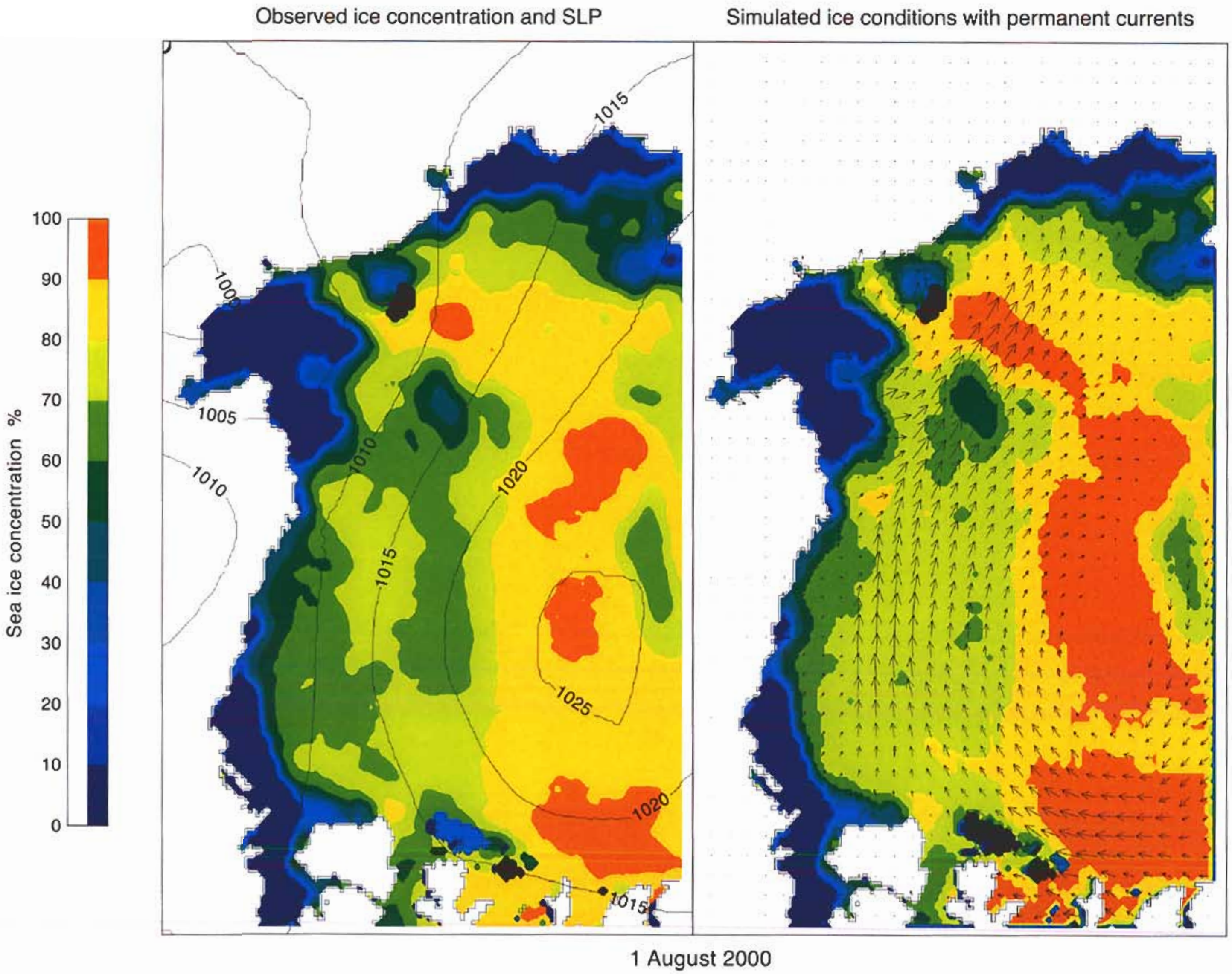


Figure 1a. Results from the 13.89-km resolution 2-D coupled ice–ocean model. Sea ice concentration and sea level atmospheric pressure (hpa) distribution from observations (left), and sea ice concentration and ice drift from model results. For 1 August 2001, maximum ice velocity is 47 cm s^{-1}.

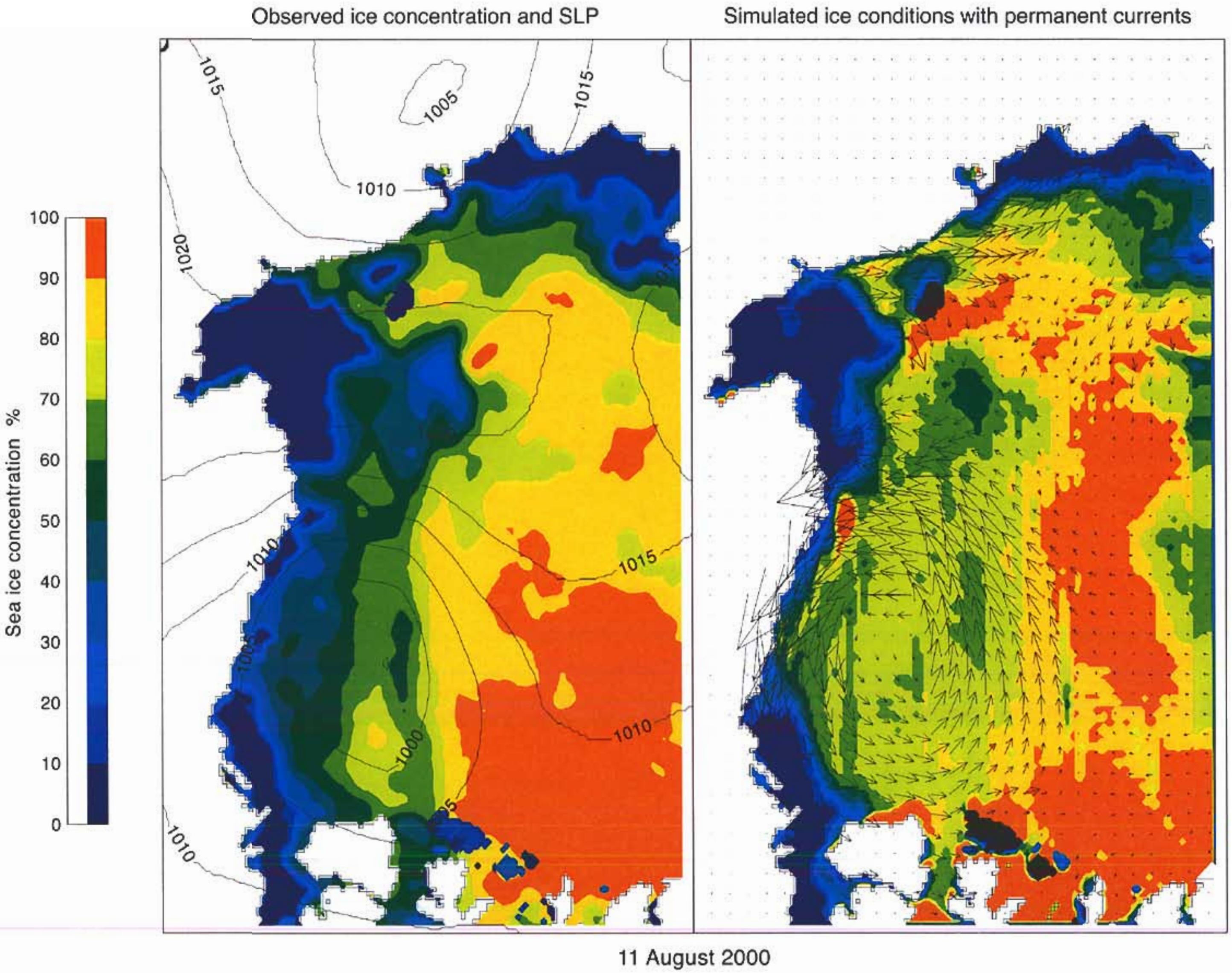
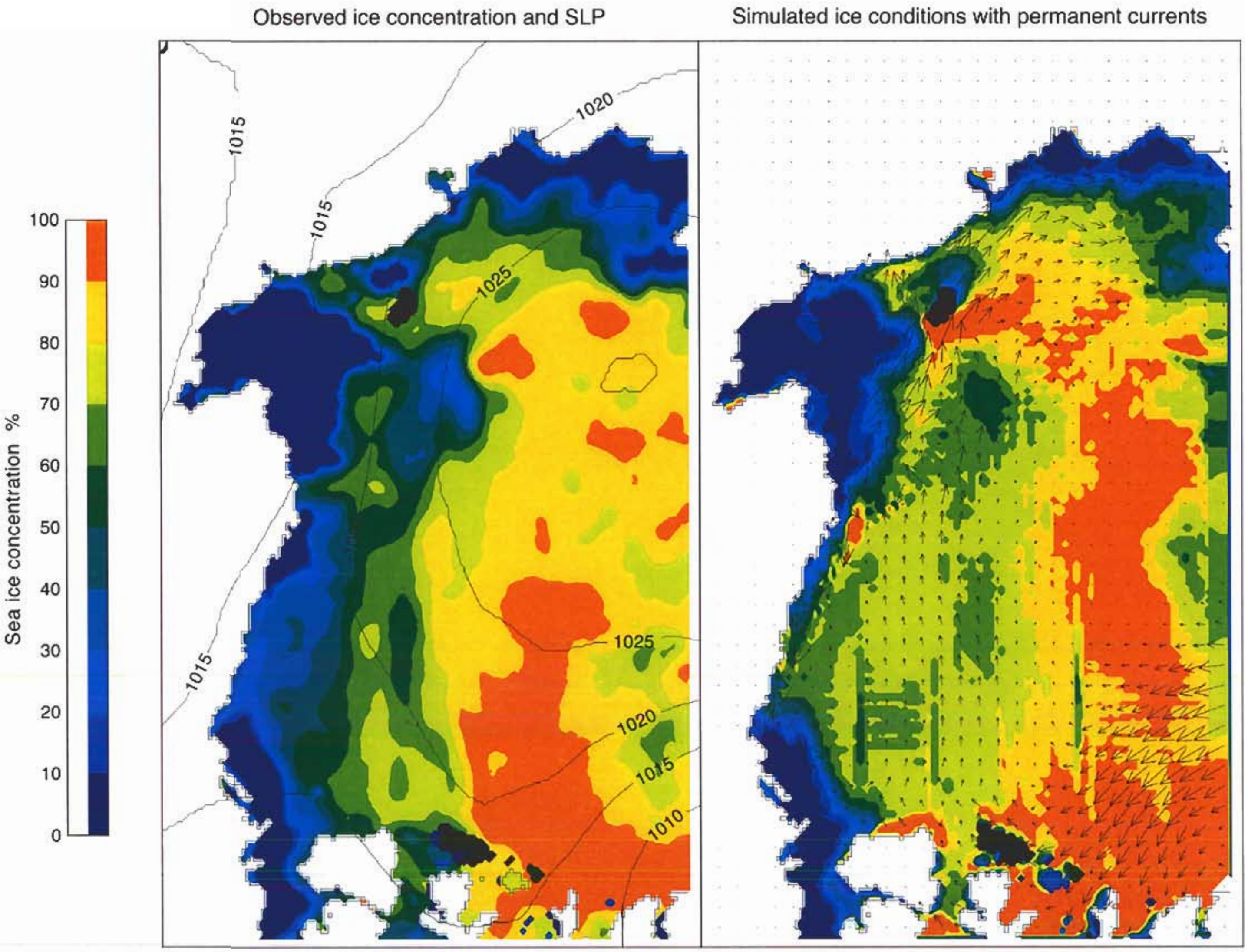


Figure 1b. Results from the 13.89-km resolution 2-D coupled ice–ocean model. Sea ice concentration and sea level atmospheric pressure (hpa) distribution from observations (left), and sea ice concentration and ice drift from model results. For 11 August 2001, maximum ice velocity is 142 cm s^{-1}.



13 August 2000

Figure 1c. Results from the 13.89-km resolution 2-D coupled ice–ocean model. Sea ice concentration and sea level atmospheric pressure (hpa) distribution from observations (left), and sea ice concentration and ice drift from model results. For 13 August 2001, maximum ice velocity is 64 cm s^{-1}.

