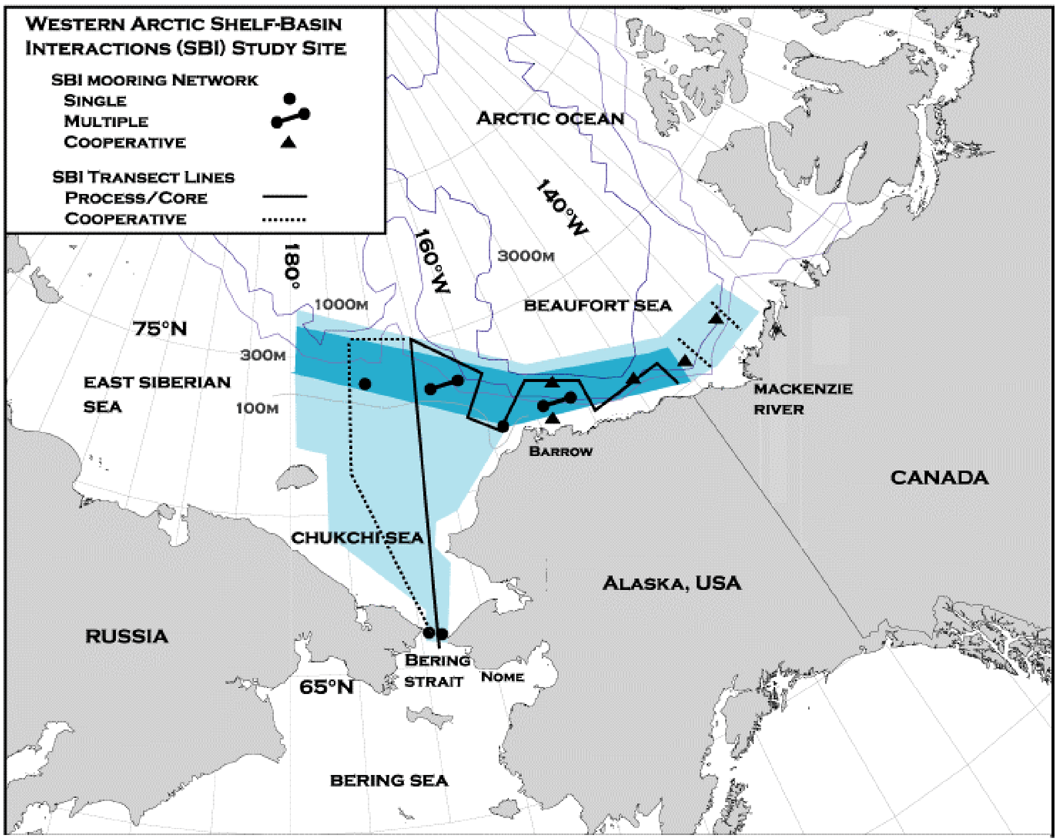
WESTERN ARCTIC SHELF-BASIN INTERACTIONS (SBI)

PRINCIPAL INVESTIGATORS MEETING

Hilton Albuquerque
Albuquerque, New Mexico, USA
8-9 February 2001



SBI Study Area-Intense study region is highlilghted in dark blue, with upstream/downstream regions in lighter blue.

Sponsored by the U.S. National Science Foundation and Office of Naval Research

Arctic System Science Program

SBI Project Office

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SBI Phase I PI Meeting
Hilton Albuquerque
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The **goal** of the open 2001 Western Arctic Shelf-Basin Interactions (SBI) Phase I Principal Investigators (PI) meeting is to update the SBI community on: 1) the SBI Phase I results to date, 2) the status of the overall SBI project, and 3) the upcoming SBI Phase II field project. With respect to Phase II, the PIs should be discussing "What have we learned from SBI Phase I that will guide SBI Phase II?"