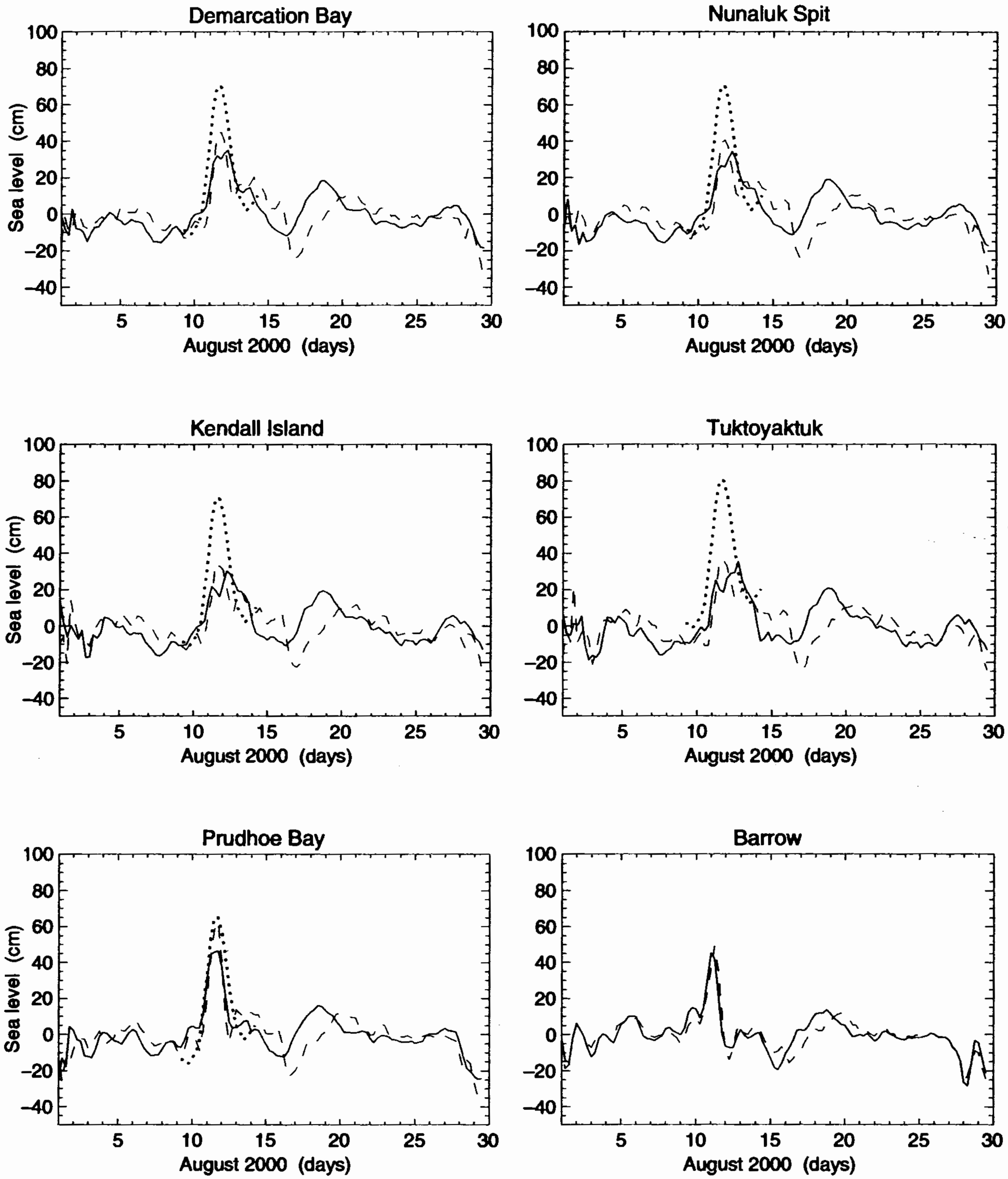


Figure 2. Sea level time series (cm) at 6 tide gauges during the August 2000 storm event. Dotted lines depict observations, solid lines show results from the 13.89-km resolution model, and dashed lines show simulated sea level from the 2.5-km horizontal resolution model.

Sea ice and water transport pathways

Understanding the two circulation regimes is useful for investigating the temporal and spatial variability of ice, water and pollutant transport in the Beaufort and Chukchi seas. To investigate this variability we calculated ice and water trajectories based on hourly mean velocities from our 2-D coupled ice–ocean model with the 13.89-km horizontal resolution model. Water parcels were released monthly in the mouth of the Mackenzie River for the period 1946–1997. In Figure 3 we present trajectories of ice markers released monthly. These trajectories are shown for 1972–1979 and 1989–1996 (typical years with the anticyclonic and cyclonic circulation regimes respectively). Water markers moving with vertically averaged velocities in the upper 200-m layer have comparatively stable trajectories (not shown) following bathymetric features and are consistent with the two circulation regimes. In years of the anticyclonic regime, parcels have trajectories with anticyclonic rotation and follow the well-known Trans-Arctic Drift. In years with the cyclonic regime, the pathways of water transport are shifted toward the Canadian Straits and are cyclonic. In this case, water parcels or contaminants distributed in the upper ocean do not penetrate to the central Arctic.

Trajectories of ice markers (Figure 3) are more variable because of the direct influence of wind. In the anticyclonic circulation years ice parcels move predominantly west, and at the 180 degree meridian they are frequently involved in the anticyclonic Beaufort Gyre, which after 3–5 years returns them to the Alaskan coastline. But in years with the cyclonic regime, their paths more closely match the water parcels. They tend to be concentrated in the eastern Beaufort Sea and move farther east and south through the Canadian Straits along the Canadian Archipelago, avoiding the central Arctic Basin.

Pollutant concentration was simulated using both water and ice trajectories. We assumed that at every time step each "pollutant particle" leaves an amount of its pollution. Summing this amount over time gives a "concentration". To have a high concentration of pollution in a region either 1) many particles pass over the region, or 2) a particle remains in the region for an extended period. Analysis of this conditional concentration (not shown) shows that there are a few regions with high potential pollutant concentration: the continental slope of the Beaufort Sea, the core of the Trans-Arctic Current, and regions near a source of pollution. Analysis of these data allows us to speculate that hypothetical sediment cores must have a layered structure with contaminants from different sources. Thickness of the layers and their composition will depend on a duration of the circulation regime. Based on this approach, Bischof and Darby [1997] analyzed ice-rafted debris in four Arctic sediment cores and found evidence of regimes similar to our cyclonic and anticyclonic circulation regimes in the Arctic Ocean within the last 700,000 years, although the duration of their regimes is much longer than the decadal scale discussed here.

Work in Progress

We plan to continue to investigate relationships between environmental parameters using statistics that may provide an improved ability to predict the likelihood of their behavior during years with cyclonic and anticyclonic circulation regimes. Continued work is needed to assess how basic circulation modes interact with more localized atmospheric patterns and underlying ice conditions, storm characteristics and coastal erosion rates.

Acknowledgements

We are grateful for information provided by EOSDIS NSIDC Distributed Active Archive Center, University of Colorado at Boulder.

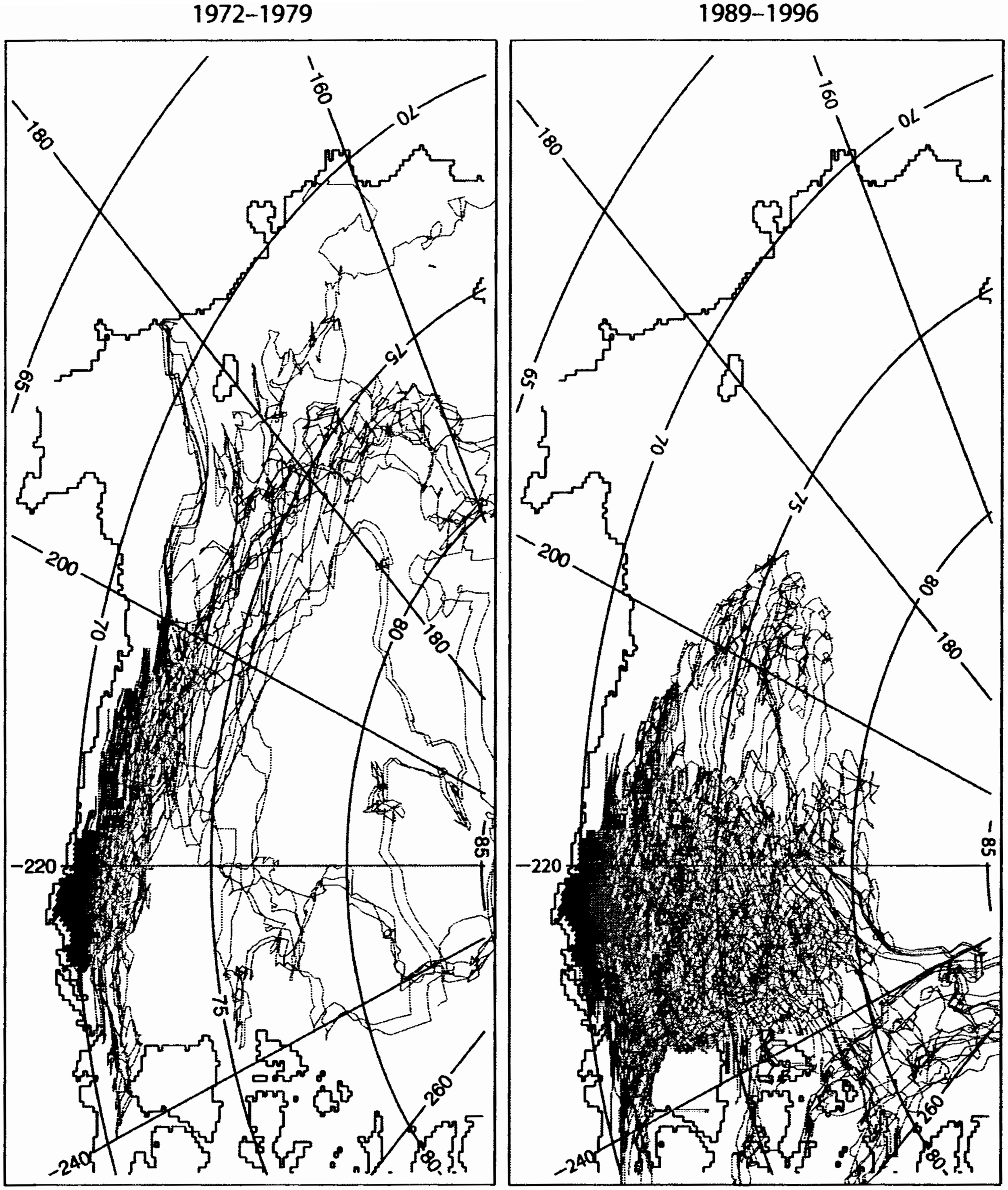


Figure 3. Simulated trajectories of ice parcels (moving with pack ice) released in the mouth of the Mackenzie River monthly. The left figure shows trajectories in 1972–1979 (typical years with an anticyclonic circulation regime) and the right figure shows results in 1986–1996 (typical years with a cyclonic circulation regime).

Study Products

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Petroleum Hydrocarbon Degrading Microbial Communities in Beaufort Sea Sediments

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Task Order 15175

Abstract

Despite large-scale development on the North Slope, no recent studies examining Alaskan arctic marine sediment microbial communities and their ability to metabolize petroleum compounds have been published. Microbial degradation of spilled petroleum hydrocarbons is a major mechanism of removal of these compounds from the environment. In this study we conducted the second year of a survey (first year near Barrow and second year near Prudhoe Bay) of marine sediment microbial populations in the Arctic Ocean to determine what microorganisms are present and what their metabolic capability is for degradation of various petroleum hydrocarbons. We are also examining the effects of sediment on the bioavailability of a polycyclic aromatic hydrocarbon (phenanthrene) to hydrocarbon degrading bacteria. In our survey we found high total numbers of microorganisms in all sediments examined (about 10^{10} cells g^{-1} dry wt sediment). *Only about* 10^6–10^8 *of these organisms were culturable in a marine heterotroph medium. Most probable numbers of culturable phenanthrene and hexadecane degraders were fairly high, about* 10^3–10^5 g^{-1} *dry wt sediment each, and populations of both types of organisms were significantly higher offshore Prudhoe Bay than offshore Barrow. In addition, culturable crude oil degraders were significantly greater offshore Prudhoe Bay than Barrow. It is likely, but not yet determined, that these differences are due to naturally occurring variability in these sediments rather than anthropogenic inputs. Mineralization potentials were low for both hexadecane and phenanthrene at both geographic locations. Despite the low organic carbon content of these sediments* ($\leq 1.5\%$)*, substantial adsorption to particles occurred; adsorption was rapid. Laboratory bioavailability studies using these same sediments are ongoing. The results of this study will be useful in predicting the fate of spilled petroleum hydrocarbons in the Arctic Ocean.*

Introduction

The response to recent lease sales in the Beaufort Sea suggests that Beaufort Sea offshore oil development projects will be increasing in number and frequency over the upcoming decade. Increased offshore oil and gas production can lead to both chronic and acute additions of petroleum hydrocarbons to the arctic marine environment. One important unanswered question in this context is, "What is the long-term fate of petroleum hydrocarbons spilled in the Arctic Ocean?"

Biodegradation often is a significant factor in removal of spilled petroleum hydrocarbons from the environment. For example, following the *Exxon Valdez* oil spill (EVOS) it was estimated that, by 1992, approximately 50% of the spilled oil had biodegraded either in situ on shorelines or in the water column [Wolfe et al. 1994]. In contrast to the many EVOS-generated studies of oil impact and fate, relatively little information is available regarding the potential fate or persistence of oil spilled in the Beaufort Sea. The marine environment of the Beaufort Sea is quite different from that in Prince William Sound, so data from the EVOS studies should be extrapolated to the Beaufort Sea environment with caution.

Microbial studies conducted in the 1970s and 1980s [Atlas et al. 1978; Haines and Atlas 1982] found that hydrocarbon-degrading microbes generally increased following oil contamination, but petroleum hydrocarbons were degraded very slowly. In general, following initial abiotic losses from their experimental systems, biodegradation of oil was limited and did not significantly alter the chemical composition of the residual oil. They pointed to several factors limiting biodegradation. These included limited populations of hydrocarbon-metabolizing microbes, localized high concentrations of hydrocarbons, low temperatures, unfavorable C:N and C:P ratios, low oxygen tensions and limited circulation of interstitial waters in fine-grained sediments. They also noted that abiotic weathering of the oil was slow, with "limited loss of low molecular weight aliphatic and aromatic hydrocarbons during two years' exposure."

No recent studies examining Alaskan arctic marine sediment microbial communities and their ability to metabolize petroleum compounds have been published. In year one we conducted a survey of Arctic Ocean offshore sediments near Barrow, Alaska, and evaluated the sediment microbial communities for their ability to metabolize petroleum hydrocarbons. In addition, laboratory acclimation studies using field sediment were used to estimate the adaptability to hydrocarbon metabolism of extant microbial communities. Sediment samples collected were also split and archived cryogenically for potential later analysis of microbial community structure by DNA or phospholipid fatty acid analysis. Samples were also collected for laboratory-based studies on the effects of sediment sorption on bioavailability of petroleum hydrocarbons. These latter studies are designed to assess the effects of Arctic Ocean sediments on biodegradability of petroleum fractions known to be toxic (e.g., phenanthrene or other polynuclear aromatic hydrocarbon). In year two we continued the study, collecting samples in coordination with the Arctic Nearshore Impact Monitoring in the Development Area (ANIMIDA) project at sites near Prudhoe Bay. This report briefly highlights our work to date, focusing on the results from year two. The results of this study will be the basis of a Master's degree project in environmental chemistry.

Methods and Materials

In the second year of this project we focused our efforts on sediments collected near Prudhoe Bay, Alaska. Sampling was conducted by Arthur D. Little, Inc. (in coordination with the ANIMIDA project) from 19–25 August 2000 (see Table 1 for specific locations). From each grab, sediment samples were collected with a disinfected metal spoon and placed into sterile containers and kept cold until processing. Additionally, a 15-mL cryovial was filled from each grab sample to be frozen and preserved to have available for genetic or fatty acid analysis at a later date. Samples for microbial analysis were chilled until return to the laboratory in Fairbanks. Cryovials were frozen (–20 °C) as soon as possible (within ca. 4 h after collection) and stored frozen until returned to Fairbanks, at which point they were transferred to an ultracold freezer (–80 °C). The unfrozen sediments were then analyzed for existing populations of microorganisms and hydrocarbon degradation potentials.

Table 1. Locations and depths of samples collected in August 2000 near Prudhoe Bay.

Sampling Sites Grouped by Location	Latitude	Longitude	Approximate Depth (m)
Liberty			
L 04	70° 17.032′ N	147° 39.897′ W	5
L 06	70° 16.881′ N	147° 33.978′ W	7
L 07	70° 16.789′ N	147° 31.966′ W	7
L 08	70° 16.701′ N	147° 30.298′ W	6
L 09	70° 16.568′ N	147° 27.130′ W	7
Northstar			
N 12	70° 27.321′ N	148° 42.078′ W	6
N 13	70° 27.004′ N	148° 43.552′ W	5
N 14	70° 25.978′ N	148° 40.459′ W	4
N 15	70° 26.710′ N	148° 44.570′ W	2
N 18	70° 29.082′ N	148° 42.151′ W	11
N 21	70° 26.819′ N	148° 40.587′ W	5
N 22	70° 29.340′ N	148° 41.868′ W	9
N 23	70° 29.340′ N	148° 41.868′ W	11
5 F	70° 26.486′ N	148° 49.550′ W	2
East of Liberty			
3 A	70° 16.988′ N	147° 05.470′ W	7
3 B	70° 17.917′ N	147° 02.549′ W	5
Boulder Patch			
4 A	70° 18.460′ N	147° 40.289′ W	5
4 B	70° 21.034′ N	147° 40.007′ W	7
L 01	70° 18.930′ N	147° 27.130′ W	7
Between Liberty & Northstar			
4 C	70° 26.144′ N	147° 42.957′ W	9
5 D	70° 24.488′ N	148° 33.605′ W	2
5 H	70° 22.210′ N	147° 47.744′ W	7
5 (0)	70° 22.210′ N	148° 47.744′ W	5
5 (1)	70° 25.024′ N	148° 03.569′ W	6
5 (5)	70° 26.106′ N	148° 18.127′ W	7
5 (10)	70° 27.323′ N	148° 29.980′ W	8
Colville River			
COL-01	70° 15.96′ N	150° 49.29′ W	
COL-02	70° 11.36′ N	150° 52.12′ W	
Kuparuk River			
KUP-01	70° 17.70′ N	148° 59.37′ W	
KUP-02	70° 17.70′ N	148° 59.37′ W	
Sagavanirktok River			
SAG-01	70° 01.68′ N	148° 33.77′ W	

Microbial population and activity assays to determine the existing potential of the sediments were initiated within two days after returning to Fairbanks. Analyses included estimates of total, heterotrophic, crude oil emulsifying, and substrate-specific degrader microbial populations, and assays for metabolic activity. Data derived from these assays were pooled to generate mean and standard error estimates for each location (see Table 1).

Table 2. Mineralization potentials, 96-h assays, for hexadecane and phenanthrene for samples collected August 2000.

Sampling Location	Mineralization Potential (ng substrate mineralized/g dry wt sediment)	
	Hexadecane	Phenanthrene
Liberty		
L 04	53 ± 8	20 ± 5
L 06	84 ± 11	30 ± 2
L 07	61 ± 8	27 ± 2
L 08	42 ± 19	38 ± 8
L 09	62 ± 6	19 ± 3
Northstar		
N 12	65 ± 19	35 ± 5
N 13	103 ± 19	38 ± 4
N 14	122 ± 7	48 ± 4
N 15	45 ± 4	14 ± 1
N 18	71 ± 13	27 ± 1
N 21	157 ± 9	53 ± 3
N 22	44 ± 4	13 ± 0
N 23	81 ± 11	33 ± 1
5 F	97 ± 9	32 ± 3
East of Liberty		
3 A	81 ± 14	34 ± 2
3 B	67 ± 5	28 ± 2
Boulder Patch		
4 A	64 ± 7	27 ± 2
4 B	99 ± 6	52 ± 5
L 01	63 ± 4	40 ± 4
Between Liberty & Northstar		
4 C	55 ± 10	31 ± 2
5 D	81 ± 13	36 ± 3
5 H	50 ± 8	26 ± 2
5 (0)	72 ± 8	30 ± 2
5 (1)	73 ± 8	31 ± 2
5 (5)	59 ± 7	30 ± 2
5 (10)	27 ± 8	21 ± 2
Colville River		
COL-01	35 ± 0	15 ± 1
COL-02	46 ± 4	19 ± 3
Kuparuk River		
KUP-01	58 ± 10	19 ± 1
KUP-02	133 ± 10	21 ± 2
Sagavanirktok River		
SAG-01	50 ± 4	19 ± 1

Microbial population analyses included most-probable-number assays (MPNs) for crude oil emulsifiers [Brown and Braddock 1990], marine heterotrophs [Lindstrom et al. 1991], substrate specific assays for phenanthrene and hexadecane [Braddock and McCarthy 1996; Wrenn and Venosa 1996; Braddock and Catterall 1999], and total microscopic direct counts of marine microbes [Braddock et al. 1990]. Mineralization potentials for phenanthrene and hexadecane were also determined using ^{14}C-labeled hydrocarbons in microcosms. To prepare each microcosm, 10 mL of a 1:10 sediment slurry in a mineral salts medium [Bushnell Haas; Atlas 1993] was added to a previously sterilized, 40-mL septum vial (I-Chem Research, Hayward, California). After the microcosms were constructed, 50 µl of a 2 g L^{-1} solution (in acetone) of radiolabeled hydrocarbon was added by syringe to each vial through the septum. The resulting initial concentration of added hydrocarbon was then 100 µg per vial (10 µg mL^{-1} culture broth; radioactivity ca. 50,000 dpm). Substrates used (Sigma Chemical Co., St. Louis, Missouri) included the alkane hexadecane (1-^{14}C-labeled), and the polynuclear aromatic hydrocarbon (PAH) phenanthrene (9-^{14}C-labeled). Each treatment was replicated three-fold, and killed controls were used to check for abiotic $^{14}CO_2$ evolution. Vials were incubated at 8 °C for 96 h, killed by adding NaOH to stop respiration, and assayed for $^{14}CO_2$ from hydrocarbon mineralization [Brown et al. 1991].

Results and Discussion

Direct counts of microorganisms in sediments collected at all sampling locations indicate high populations (approximately 10^9–10^{10} cells g^{-1} dry sediment) of microorganisms present in surface sediment from all sample locations (results not shown). There were no significant differences among any of the sites where samples were collected. These numbers are consistent with total direct counts, on average of 2×10^9 cells g^{-1} dry wt sediment, reported by Kaneko et al. [1978] for the Beaufort Sea. The cultivatable marine heterotrophs were lower (on average about 3 orders of magnitude lower) than direct counts (Figure 1). These numbers are also consistent with Kaneko et al. [1978] who found about 10^5 heterotrophic microorganisms g^{-1} dry wt sediment in samples from the Beaufort Sea. There were no statistically significant differences among locations sampled either near Barrow or near Prudhoe Bay for either total direct counts or culturable heterotrophs.

Phenanthrene and hexadecane degrader populations ranged between 10^3 and 10^4 cells g^{-1} dry sediment. For both carbon substrates, samples collected offshore the townsite of Barrow and offshore the former Naval Arctic Research Laboratory (NARL) had significantly lower populations than samples collected in Elson Lagoon or near Prudhoe Bay (Figure 1). In addition, the culturable population growing on Prudhoe Bay crude oil (oil degraders) was greater at all sites near Prudhoe Bay than at sites near Barrow (including Elson Lagoon) (Figure 1). The reasons for the results are at present unclear. However, it is likely that differences in sediment properties or naturally occurring carbon substrates may account for the results obtained. Since our samples were co-collected with samples which will be extensively analyzed for physical and chemical properties (ANIMIDA project), we should be able to determine if hydrocarbon chemistry or other measured properties can account for differences seen among the sites. Based on the data reported in the draft final report for the ANIMIDA project from 1999, we predict that the higher populations of hydrocarbon-degrading microorganisms in samples collected near Prudhoe Bay are more likely due to naturally occurring phenomena rather than anthropogenic hydrocarbon inputs.

While populations of microorganisms are present in these Arctic Ocean sediments, their ability to readily degrade petroleum hydrocarbons appears to be limited. As was seen for samples collected near Barrow in year one of this project [see Braddock and Gannon 2000], mineralization potentials for phenanthrene and hexadecane were uniformly low in sediments collected near Prudhoe Bay (Table 2). These sediments universally showed higher potentials for mineralization of the linear alkane, hexadecane, than the polycyclic aromatic hydrocarbon, phenanthrene. A further indicator of low activity is that our efforts to enrich for a consortium that both degrades hexadecane and phenanthrene have been difficult. However, we have recently acquired both a consortium and isolates that have high levels of activity for phenanthrene and hexadecane.

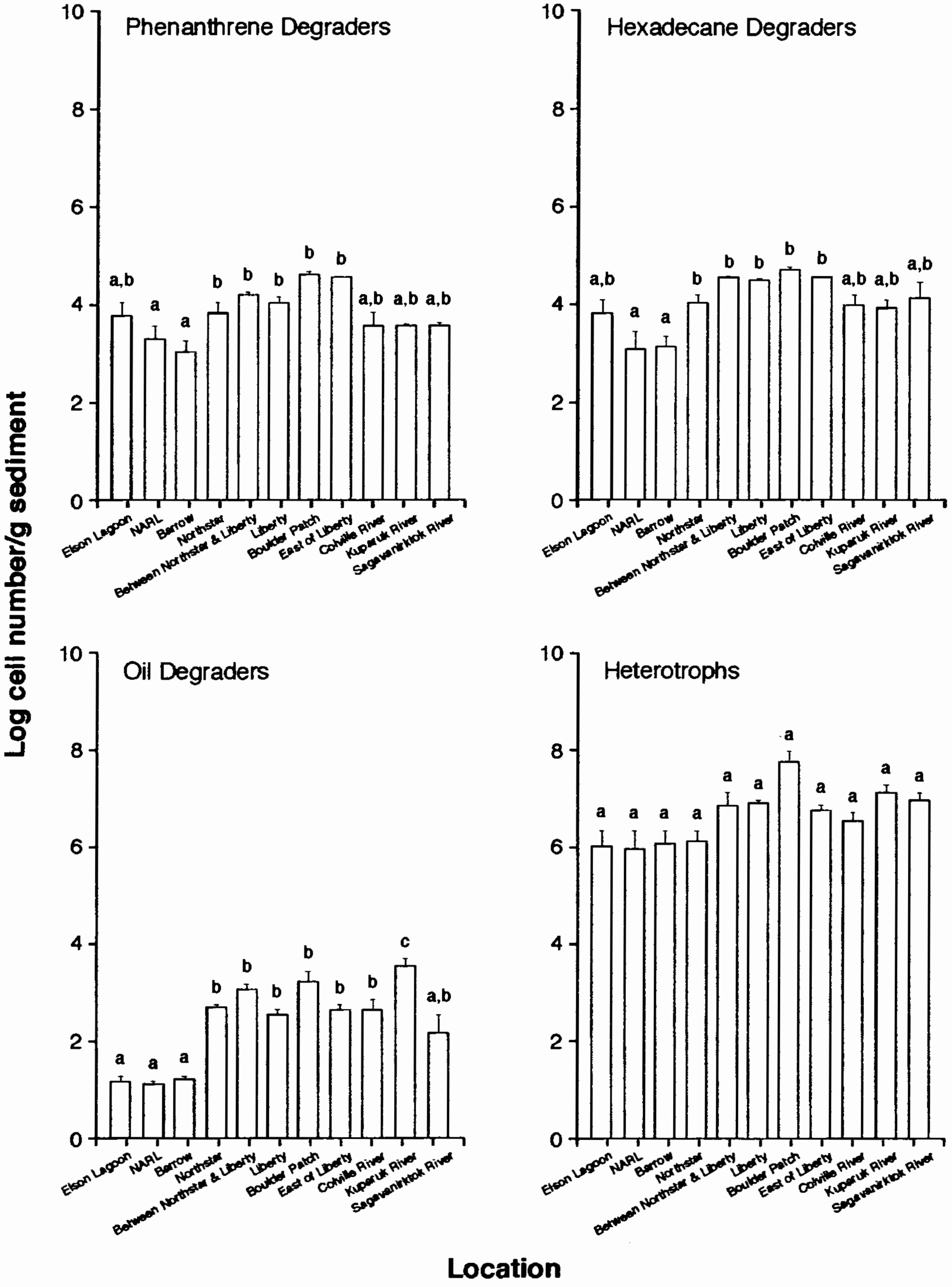

Figure 1. Populations of culturable microorganisms in sediments collected from sites near Barrow and near Prudhoe Bay, Alaska. Different letters appearing above the bars indicate significant differences among sites. Values represent the mean ± SE.