SBI PI MEETING AGENDA

Wednesday, February 7-Arrival in Albuquerque, NM
2000-2100 SBI Meeting Registration (Colorado/Texas Room)

Thursday, February 8
0745-0830 Continental Breakfast, Registration (Colorado/Texas Room)

0830-0850 Welcome, SBI Overview and meeting format (Jackie Grebmeier)

0850-0910 Update: ARCSS/SBI II-Announcement of Opportunity (Mike Ledbetter)

0910-1000 SBI Phase I-PI Presentations (Speakers -5; Session Chair: Jackie Grebmeier)
- Aagaard, Knut
- Chapman, Dave
- Plueddemann, Al
- Woodgate, Rebecca
- Weingartner, Tom

1000-1030 Break

1030-1120 Continued presentations (Speakers - 5)
- Cendese, Claudia
- Maslowski, Wieslaw
- Stamnes, Knut
- Kadko, Dave
- Cutter, Greg

1120-1200 Open discussion

1200-1330 Lunch (on own)

1330-1430 Cont. SBI PI presentations (5)
- Cota, Glenn
- Skoog, Annelie

- Lane, Peter; Idrisi, Nasseer
- Dunton, Ken et al.
- Harvey, Rodger

1430-1500 Discussion

1500-1530 Break

1530-1545 SBI Phase I Data Support: JOSS/SBI PO (Jim Moore)

1545-1700 Continued Discussion Phase I data

1700-1830 Poster Session, with Reception (no-host bar)

1830- Dinner (on own)

Friday, February 9

0745-0830 Continental Breakfast

0830-0900 Phase II Field Implementation Plan (Jackie Grebmeier)

0900-0930 Phase II Data Support: JOSS/SBI PO (Jim Moore)

0930-1000 US Coast Guard SBI Field Support Operations (*Healy, Polar Sea, and Polar Star*) icebreakers (CDR Joseph Bodenstedt)

1000-1030 Break

1030-1100 US Navy SBI Potential Cooperative opportunities (Jeff Gossett)

1100-1200 Discussion SBI Phase I results/future plans, interactions, Phase II

1200-1330 Lunch on own (SBI SSC Executive Meeting Lunch (Santa Clara Room)

1330-1500 Continue SBI discussions

1500-1530 Break

1530-1700 Upcoming timeline and events (Jackie Grebmeier)
- SBI Timeline, funded SBI II PI field planning meeting, fall 2001
- OAII All Hands Meeting (Nov. 2001), ARCSS All Hands Meeting (Feb. 2002), 2002 Oceans Meeting-SBI Special Session Phase I results
- Wrap-up

1700 Meeting adjourns

TABLE OF ABSTRACTS FOR TALKS AND POSTERS

TALK AND POSTER ABSTRACTS

BERING STRAIT: A VITAL AND VARIALE FORCING OF THE WESTERN ARCTIC SHELVES, SLOPES, AND BASINS

Knut Aagaard and Rebecca Woodgate, Applied Physics Laboratory, University of Washington, 1013 NE 40th Street, Seattle, Washington 98015, USA.; aagaard@apl.washington.edu
Thomas Weingartner, Institute of Marine Science, University of Alaska Fairbanks, Fairbanks, AK 99775, USA

During summer 2000 - 2002 flow and water properties are being measured in Bering Strait under SBI Phase 1 auspices. The field work combines time series measurements from two moorings with detailed section work during the mooring deployments and recoveries. One of the moorings is located in the eastern channel of the strait, while the other is sited slightly to the north, just east of the Russia-U.S. convention line. The latter mooring serves as a surrogate for the western channel of the strait, where we have not been able to measure since 1994 because of an effectively closed Russian EEZ. The present measurements extend a time series begun in 1990, with only one gap, in 1996-97. The time series have included temperature and salinity with the current measurements, and in 1999 K. Falkner (OSU) deployed an automated water sampler on the western mooring, while in 2000 T. Whitledge (UAF) added *in situ* nutrient measurements to the same mooring. The premise of the work is that the flow through Bering Strait conditions the Chukchi Sea and is the primary source of shelf waters injected into the Pacific sector of the Arctic Ocean.