The results of this study indicate that sediment microbial populations have not changed appreciably since 1976. High numbers of microorganisms exist in these sediments, many of which were culturable with either hexadecane or phenanthrene supplied as a sole carbon source. But, interestingly, there were significant differences in populations among sites, with Prudhoe Bay sites generally having higher populations than those seen for sites near Barrow. However, mineralization potentials were low at all sites sampled relative to other locations [e.g., Prince William Sound Alaska; Braddock et al. 1990], indicating that the populations may only slowly acclimate to biodegradation of these hydrocarbon substrates. Adsorption isotherm experiments with the polycyclic aromatic hydrocarbon, phenanthrene, indicate rapid and extensive adsorption [see Braddock and Gannon 2000]. The sediments examined in these experiments did show differences in their adsorptive properties. This is likely due in part to differences in organic carbon content and to other unidentified differences among the sediments. Bioavailability experiments are ongoing with these sediments. Finally, as the results of the ANIMIDA survey from summer 2000 become available, we will hopefully be able to determine what factors might lead to the elevated populations of hydrocarbon degrading microorganisms we saw in samples collected near Prudhoe Bay. The results of this study will be useful in predicting the fate of spilled hydrocarbons in the Arctic Ocean. This study has supported the Master's thesis work of Kathleen Gannon who anticipates defending her thesis for a degree in environmental chemistry from the University of Alaska Fairbanks in winter 2000.

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Alaska Sea Ice Atlas

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Task Order 15177

Abstract

University of Alaska and Cold Regions Research and Engineering Laboratory (CRREL) specialists are preparing an updated GIS-based Alaska Sea Ice Atlas with a view toward risk assessment for navigation and mineral developments. Undergraduate and graduate geomatics and engineering students are integrally involved in the development. This project responds to the "Updated Ice Atlas" objective of the MMS Alaska Environmental Studies Program, Annual Studies Plan, FY 2000–2001. All ice-covered federal outer continental shelf and coastal waters of Alaska are being mapped. National Weather Service (NWS) ice reports for the Beaufort, Chukchi, and Bering seas are being scanned, geographically registered, and rectified to a standard map projection. Areas of uniform ice concentration, stage, and form are traced as polygons for superposition on a 5-km-square grid. Ice data archived by the U.S. National Ice Center (NIC) is treated similarly. Ice information from other sources, such as the Canadian Ice Service, is being applied to fill in gaps and to verify NWS and NIC data. Equivalent information for Cook Inlet, Alaska, previously prepared under separate contract, will be included. Verbal history has been collected through interviews of long-time residents of the Alaska coast and will be applied to verify measured data and statistics. The GIS database will allow users to view a statistical average over a broad area, a time series of conditions at a point, or an individual historical ice report. Meteorological data related to ice growth, behavior, deformation, and decay is being retrieved from agency archives and incorporated in the GIS database. Parameters to be incorporated include air temperature, freezing and thawing degree-days, sea surface temperature, and wind speed and direction. Historic isobaric maps will be applied to hindcast surface winds and wind stress divergence over ice as an index of ice compression, the primary cause of ridge formation. A chapter will portray multi-year cycles of arctic climate. Final products will include an executable GIS on CD-ROM and on the world wide web.

Introduction

The two-year Alaska Sea Ice Atlas compilation was begun in June 2000, sponsored by the University of Alaska Coastal Marine Institute, U.S. Minerals Management Service, Alaska Science and Technology Foundation, Alaska Department of Transportation and Public Facilities, Cominco Alaska, Inc., and the University of Alaska Natural Resources Fund. The Atlas is intended to aid mariners, regulatory agencies, engineers, and disaster response planners in the assessment of sea-ice impacts on current and future logistical operations and construction works. The project is scheduled for completion in June 2002.

The Marine Ice Atlas of Alaska [LaBelle et al. 1983] was compiled from short records of sparse ice information available from the early years of offshore development in Alaska. Precision and comprehensive coverage of reported ice conditions has increased during the subsequent 17 years through use of satellite imagery and an expanding network of aerial, shipboard, and coastal observations. The U.S. National Ice Center (NIC) has recently compiled weekly summary ice reports from 1972 to the present [National Ice Center 2001]. The U.S. National Weather Service (NWS) has also archived periodic ice reports at different scales [National Weather Service 2001]. Furthermore, geographical information systems (GIS) and computer database software improvements make archival, analysis, and portrayal of geospatial information, such as the NIC and NWS ice reports, much more practical to distribute as digital products via electronic media, especially the internet. The Alaska Sea Ice Atlas applies these new resources to improve the service offered by the earlier work.

Progress to Date

Ice Atlas team

The team includes:

- Orson Smith, UAA School of Engineering, Principal Investigator
- Cherie Northon, UAA Department of Geomatics, Co-Investigator
- Thom Eley, UAA Department of Geomatics, Co-Investigator
- Kenrick Mock, UAA Department of Mathematics and Computer Science, Co-Investigator
- Terry Tucker, Cold Regions Research and Engineering Laboratory, Co-Investigator
- Dwight Pollard, Alaska State Climatologist, Co-Investigator
- Andrey Proshutinsky, Woods Hole Oceaonographic Institution, Co-Investigator
- Tatiana Proshutinsky, UAF Institute of Marine Science, Co-Investigator
- Bill Lee, UAA Department of Geomatics, Head Geospatial Analyst
- UAA engineering, geomatics, and computer science students

Project technical steering committee

A steering committee of state and federal agency and private industry representatives has met twice, in June 2000 and in July 2001. This committee first approved plans for the Ice Atlas compilation and many conventions to be applied in the analysis of ice and ice-related information. The committee will next meet in January 2002 after review of the draft Ice Atlas.

NIC digital reports

The Ice Atlas project has already incorporated a large volume of diverse spatial and non-spatial data. The core data is the NIC Legacy Data Set [National Ice Center 2001], a collection of weekly summary maps of ice conditions from January 1972 to 2000, available on the internet as graphics images and ArcInfo export files. The NIC ice reports are typically compiled from satellite data including Canadian RADARSAT, U.S. Defense Meteorological Satellite Program SSM/I, AVHRR, and intermittent aerial, shipboard, and shore observations. The National Ice Center publishes a corresponding account of each ice report's production that outlines the extent to which each data source was applied. Descriptive spatial statistics in the Ice Atlas will rely almost exclusively on the NIC weekly summary reports.

Cook Inlet Ice Atlas

The Cook Inlet Ice Atlas [Mulherin et al. 2001] includes products to be incorporated in the Alaska Sea Ice Atlas. This earlier project was sponsored by the U.S. National Oceanic and Atmospheric Administration. The Cook Inlet Ice Atlas is based on NWS [2001] paper maps that were digitized and rectified before a grid of 1-km-square cells was applied. Two-week average conditions over Cook Inlet were derived from reports published by the National Weather Service from 1984 to 1999. The products of the Cook Inlet Ice Atlas are to be incorporated in the Alaska Sea Ice Atlas with enhanced GIS-based products to match the standards and web-based delivery of the statewide project.

Older paper ice reports

Copies of annually compiled and printed ice reports have been acquired as far back as 1953 [Naval Oceanographic Office 1953–1971]. These hard-to-find reports contain valuable information on historical ice conditions, including narrative descriptions of ice observing missions and forecasting procedures. The complete set has been scanned to create image files that can be browsed using common software.

Other ice information

A collection of heterogeneous information on particular areas has also been acquired for limited periods of time from personal collections, Native knowledge, and site-specific studies. Heterogeneous information has been stored and indexed with metadata for selective retrieval. Native knowledge compiled by others is being enhanced by interviews with elders in coastal arctic communities, regarding historical sea ice conditions. Narrative reports of Native knowledge will be incorporated in the ice atlas by map reference to the location for which they apply.

Meteorological data

Selected ice-related meteorological data from coastal monitoring stations were retrieved to compute statistical summaries. The meteorological data collection generally covers the past 50 years (1950–2000). A database was constructed that permits Atlas users to query data records and to construct statistical summaries useful for ice-related risk analyses.

Simulated ice-related parameters

Hindcast numerical simulation results have been compiled to map some historical environmental parameters pertinent to ice conditions offshore of Alaska including:

1. Atmospheric sea-level pressure [National Center for Atmospheric Research 1990];
2. Simulated surface wind velocity;
3. Simulated wind-induced ocean surface currents;
4. Simulated wind-induced water level changes (storm surges); and
5. Astronomical tides.

Analysis

Boundaries

Geospatial data is first translated to meet the geodetic specifications of the Atlas. Geospatial data is presented in WGS-84 (World Geodetic System) coordinates in a polar stereographic projection of true scale at 60°N latitude and origin at 90°N, 180°W. These are the same geodetic specifications as NIC ice reports. [National Ice Center 2000]. Ice Atlas users will be able to transform the data to any other suitable projection. The project's technical steering committee concurred on a region bounded at 180°W and 132°E longitude. Its north–south extent is from 80° to 54°N latitude (Figure 1).

Figure 1. Geographical boundaries of the Alaska Sea Ice Atlas.

Cell-based data model

Statistical analyses of the Ice Atlas are being compiled in the second half of the project through cell-based modeling with the GRID feature of ArcInfo GIS software (© Environmental Systems Research Institute, Inc. [ESRI]). A Cartesian matrix is established between the geographical boundaries of the Atlas (Figure 1) that is divided into a hierarchical block–cell structure to economize data management and reflect varying resolution of environmental records. The Atlas area is divided into 25-km square blocks and blocks are divided into 5-km square cells. The gridded GIS database representation of these variables is a matrix of floating-point values, identified with a point in time. The 1972–2000 sequence of weekly reports organized in this way can be visualized as a stack of gridded matrixes, each associated with a unique time, as illustrated in Figure 2.

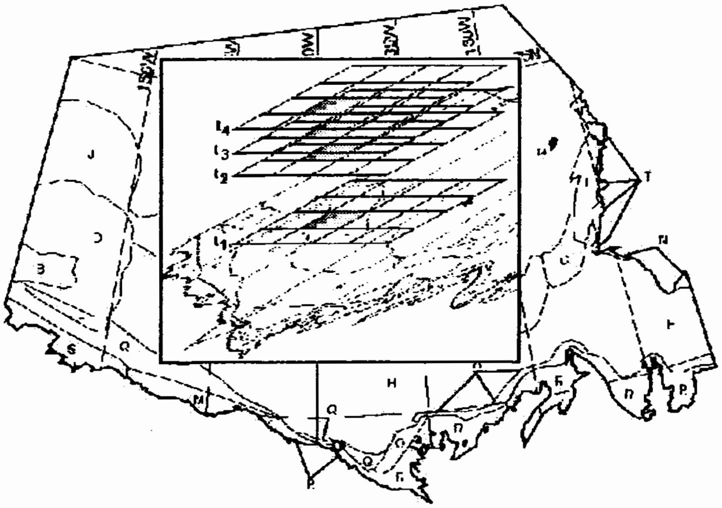

Figure 2. National Ice Center ice report with inset illustrating the concept of gridded ice and ice-related information as a sequence of weekly time steps (t_1, t_2....).

Statistical products

Other parameters not reported by NIC (e.g., wind-related parameters) are organized in an identical arrangement of gridded floating-point values on a weekly time scale. New parameters, such as superstructure icing potential, can be derived from algebraic combinations of parameters for a given cell at a given time. Any original or derived parameters can be compared with others at different times or incorporated in statistics computed from the entire time series. Minimum, mean, and maximum values are to be determined for each parameter. Maps of average concentration and average stage for Cook Inlet during the first half of February are shown in Figure 3.

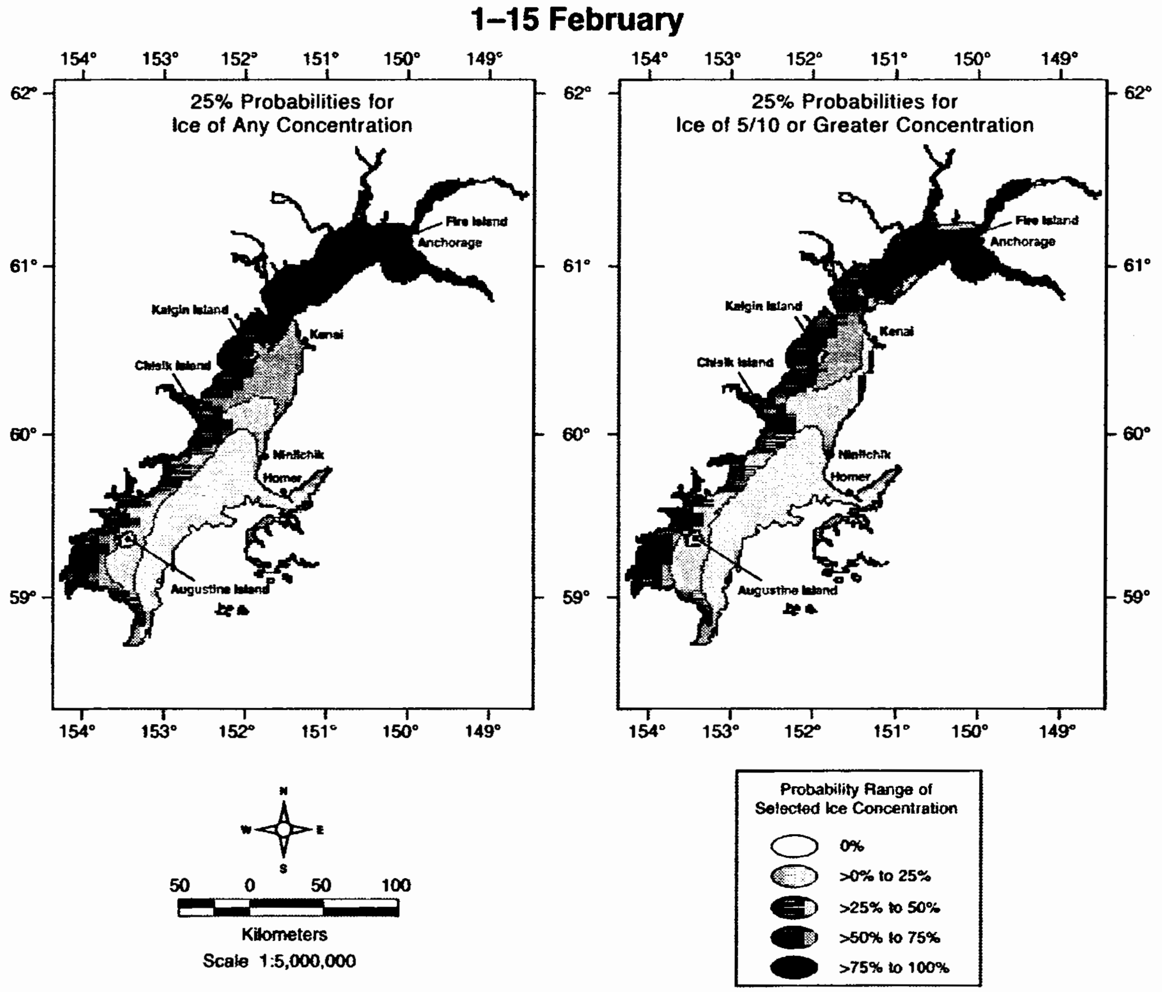

Figure 3. Maps of average values for the period of record of ice concentration and stage of development in Cook Inlet, Alaska, during the first half of February.

Ice Atlas analytical products now under development include:

- Maps of average and extreme ice classification (concentration, stage, and form);
- Time series, extremal statistics, and other parameters in any grid cell;
- Ice-related meteorological and oceanographic parameters;
- Ice-related parameters derived from basic measurements, such as freezing and thawing degree-days, commonly used in modeling ice growth;
- An index of wind-induced ice compression, computed as mathematical divergence of hindcast wind stress;
- Superstructure icing potential;
- Potential for reduced visibility from fog or precipitation; and
- An ice navigability index, based on a vessel traffic management system developed by Transport Canada [1996].

Conclusion

GIS technology reaches a new level of practical application in the Alaska Sea Ice Atlas. GIS software is directly applied for planning and design decisions by computing geo-referenced parameters derived from a geospatial database. The term "atlas", by this example, will come to have a new meaning in the 21st century. Availability of this service on the internet assures streamlined transfer of technology to the widest possible population of ice information users. Ice Atlas progress, example products, and related publications are linked to the web site: http://www.engr.uaa.alaska.edu/ice.

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A Nowcast/Forecast Model for the Beaufort Sea Ice–Ocean–Oil Spill System (NFM-BSIOS)

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Task Order 15178

Abstract

A nested coupled ice–ocean model is being developed under the CMI/MMS project entitled "A Nowcast/Forecast Model for the Beaufort Sea Ice–Ocean–Oil Spill System (NFM-BSIOS)". At the first step, the nested ocean model (3.4375 km) is described. We developed a transport-conserved nested scheme to pass information from the coarse model to the fine model. The fine (-resolution) ocean model was run for several months, far beyond the need for the operational purpose [Wang 2001]. We found that surface circulation follows the wind direction (to the west), while the slope current along the Beaufort Sea slope is reproduced below 100 m, flowing to the east, just opposite to the surface current. There are some mesoscale eddies in the fine model. Neither the slope current nor the mesoscale eddies are captured in the coarse model. Thus, this fine nested model preliminarily captures some dynamic features in the Beaufort Sea and its shelves.

Introduction

The Beaufort Sea is located on the U.S. shelf of the Arctic Ocean. It draws much attention from world researchers for its oil exploration and climate research. Hydrography of the Beaufort Sea shows that a coastal current exists along the shelf of the Beafort Sea. The ocean circulation is dominated by the inflow through the Bering Strait and Arctic circulation. Eddy motion is the important feature of circulation in the Beaufort Sea [Manley and Hunkins 1985]. Chu et al. [1999] classify the thermohaline structure and give four types of structure features.

The aim of this study is to develop a nested coupled ice–ocean model to study the ice and ocean features and to implement the nowcast/forecast models for the Beaufort Sea. The Beaufort Sea is perennially an ice-covered area; ice growth/decay and movement play an important role in the heat budget and hydrodynamics of the ocean. It is necessary to use a coupled ice–ocean model to simulate ocean circulation and thermohaline structure. In order to achieve this goal, a fine-grid model with higher horizontal resolution (3.4375 km) is being developed and nested into a coupled ice–ocean model for the pan-Arctic Ocean and North Atlantic Ocean. A simple description of the nested coupled model is given below. Some preliminary results on the circulation and thermohaline structure are shown in the Model Simulation section.

Model Description

Sea ice exists perennially in the Beaufort Sea, although the ice melts in summer in the coastal region. Sea ice plays an important role in oceanic circulation and ocean heat and fresh water budgets. Thus, a fine-grid coupled ice–ocean model is used to simulate the ocean and sea ice. The fine (3.4375 km) model is nested into a coarse (27.5 km) coupled ice–ocean model possessing the same physical processes covering the pan-Arctic and North Atlantic oceans.

Sea ice model

The sea ice component of the coupled model is a thermodynamic model based on a multi-category ice thickness distribution function [Thorndike et al. 1975; Hibler 1980] and a dynamic model based on viscous-plastic sea ice rheology [Hibler 1979; Wang et al. 1994].

The evolution of the thickness distribution function satisfies a continuity equation

$$\frac{\partial g}{\partial t}+\nabla\bullet(u_i g)=-\frac{\partial(fg)}{\partial h}+\Psi \tag{1}$$

where $f(h)$ is the thermodynamic vertical growth rate of ice determined by the ice thermodynamics with snow cover and g is the sea ice thickness distribution function. Ψ is the mechanical redistribution function which represents the creation of open water and ridging during ice deformation. The redistribution process conserves ice volume. The redistribution function is parameterized as multiple categories used by Yao et al. [2000]. In the equations below $g(h)dh$ is defined as the fraction of area covered by the ice with a thickness between h and $h+dh$. The concentration A and averaged thickness $\bar{h}$ of sea ice in a grid are expressed from $g(h)$ as

$$A=\int_{0+}^{h} g(h)dh \tag{2}$$

and

$$\bar{h}=\int_{0}^{h} g(h)hdh \tag{3}$$

The ice drift velocity u_i is determined from the momentum equation

$$m\frac{d}{dt}u_i+m\hat{f}\times u_i=-m\hat{g}\nabla H+A(\tau_a-\tau_w)+\nabla\bullet\sigma \tag{4}$$

where $\hat{f}$ is the Coriolis parameter and m is the ice mass in a grid. ∇H is the gradient of sea surface elevation, A is the ice-covered fraction, and τ_a and τ_w are the air and water stresses, respectively. σ is the two-dimensional internal ice stress tensor, which is derived from the viscous-plastic rheology [Hibler 1979].

Ocean model

The Princeton Ocean Model [Blumberg and Mellor 1987; Mellor 1996; Wang 2001] is used as the ocean component of the coupled model in this study. The model has a free surface, uses sigma coordinates in the vertical, and employs a mode time split technique. The model embeds a second-order turbulence closure sub-model. Smagorinsky diffusivity along sigma surfaces is employed in the horizontal diffusion.

The governing equations for temperature and salinity are

$$\frac{\partial TD}{\partial t}+\nabla\cdot(Tu_w D)+\frac{\partial T\omega}{\partial \sigma}=\frac{\partial}{\partial \sigma}\left(K_H\frac{\partial T}{\partial \sigma}\right)+F_T-(1-\alpha_w)\frac{\partial I_0}{\partial \sigma} \tag{5}$$

and

$$\frac{\partial SD}{\partial t}+\nabla\cdot(Su_w D)+\frac{\partial S\omega}{\partial \sigma}=\frac{\partial}{\partial \sigma}\left(K_H\frac{\partial S}{\partial \sigma}\right)+F_S \tag{6}$$

where α_w is the sea surface albedo and I_0 is the solar radiation flux reaching the sea surface. The surface heat forcing excluding the solar radiation for a grid cell is

$$AQ_{IW}+(1-A)Q_{AW} \tag{7}$$

where A is the ice concentration, Q_{IW} is the oceanic heat flux under ice, and Q_{AW} is the heat budget of open water. The salt flux forcing at the ocean surface is

$$Q_S=AQ_{SI}+(1-A)S(P-E) \tag{8}$$

where Q_{SI} is the salt flux between ice and ocean, S is the salinity at the uppermost model grid point, and $(P–E)$ is the volume flux of precipitation minus evaporation.

Ice–ocean coupling

Heat and salt flux at the ice–ocean interface were governed by the boundary processes as discussed by Mellor and Kantha [1989]. In grid cells in which ice is present the heat flux out of the ocean is

$$Q_{IW}=-\rho_w C_p C_{Tz}(T_f-T) \tag{9}$$

where C_p is the specific heat of seawater and T is the ocean temperature at the uppermost model grid (in our model the midpoint of the uppermost ocean layer). The heat transfer coefficient C_{Tz} is given by

$$C_{Tz}=\frac{u_*}{Pr_t\ln(-z/z_0)/\mathrm{k}+B_T} \tag{10}$$

$$B_T=\mathrm{b}(z_0u_*/\nu)^{1/2}Pr^{2/3}Q_{AW} \tag{11}$$

where u_* is the friction velocity, Pr_t is a turbulent Prandtl number, z is the vertical coordinate corresponding to the temperature T, z_0 is the roughness length, and k is the von Karman constant. The molecular sublayer correction is represented by B_T where Pr is a molecular Prandtl number, ν is the kinematic viscosity, and b is an empirical constant.

Analogous to the heat flux (9), the salt flux Q_{SI} is defined

$$Q_{SI} = -C_{Tz}(S_0 - S) \tag{12}$$

where S_0 is the salinity at the ice–ocean interface. The salt transfer coefficient C_{Sz} is

$$C_{Sz} = \frac{u_*}{Pr_t \ln(-z/z_0)/\mathrm{k} + B_S} \tag{13}$$

$$B_S = \mathrm{b}(z_0 u_* / \nu)^{1/2} Sc^{2/3} \tag{14}$$

where Sc is a Schmidt number. Since Sc=2432 and Pr=12.9, $C_{Tz}>C_{Sz}$, this can lead to the production of frazil ice in the water column as discussed by Mellor and Kantha [1989]. Frazil ice is immediately added to the floating ice.

The ice–water stress is

$$\tau_w / \rho_w = \frac{k u_*}{\ln(z/z_0)}(u_i - u_w) \tag{15}$$

where u_w is the ocean velocity at the uppermost model grid.

Model domain and grid system

The nested fine (-resolution) model domain covers the Beaufort Sea with three open boundaries (Figure 1). The coarse grid model domain includes the pan-Arctic and North Atlantic oceans (Figure 1a). Bathymetry has been smoothed. The Bering Strait is enclosed. The only open boundary of the domain is in the northern Atlantic Ocean. The ocean model variables are in the Arakawa C-grid system. The variables for the sea ice model are staggered in the Arakawa B-grid system.

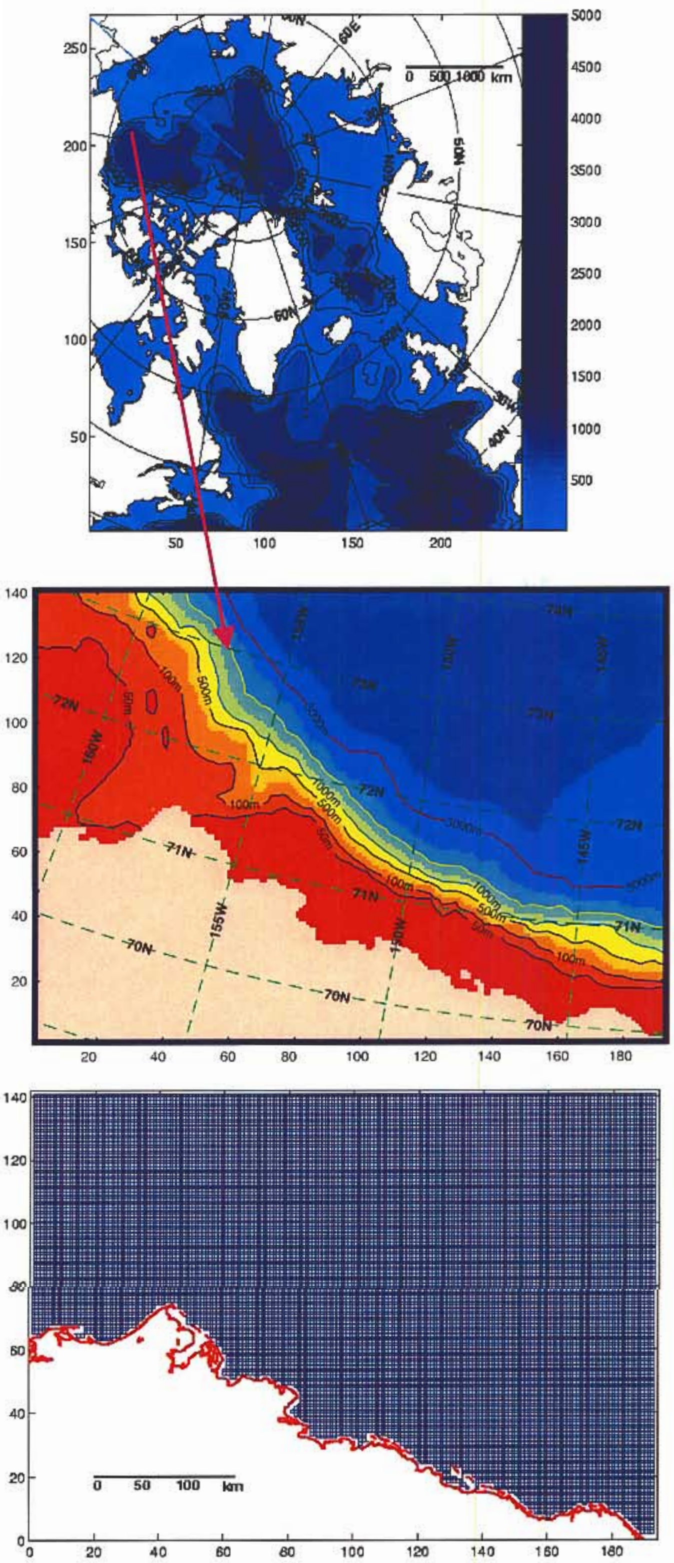


Figure 1. The domain and bathymetry for the coarse (top) and nested fine-resolution (middle) coupled ice–ocean model in the Beaufort Sea. The bottom figure is the fine-resolution grid.