The mean transport through the strait is near 0.8 Sv, typically with about 50% greater flow in summer, under northward winds, and correspondingly less in winter, when there are frequent strong southward winds. The salinity cycles annually, with an average peak-to-peak amplitude of about 1.5 psu, driven by freezing. In addition to the seasonal cycle, there are important longer-term variations. In particular, the record of salinity through the past decade shows that the Bering Strait inflow to the Arctic freshened about 1 psu during 1991-92 and then remained relatively fresh until 1999-2000, when about one-half of the earlier freshening effect was reversed. The temperature of the inflow has also changed significantly during the past decade, with a dramatic long-term warming that peaked during 1996-97. This was followed by rapid cooling, so that water as cold as observed in summer 2000 was last seen in 1990-91.

The effect on the Arctic Ocean of this interannual variability in water properties in Bering Strait is likely to be large. For example, the difference between the maximum monthly mean salinity in 1991 and 1996 corresponds to a difference in equilibrium depth within the Arctic Ocean pycnocline of about 80 m (e.g., 80 m vs. 160 m). The difference in injection depth of associated nutrients will be equally large.

BENTHIC COMMUNITY COMPOSITION AND BIOMASS DISTRIBUTION: GULF OF ALASKA TO THE CANADIAN ARCHIPELAGO

Arianne L. Balsom, Jackie M. Grebmeier, and Lee W. Cooper, Dept. of Ecology and Evolutionary Biology, 569 Dabney Hall, The University of Tennessee, Knoxville, TN 37996, USA; Merrow1@aol.com

Benthic production and standing stock have been found in past studies to be variable within the Canadian Archipelago, and considered generally lower than in the Bering and Chukchi Seas. During the 2000 US-Canada biodiversity collaboration functioning as part of the St. Roch II "Voyage of Rediscovery" to the Northwest Passage, several "hot spots" of standing stock were encountered with biomass values rivaling sampled Bering and Chukchi Sea sites, with an extreme value of 81.95 gC/m^2 at Hat Island off Requisite Channel in Queene Maude Gulf. Sampling within the Archipelago also demonstrated the other end of the biomass spectrum, finding a biomass value of 0.024 gC/m^2 at Clifton Point off of Victoria Island, near Dolphin and Union Strait in Amundsen Gulf. Average biomass appears to be lowest in the Gulf of Alaska, reaching the highest measured average values in the Bering and Chukchi seas, and decreasing in the Beaufort Sea and into the Canadian Archipelago where the most extreme values of the cruise were found.

These results are preliminary due to continuing analysis of station samples, with numbers presented ranging from one to the four total replicates per station completed. Single grabs are presented for a preliminary spatial description. This spatial description indicates a possible trend of bivalve dominance in more southerly latitudes, *Yoldia sp*. dominant in the Gulf of Alaska,, *Nuculana radiata* and *Nucula belloti* dominant in the Bering and Chukchi seas. The amphipod *Ampelisca sp*. and bivalve *Macoma calcarea* were dominant in the Bering Strait region. The polychaete *Sternaspidae* and amphipod *Byblis sp*. were dominant in the Beaufort Sea samples and entering the Canadian Archipelago. At Hat Island, bivalves were again dominant, consisting of *Astartidae* and *Hiatellidae*. The most northeasterly station (near Spence Bay, Nunavut) was largely dominated by sponge *Porifera*.