Model forcing, model run and experiments

Atmospheric forcing includes wind at 10 m, air temperature at 2 m, air specific humidity at 2 m, sea level pressure (SLP), precipitation and atmospheric long wave radiation. These data are interpolated to every day from monthly climatological atmospheric data from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) re-analysis [Kalnay et al. 1996], which are averaged over 40 years from 1958 to 1998. All atmospheric data are bilinearly interpolated to the model grid.

Over water the drag coefficient of wind stress is calculated as a function of wind speed and air–sea temperature differences [Smith 1988]. Over ice a constant drag coefficient of 2.3×10^{-3} is used. The water–ice drag coefficient is a constant of 18×10^{-3}.

Sensible and latent heat fluxes are calculated using standard bulk formulae. Over water the sensible heat flux coefficient is calculated following Smith [1988]; over ice a constant value of 1.75×10^{-3} is used. The latent heat flux coefficient is set to 1.2 times the sensible heat flux coefficient and evaporation is calculated according to Reed [1977]. Shortwave radiation penetrates the water column. Assuming 31% of the radiation is absorbed below the first few meters, the absorption decays exponentially with depth with a decay scale of 23.8 m.

The nested fine-grid model runs after the coarse model runs for eight years, starting from an ice-free ocean, using climatological temperature and salinity of various sigma layers which are interpolated from PHC2.0 (Polar Science Center [University of Washington] Hydrographic Climatology) [Steele et al. 2001]. The initial field and open boundary conditions for the nested fine-grid model are interpolated from the simulations of sea ice and ocean variables in the eighth model year of the coarse grid model when the coarse-grid model closes to a quasi-stationary state, which can be observed from ocean kinematic energy (Figure 2).

The restoring forcing is used for sea surface salinity (SSS) and sea surface temperature (SST) to decrease the climate drift. The climatological SST and SSS are interpolated to every day from PHC2.0 and used to restore forcing with the restoring time scale of 36 days.

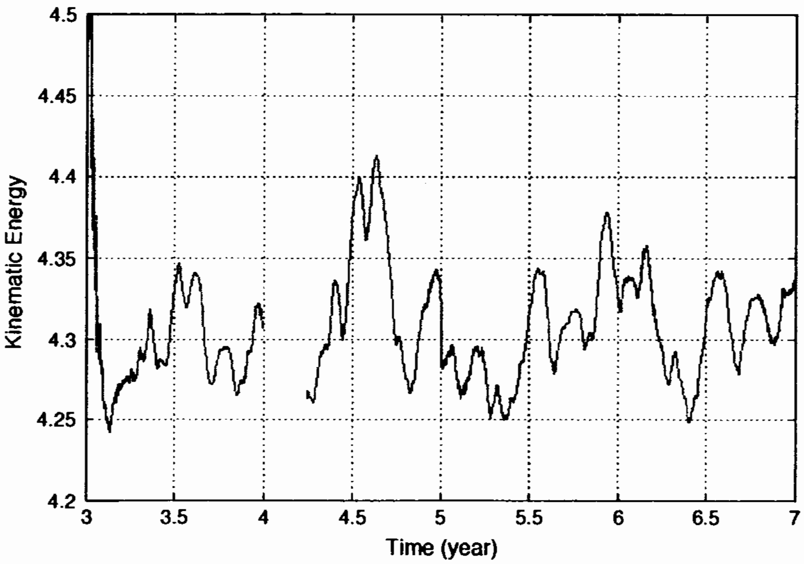


Figure 2. Mean kinematic energy of the coarse-grid model.

Model Simulation

Figure 3 shows the coastal current at layers of 10 m, 100 m, 250 m and 500 m in the Beaufort Sea. (The thick velocity vectors (in red) are used to keep the figures more legible.) A coastal current system and eddies with various length scales exist. The coastal current system flows to the west in the upper ocean layer from the surface to about 100 m (see Figures 3a and b), and to the east in the deep layers below 100 m (see Figures 3c and d). The upper-layer coastal current is driven by the anticyclonic wind and affected by the Alaska coast and topography of the shallow water. The deep-layer cyclonic circulation is part of the Arctic basin-scale circulation and results from the sloping topography of the Alaska Shelf. Oceanic eddies are complex—some being cyclonic, some anticyclonic. Their horizontal and vertical scales vary.

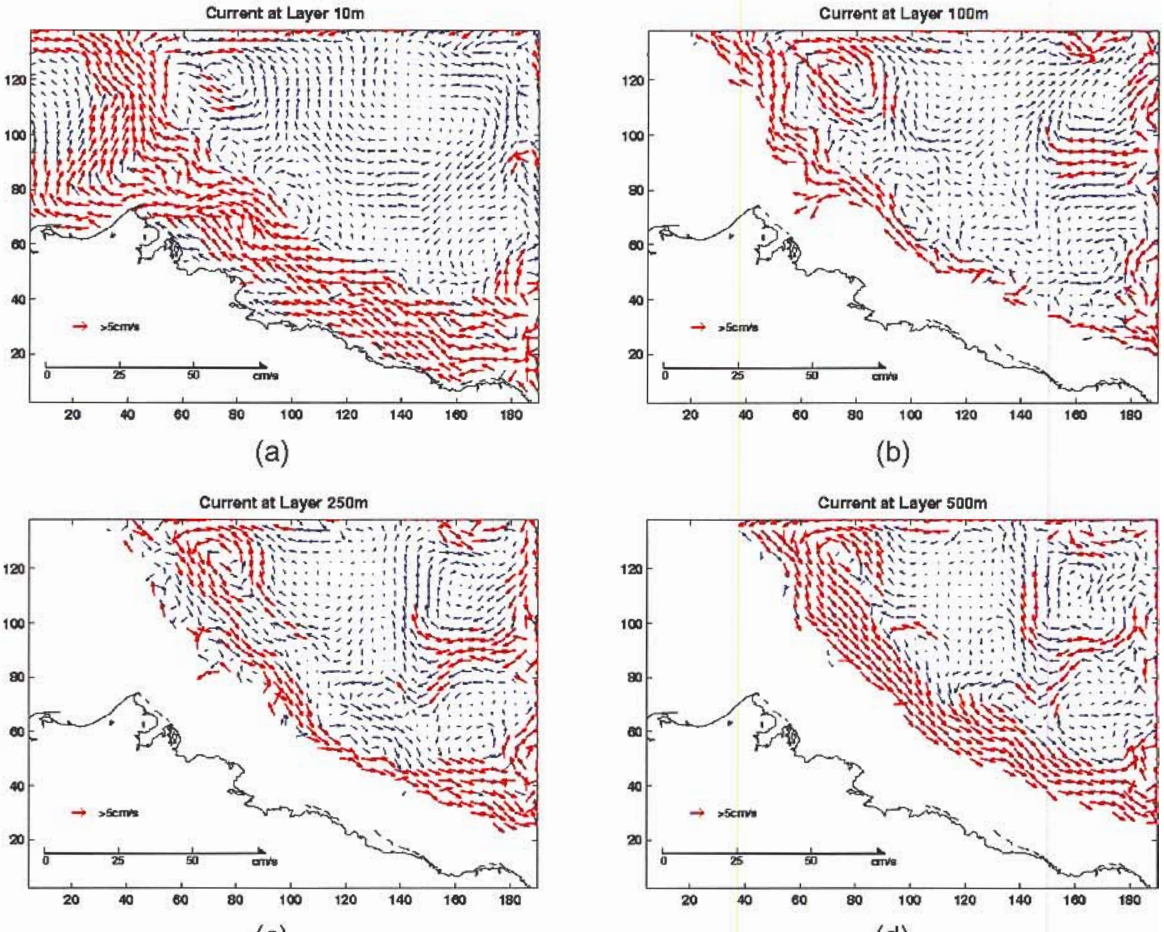
The volume transport is divided into several belts (Figure 4). The main branch is the eastward flow in the slope. The eddy transport is not as strong as the main branch. Transport in shallow water near the coast provides only a small contribution to the total transport. The transport belt along the Barrow Canyon slope is obvious.

Four cross sections of salinity and temperature (Figure 5) are analyzed. Section A is along the Alaska Shelf. Sections B, C and D are across the shelf from the coast to the deep water area.

At Section A, water temperature (Figure 6a) is colder at the upper layer and near the freezing point of seawater. The low temperature (Arctic surface water) layer can extend to 100 m in the shallow area and to about 200 m in the deep water region. The warmer core is at 500–1000 m, the Atlantic water layer. Surface salinity (Figure 6b) is fresh. A low salinity (<32 psu) layer extends from the surface to about 200 m (Arctic surface water). The halocline is obvious in the subsurface, compared to the lower temperature at the surface.

Only temperature and salinity along Section B are shown in this report. Temperature (Figure 7a) is at or near the freezing point of seawater at the upper 10 m. Temperature increases with depth from the upper layer to about 500–1000 m and decreases with depth below 1000 m. The warmer core (Atlantic water) occupies the layer between 500–1000 m and almost extends through the entire deep-water area. The warm core may be due to the intrusion of the North Atlantic warm water.

Salinity (Figure 7b) is lower in the shallow water near the Alaska coast and remains mostly uniform in the entire water column. In deep water, salinity increases from 31 psu at the surface layer to 35 psu at the bottom.



(a) (b)

(c) (d)

Figure 3. Simulated circulation at 10, 100, 200, and 500 m in the Beaufort Sea.

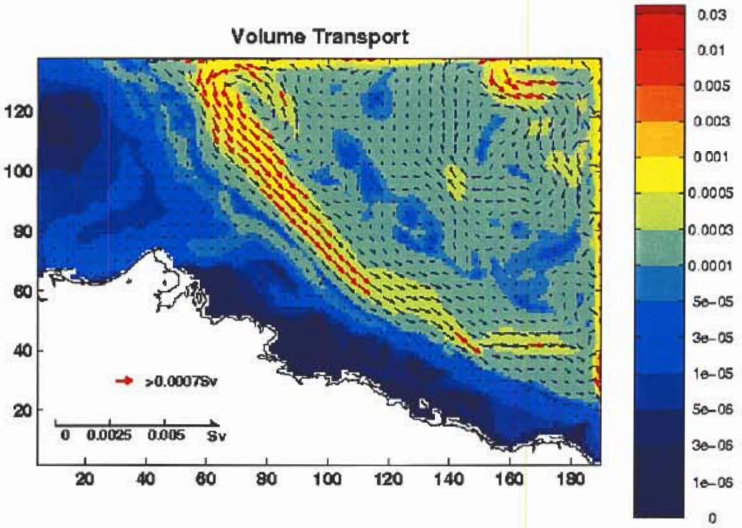


Figure 4. Simulated volume transport and transport belts.

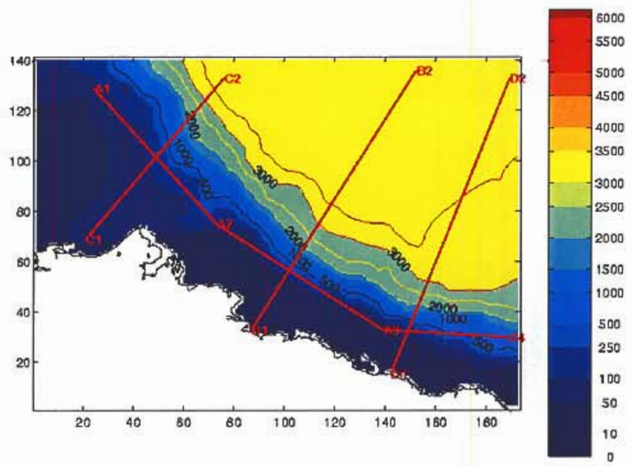
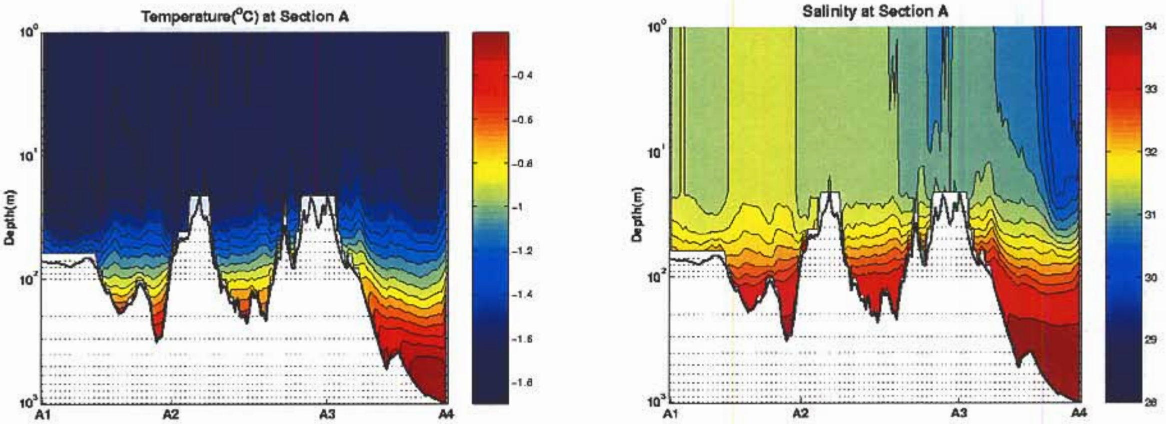
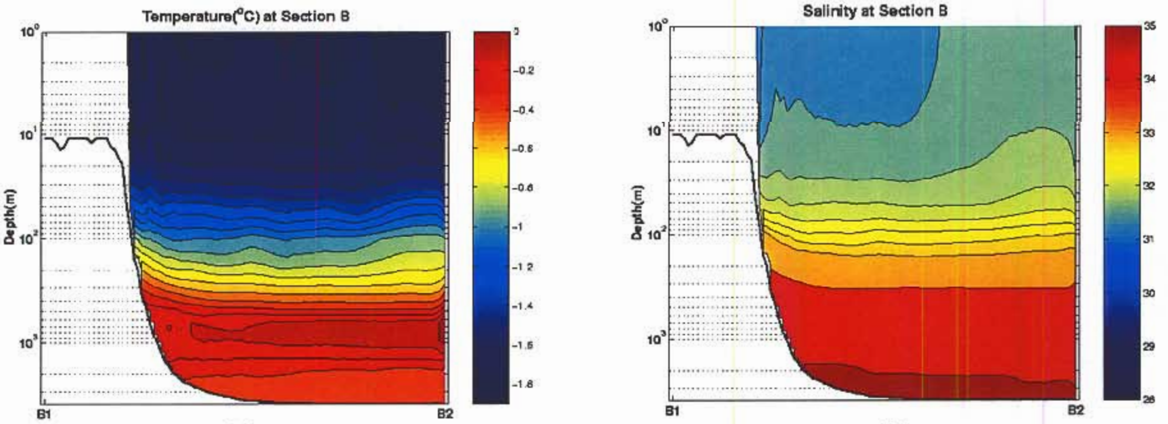


Figure 5. Vertical cross sections.



(a) (b)

Figure 6. Temperature (a) and salinity (b) along the Alaska shelf along Section A. Note that the vertical coordinate is in logarithm scale in meters (0, 10, 100, 1000, …).



(a) (b)

Figure 7. Temperature (a) and salinity (b) along Section B. Note that the vertical coordinate is in logarithm scale in meters (0, 10, 100, 1000, …).

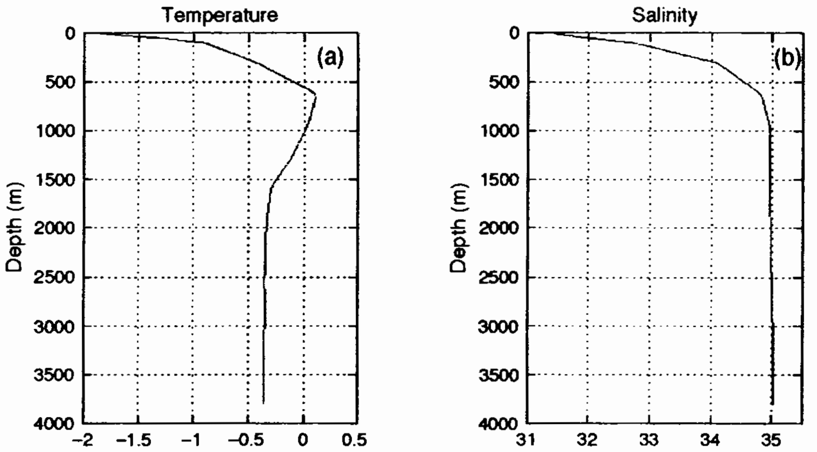


Figure 8. Temperature (a) and salinity (b) profiles in the deep water region.

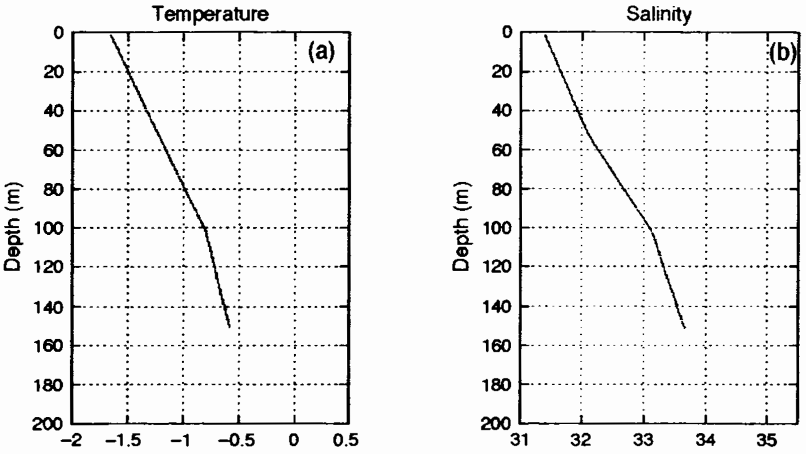


Figure 9. Temperature (a) and salinity (b) profiles in the shallow water region.

Concluding Remarks

A fine-grid coupled ice–ocean model, which is nested into a coarse coupled ice–ocean model for the pan-Arctic and North Atlantic oceans, is being developed to simulate the ocean circulation in the Beaufort Sea. The ocean circulation, transport and vertical distribution of salinity and temperature are analyzed. The major conclusions are:

1. There is a significant coastal current along the Alaska coast slope. The coastal current is westward in the top layer and coincides with wind forcing. The reverse coastal current exists below 100 m and extends to a deeper layer.
2. Mesoscale eddies are a typical phenomenon in the Beaufort Sea and extend to a deep layer. Some eddies are cyclonic, some anticyclonic.
3. A low salinity layer exists in all domains and can reach a depth of 200 m. The thickness of the low salinity varies from place to place.

4. The simulated temperature agrees with the observations and analyses of others. A warmer core layer (Atlantic water) lies between 500–1000 m.
5. Vertical mixing is a DP type in the shallow water region, but is an SM type for salinity and an AD type for temperature in the deep water region.

The model reproduces some important features of ocean circulation and thermohaline structure in the Beaufort Sea. We have collected data on salinity and temperature profiles in this area since 1953. The data are being analyzed. After completing the data diagnostic analysis, further model-data validation will be carried out.

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Satellite Tracking of Eastern Chukchi Sea Beluga Whales in the Beaufort Sea and Arctic Ocean

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Task Order 15179

Abstract

Beluga whales occur in northern and western Alaska and are important for subsistence to many Alaska Native hunters. Despite this importance and protection of belugas under the Marine Mammal Protection Act, relatively little is known about the movements and distribution of belugas in Alaska. Much information is available from when belugas inhabit coastal waters during the summer but little is known about them during the rest of the year. Satellite tagging provides a means to determine beluga distribution and movements outside of summering areas. Recent satellite tagging studies of belugas in the eastern Chukchi Sea revealed that these animals spent a good portion of the summer in the Beaufort Sea and the Arctic Ocean north of the Beaufort Sea. Only a few belugas have been tagged to date in the Chukchi Sea, and most of those were large males. It is unknown whether the females and smaller males also regularly move into the Beaufort Sea, although initial results indicate that some of them do. Oil and gas exploration and development have the potential to negatively impact the eastern Chukchi Sea stock of beluga whales.

In this study, we proposed to capture and attach satellite tags to female and small male belugas to determine their distribution and movements during the summer and early fall. It was our intent to attach eight satellite tags in 2000 and an additional nine in 2001. Due to unusually heavy ice conditions at Point Lay in late June and early July 2000, it was not possible to attach satellite tags. However, during July 2001, we successfully tagged eight belugas in Kasegaluk Lagoon near Point Lay. This included four adults and four juveniles. Four of these eight (three gray subadults and one adult male) were still transmitting data as of 3 September. Male belugas moved the farthest north and east during July and August. However, none of the males tagged in 2001 traveled as far north as belugas tagged in 1998 and 1999. Both adult and gray female belugas stayed on the continental shelf or near the shelf break. This report describes progress made from project inception through August 2001.

Background

Beluga whales occur in northern and western Alaska and are important to Alaskan Native hunters for subsistence; more than 300 belugas are harvested annually in Alaska. These same belugas migrate through both Alaskan and Canadian offshore oil and gas leasing areas and are a subject of increasing international discussion regarding cooperative population management for stocks shared by Alaskans, Canadians, and Russians. Concerns about potential effects of offshore oil and gas exploration and development on beluga whales exist on local, national, and international levels. However, despite the importance of belugas as a subsistence resource and their protection under the Marine Mammal Protection Act, late summer distribution and fall migration patterns are poorly known, wintering areas are effectively unknown, and areas that are particularly important for feeding have not been identified.

In Alaska, there are five stocks of beluga whales, which are identified based on traditional summering areas. Two of these stocks, the eastern Beaufort Sea and the eastern Chukchi Sea stocks, occur seasonally in the Beaufort Sea. The Beaufort Sea stock migrates along the spring lead in April and May from the Bering Sea to the eastern Beaufort Sea and returns west through the Beaufort Sea in September and October. The eastern Chukchi Sea stock occurs off northwestern Alaska in late June and early July and, as discovered recently, travels into the Beaufort Sea for the remainder of the summer. A greater understanding of the fall migration of the Beaufort Sea stock and a determination of late summer movements of Chukchi Sea stock have been obtained through the use of satellite tagging.

Satellite tagging offers a proven cost-effective and technologically sound approach to obtaining information on beluga distribution and movements. In the early 1980s, the Minerals Management Service Alaska OCS Region managed a pioneering tagging study of belugas in Bristol Bay by the Alaska Department of Fish and Game. Although ADF&G scientists were able to attach only two VHF tags, the results of this work provided the basis for the first data-linked correction factors for beluga aerial surveys. Capture techniques pioneered in that study have since been applied to tagging efforts in other areas. More recently, belugas have been captured and instrumented with satellite-linked tags at a variety of locations across the Canadian Arctic and Alaska.

Canadian scientists captured and satellite tagged 30 belugas from the eastern Beaufort Sea stock during 1992–1997. Information from those tagging efforts has dramatically changed our understanding of habitat use, distribution and movements of Beaufort Sea belugas. It is now clear that belugas tagged in the Mackenzie region do not remain in shallow, nearshore waters but travel hundreds of kilometers to the north through heavy pack ice to feed. They often dive to depths exceeding 600 m and routinely travel through pack ice of ≥ 9/10 coverage.

In 1998 and 1999, the Alaska Beluga Whale Committee, North Slope Borough, ADF&G, National Marine Fisheries Service/National Marine Mammal Laboratory (NMFS/NMML), and village of Point Lay captured and tagged a total of ten belugas from the eastern Chukchi Sea stock. The data from these first satellite tagged belugas in the eastern Chukchi Sea have provided new and surprising information about their movements and distribution during late summer and autumn. These tagged belugas did not, in contradiction to previous assumptions, spend the summer in pack ice of the north central Chukchi Sea. Instead, they moved into the Beaufort Sea and Arctic Ocean [Suydam et al. 2001]. Some traveled more than 2000 km from the tagging location. Additional data are needed about the use of the Beaufort Sea and Arctic Ocean by the eastern Chukchi Sea beluga stock.

As part of its lease sale planning in the Beaufort Sea, MMS has focused on the eastern Beaufort Sea stock of belugas since they were known to migrate through and summer in this region. Satellite tracking of eastern Chukchi Sea belugas has revealed that they, too, spend a portion of the summer in the Beaufort Sea [Suydam et al. 2001]. Satellite tagged belugas moved north along the Chukchi Sea coast of northwestern Alaska and into the Beaufort Sea. Most of the tagged belugas moved far to the north and east through up to 700 km of 90%–100% ice cover, as far as 80° N, 134° W, and then moved south in the Beaufort Sea toward the northern Alaska coast. Eight of the ten belugas tagged in the eastern Chukchi Sea were large males, one was a large female and one was a small female. All of the large belugas moved far to the north into the Arctic Ocean pack ice, but the small female only moved to approximately 72° N in the western Beaufort Sea. This indicates that there may be some sex- or age-related differences in distribution and movement patterns.

In early 2000, this project was funded by the Coastal Marine Institute to attach satellite tags to additional belugas at Point Lay. The objective of this study is to examine possible sex- or age-related differences in distribution and movement patterns. Field work and tagging were intended to take place in June/July of 2000 and 2001. However, a great deal of sea ice was still present along the outside of the barrier islands of Kasegaluk Lagoon in early July of 2000. The presence of sea ice prevented beluga hunters and biologists from either harvesting or catching/tagging belugas. Consequently, since no belugas were tagged in 2000 the project was delayed for one year. The first year of tagging instead took place in 2001, with additional tagging to occur in 2002.

Methods

The tagging effort was designed as an integrated part of ongoing harvest monitoring and other beluga studies at Point Lay. The North Slope Borough (NSB) maintains facilities in Point Lay that have been used for beluga field work in that village since 1990. Those facilities were used for this project in late June–July 2001. Facilities included housing and office space. Equipment such as boats, motors and other necessary field equipment were provided by the NSB Department of Wildlife Management. Other logistical support came from the Alaska Beluga Whale Committee and the hunters of Point Lay. The tagging crew included Greg O'Corry-Crowe and Lauren Hansen (NMFS San Diego), James Tazruk, Nick Hank and Charles Aniskette (Point Lay), Laura Litzky (University of Washington), and Todd Robeck (Sea World San Antonio).

Beluga hunters from the village of Point Lay conducted a successful drive hunt during the night and early morning of 2 and 3 July. Belugas were located near Omalik Lagoon, and driven more than 50 km to the lagoon in front of the old village site at Point Lay where the harvest took place. Approximately 30 belugas were harvested.

In conjunction with and immediately following the harvest, two adult belugas were captured and satellite-tagged. They were captured in a set net, 200 m long, 4 m deep, and with 37.5 cm stretched mesh. The net was set across the channel of the lagoon. Individual whales were driven into the net where they became entangled. They were removed from the set net and secured with a hoop net over their head and flippers. Once we pulled the belugas to shore, a padded rope was secured around their peduncle. The belugas were held in water shallow enough that their dorsum was exposed. They were released immediately after the transmitters were attached. Both left the lagoon soon after their release.

The remaining six belugas were captured with hoop nets during two separate capture events. Point Lay hunters assisted biologists by driving a small group of belugas from outside a lagoon pass into shallow lagoon waters where they could be maneuvered close to shore for netting. The first three of these (all juvenile gray animals) were caught on 5 July approximately 8 km north of Point Lay. The other three (one juvenile and two adult males) were caught on 7 July at the same location. After capture, these belugas were handled in the same manner as those initially caught in set nets. Due to low water in the lagoon all six remained in the channels of the lagoon for 2–5 days after they were tagged.

Satellite transmitters were manufactured by Wildlife Computers. They were configured for mounting in three ways: a) nylon saddles, b) side mounts, and c) spider tags. Saddle tags and side mounts were anchored with three nylon pins, approximately 0.33 m long. These pins were inserted through the skin and blubber of the dorsal ridge. Spider tags were anchored with three pins. The tags were powered by lithium batteries with 0.5 watt output; they collected data continuously, but a conductivity switch allowed transmissions only when the tag was out of the water.

Results

Eight belugas were captured and tagged during July 2001 near Point Lay (Table 1). This included four white adults (one female, three males) ranging from 340–381 cm in length and four gray animals (two females and two males) ranging from 316–335 cm. We deployed one saddle-mount style transmitter, three side mounts, and four spider mounts.

Three of the four adult beluga tags failed prematurely (two males, one female). These four included three spider mount attachments and one saddle mount. Possible causes for failure could include tag malfunction, antenna breakage when the animals were in the ice, or problems with the attachment (tissue rejection of the tag anchor). We think that tag malfunction is the least likely cause for failure. Both of the males were about 60 km northeast of Point Barrow and within a few kilometers of each other when their tags failed. One of these males (PTTID 2093) made the farthest movement north and east of any of the tagged belugas, reaching 75.6° N, 145.8° W on 23 July, just three weeks after it was tagged. However, this was still not as far north and east as tagged males moved in 1998 and 1999. Male 2282 also moved well north of the continental shelf break into water deeper than 3000 m before returning south. The adult female was less than 30 km north of Point Barrow when her tag failed. One adult tag was still transmitting when this report was written on 3 September. At that time, this male (11037) was along the shelf break and approximately north of the mouth of the Colville River (250 km eat of Barrow). However, only one week earlier this male was more than 500 km to the west over the continental shelf of the Chukchi Sea.

Three of the four tags attached to gray belugas were still transmitting on 3 September. Only one tag attached to a light gray beluga failed early. This young male was in the same general location northeast of Barrow as the two adult males with early tag failures. All three of the active tags were located along the Beaufort Sea shelf break on 3 September. The gray male was more than 400 km east of Barrow, and about 80 km offshore. The two gray females were 200–250 km east of Point Barrow, about 60 km offshore, and about 30 km apart. The deepest dives for these four belugas during the first two months they were tagged were 316–364 m.

Preliminarily, based on tags deployed in 1998 and 1999, as well as this year, it appears that female belugas may not move as far north and off the shelf break as do males. All four females tagged in 2001, as well as the small female tagged in 1999, remained within about 60 km of shore and quite near the continental shelf break in the Beaufort Sea. In contrast, all of the males traveled north of the shelf break over waters exceeding 3000 m in depth. We hope to increase our sample size of females and gray belugas in 2002 and see if this difference is consistent among years.

Table 1. Beluga whales instrumented with satellite tags during 3–7 July 2001 near Point Lay, Alaska.

Date	Sex	Color	Length (cm)	PTTID	PTT Type	Tag Location	Last Location	Date
3 July	Male	White	381	2093	spider	69.7°N 163.1°W	71.8°N 154.4°W	8/10
3 July	Female	White	359	2094	spider	69.7°N 163.1°W	71.6°N 156.8°W	7/22
5 July	Female	Gray	316	11038	side mount	69.8°N 162.9°W	71.4°N 150.8°W	9/2
5 July	Male	Gray	324	11041	side mount	69.8°N 162.9°W	71.2°N 147.0°W	9/2
5 July	Female	Gray	335	2280	side mount	69.8°N 162.9°W	71.2°N 149.8°W	9/2
7 July	Male	White	340	11037	spider	69.8°N 162.9°W	71.2°N 149.9°W	9/2
7 July	Male	Lt. Gray	320	2281	spider	69.8°N 162.9°W	71.8°N 154.3°W	7/24
7 July	Male	White	373	2282	saddle	69.8°N 162.9°W	71.9°N 154.5°W	8/13

Anticipated Activities (October 2001–September 2002)

During the upcoming 12 months, we anticipate the following:

- Participate in annual MMS workshop
- Analyze satellite tag data from 2001 Point Lay belugas
- Present "brown bag" seminar on results of beluga tagging from 2001
- Attend annual Alaska Beluga Whale Committee meeting and report on study progress
- Work on tag development for 2002 satellite tags
- Conduct field work (attach satellite tags) in Point Lay during late June–July 2002

Study Products

No publications to date. No belugas tagged until July 2001.

Acknowledgments

This project would not have been possible without the help and cooperation of the people and hunters of Point Lay. They invited us into their village to live and work, they allowed us to tag in conjunction with their hunt, and they shared their knowledge about belugas in this area. Special recognition goes to James Tazruk, Nick Hank and Charles Aniskette who served as an integral part of our field crew and helped us to catch and tag belugas, and to Bill Tracey for helping with all aspects of our stay in Point Lay. We also especially thank Greg O'Corry-Crowe for acting as crew leader during the tagging operations and ensuring the success of this year's project. This project would not have happened without the contributions and support of multiple people and organizations, including not only the funding from the University of Alaska Coastal Marine Institute, but also funding and in-kind support from the Village of Point Lay, North Slope Borough Department of Wildlife Management, National Marine Mammal Lab, the Alaska Beluga Whale Committee, Commander Northwest, the Alaska Department of Fish and Game, and the University of Alaska Fairbanks.

Reference

Suydam, R.S., L.F. Lowry, K.J. Frost, G.M. O'Corry-Crowe and D. Pikok, Jr. 2001. Satellite tracking of eastern Chukchi Sea beluga whales into the Arctic Ocean. Arctic 54: 237–243.

Timeline

Beluga whale satellite tagging study

Project Activities	**Federal Fiscal Year (FFY)**											
	1999–2000 (FFY 2000)				2000–2001 (FFY 2001)				2001–2002 (FFY 2002)			
	Quarter				Quarter				Quarter			
	1 Oct–31 Dec	1 Jan–31 Mar	1 Apr–30 Jun	1 Jul–30 Sep	1 Oct–31 Dec	1 Jan–31 Mar	1 Apr–30 Jun	1 Jul–30 Sep	1 Oct–31 Dec	1 Jan–31 Mar	1 Apr–30 Jun	1 Jul–30 Sep
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Project planning		Done	Done			Done	Done			X		
Equipment ordering		Done				Done				X		
Logistical organization/preparation		Done	Done			Done	Done			X		
Field work			Tag Delay	Tag Delay			Done	8 Tags on			X	X
Data analysis					Delay	Delay			X	X		
Report preparation				Done				Done				X
Quarterly report submission					Done	Done	Done		X	X	X	
Annual report submission				Done				Done				X
Draft final report submission											X	
Final report submission (including slides, technical summary, maps, and field data)												*Delay
Submission of manuscript to journal												*Delay
Project presentations						ITM-done				X		

* Final report and manuscript will be delayed until spring of 2003 due to one-year delay in field programs caused by poor ice conditions in 2000. First group of belugas was tagged in 2001. Another group will be tagged in 2002.

New Projects

Three new projects are being funded this federal fiscal year along with the ongoing projects reported above. Abstracts are presented here to show the full range of work being supported by the University of Alaska Coastal Marine Institute.

Timing and Re-Interpretation of Ringed Seal Surveys

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Task Order 15180

Abstract

Ringed seals are an important resource for Native people of northern and western Alaska and an important ecological component of the northern marine ecosystem. Aerial surveys have been used to monitor trends in the distribution and density of ringed seals in the Alaskan Beaufort Sea without correction for variation in the proportion of seals visible to aerial observers. With CMI support, we showed that the proportion of seals visible changes rapidly during the typical survey period as seals shift from resting in lairs to resting in the open. The end of that transition was associated with measured changes in snow conditions during a two-year study. The aim of this project is to develop models of the proportion of seals visible as a function of snow conditions and to re-analyze previous aerial surveys.

Trace Metals and Hydrocarbons in Sediments in Elson Lagoon (Barrow, Northwest Arctic Alaska) as Related to the Prudhoe Bay Industrial Region

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Task Order 15181

Abstract

The goal of this research is to analyze the concentrations of ten selected trace metals (Cu, Cr, Cd, Ni, V, Pb, Zn, Sn, Ba and As) in the mud fraction (< 63 μm size) and the total and methyl Hg contents in gross fractions of five surficial sediment samples and ten stratigraphic sections of a core sample that we have already collected from Elson Lagoon, northwest arctic Alaska. We will also analyze the concentrations of saturated hydrocarbons (normal and isoprenoid alkanes, triterpenoids and steranes) and polycyclic aromatic hydrocarbons (PAH) in the three gross surficial sediments. The geochronology on the core will be established by the ^{210}*Pb- and* ^{137}*Cs-based methods. The analyses on the surficial sediments will provide a baseline for monitoring contaminants resulting from petroleum-related activities, and the stratigraphic analysis that will provide evidence for any historical changes that might have occurred in the trace metals as a result of progressive urbanization of the Barrow area. By comparing the results from this study with those we collected earlier from the Prudhoe Bay–Colville Delta region, a basis could be established to identify sources of anthropogenic contaminants of trace metals and hydrocarbons derived from diverse origins in the North Slope nearshore, for example municipal and petroleum-related activities. This information will be critical for efforts relating to ecological risk assessment of the study area in context of contaminant inputs.*

Importance of the Alaskan Beaufort Sea to King Eiders (*Somateria spectabilis*)

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Task Order 15182

Abstract

*King Eiders (*Somateria spectabilis*) migrate east along the Beaufort Sea during spring (May–June) to arctic nesting areas in Russia, Alaska and Canada. During the molt migration (early July–August) and fall migration mid-August–October), eiders move west along the Beaufort Sea coast to areas in the Chukchi and Bering seas; however, some adult male king eiders molt in the Beaufort Sea. Although the timing and route of the offshore spring migration is likely determined by the availability of open water in the pack ice, information on distance offshore and the frequency and location of potential areas is lacking. Little is known about the migration corridor and staging and molting areas of non-breeders. The aim of this project is to better understand use (timing, location, duration) of nearshore (barrier islands to the mainland coast) and offshore (seaward of the barrier islands) habitats of the Beaufort Sea to migrating, staging, and molting adult female king eiders (successful versus unsuccessful breeders). The researchers will implant 30 satellite transmitters per year in adult female king eiders (15 successful and 15 unsuccessful breeders) on breeding grounds in Prudhoe Bay, Alaska over a period of two years. Transmitters will be programmed to record bird locations during breeding and brood-rearing (June–August), fall migration (mid-August–October), early winter (November), and the following spring migration (late April–June). A graduate research assistant in the Biology and Wildlife Program, University of Alaska Fairbanks will conduct research under the supervision of two research faculty (Abby Powell and Eric Rexstad) at the Institute of Arctic Biology, UAF. Results of this study will be used to complement ongoing eider migration counts at Barrow, Alaska and aerial waterbird surveys along the Arctic Coastal Plain and Beaufort Sea (U.S. Fish and Wildlife Service). Because eiders congregate in large, dense flocks during migration and molt, they may be particularly vulnerable to an offshore oil spill in the Beaufort Sea. The researchers will identify when, where, and how long adult female king eiders use the Beaufort Sea. Valuable information on the importance of the Alaskan Beaufort Sea will be gained from this study. Expected results include interim and final reports, an M.S. thesis, and peer-reviewed scientific publications.*

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:

	Funds from MMS	Matching Funds
Fiscal Year 94		
2 Ph.D. students	$ 23,000	$ 9,200
7 M.S. students	67,000	37,400
Source Total	$ 90,000	$ 46,600
Fiscal Year 95		
4 Ph.D. students	59,600	12,800
7 M.S. students	115,400	57,200
Source Total	$ 175,000	$ 70,000
Fiscal Year 96		
1 Ph.D. student	4,000	0
10 M.S. students	133,000	31,800
Source Total	$ 137,000	$ 31,800
Fiscal Year 97		
1 Ph.D. student	0	21,500
4 M.S. students	76,700	0
1 undeclared/undergrad	3,900	0
Source Total	$ 80,600	$ 21,500
Fiscal Year 98		
2 Ph.D. students	27,240	0
1 M.S. student	10,560	0
2 undeclared/undergrads	2,610	0
Source Total	$ 40,410	$ 0
Fiscal Year 99		
4 Ph.D. students	26,318	28,710
4 M.S. students	32,419	15,444
2 undeclared/undergrads	0	8,244
Source Total	$ 58,737	$ 52,398
Fiscal Year 00		
1 Ph.D. student	7,630	8,305
1 undergrad	0	15,826
Source Total	$ 7,630	$ 24,131
Fiscal Year 01		
1 Ph.D. student	28,557	15,000
4 undergrads	0	16,530
Source Total	$ 28,557	$ 31,530
Total to Date	$ 617,934	$ 277,959

Total CMI Funding

The total MMS funding committed to CMI projects through federal fiscal year 2001 is approximately $7.3 million. Since all CMI-funded projects require a one-to-one match with non-federal monies, total CMI project commitments through fiscal year 2001 have totaled approximately $14.6 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)
- Alaska Department of Transportation and Public Facilities
- Alaska Science and Technology Foundation
- Alyeska Pipeline Service Company
- Ben A. Thomas Logging Camp
- BP Amoco
- British Petroleum Exploration
- Cominco Alaska, Inc.
- Cook Inlet Regional Citizens Advisory Council
- Department of Fisheries and Oceans Canada
- 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
- University of Alaska Anchorage
- University of Alaska Fairbanks
    - College of Science, Engineering and Mathematics
    - Institute of Arctic Biology
    - Institute of Marine Science
    - International Arctic Research Center
    - School of Agriculture and Land Resources Management
    - School of Fisheries and Ocean Sciences
    - School of Management

- 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

Some of the CMI-funded projects are closely related to other federally-funded projects which cannot be considered as match but nevertheless augment and expand the value of a CMI project. Related projects have been funded by the National Science Foundation, the Office of Naval Research, the National Aeronautics and Space Administration, the National Oceanographic and Atmospheric Administration including the National Marine Fisheries Service, and the Alaska Sea Grant College Program.

A positive relationship has been fostered between MMS, the University of Alaska, and the State of Alaska since the formation of CMI. Residents of Alaska, as well as the parties to the agreement, benefit from the cooperative research that has been and continues to be funded through CMI.

University of Alaska CMI Publications

These publications may be obtained from CMI until supplies are exhausted. Reports marked with an asterisk are no longer available in hard copy from CMI.

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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.