US COAST GUARD SBI FIELD SUPPORT OPERATIONS (USCGCs *HEALY*, *POLAR SEA* AND *POLAR STAR*)

CDR Joseph Bodenstedt, U. S. Coast Guard Commandant (G-OPN-2), Chief, Short Range Aids to Navigation Division, 2100 2nd St. SW, Washington, DC, 20593; jbodenstedt@comdt.uscg.mil

LABORATORY STUDIES OF DENSITY INCREASE ON SHELVES

Claudia Cenedese and Jack Whitehead, MS#21, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA; ccendese@whoi.edu

The SBI region is known to be a primary region for the formation of dense salty water which leaves the shelf region and intrudes into the base of the halocline in the Arctic Ocean. The mechanisms for the migration of the dense water from the formation region on the shelf into the interior of the Arctic Ocean are only understood in part. We have been studying processes which may effect these dense currents as they descend to the shelf break, including Earth's rotation, the variation of density in the halocline, and bottom shape.

Initial laboratory experiments reveal the features of a dense plume of salt water flowing down a slope in a tank of rotating fresh water. Over a wide range of parameters three flow types are found: laminar flow, waves, and eddies. Regime diagrams illustrate the range of variables that produce these three different types, and the parameters indicate some aspects of the dynamics for their formation. Kelvin-Helmholtz instability seems the most likely candidate for wave generation. All three types may be expected in the shelf break at the edge of the Barents and Chukchi Seas. The wave instability may lead to more intense mixing between shelf and Arctic waters. The eddy instability may be associated with eddy formation in the Arctic Ocean. From this work we hope to determine criteria required for roll waves or eddies in water flowing from the shelf to the Arctic Basin.

Furthermore, we have investigated the possibility of vortex generation by a dense water current flowing first over a gentle slope and then over a steep shelf break topography.
First, we reproduced the geometry present near the north-eastern part of the Chukchi shelf: a canyon with a gentle slope (Barrow Canyon, Alaska) and a steep continental shelf break in contact with deep water (Arctic Ocean). This very simplified model of dense current flowing out of a canyon, turning right and then flowing along the shelf break suggested the possibility of eddy formation when the dense fluid moves from a gentle slope in a shallow environment, such as the Chukchi shelf, to a steep deep environment, such as the shelf break. We then focused on eddy formation due to this sudden change in the sloping topography by utilizing a more idealized model in which the canyon geometry was omitted.

MODELING THE FORMATION AND OFFSHORE TRANSPORT OF DENSE WATER FROM HIGH-LATITUDE COASTAL POLYNYAS

David C. Chapman and Glen Gawarkiewicz, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA; dchapman@whoi.edu

The mean flow through Bering Strait transports about 0.8×10^6 m^3/s of relatively fresh Pacific Ocean water onto the Chukchi Shelf, where it appears to split into several branches as it crosses the shelf. Water properties may be substantially altered during this transit before the waters ultimately make their way into the interior Arctic basins. Where and how these modified shelf waters are exchanged with offshore water are largely unknown. However, if we are to assess the impact of global change on the Arctic Ocean, we must improve our understanding of both the dynamical processes that modify shelf water properties and the physical mechanisms that produce shelf-basin exchange.

One important modification process occurs beneath coastal polynyas where salt is rejected during ice formation, thereby increasing the density of the underlying water. Our process models have shown that the ocean responds to coastal polynyas by generating a complex three-dimensional flow field filled with small-scale (15-30 km) eddies that carry the dense water offshore. The pathways that the dense-water eddies follow depend critically on both the ambient currents and the local bottom topography. Recent observations by Weingartner et al. (1998) provide some support for many features found in the process models.

Obviously, shelf-basin exchange must involve flow across the shelf edge and the steep continental slope. Dynamically, this is notoriously difficult to accomplish because ambient flows are strongly constrained by Earth's rotation to follow the local topography. In particular, low-frequency flows, upon reaching the shelf edge, will turn and flow along the slope rather than across it, resulting in strong, narrow currents along the shelf edge and very little shelf-basin exchange. Transport across such currents requires other processes, such as tides, wind forcing, dense-water eddies or instabilities. For example, rapidly rotating dense-water eddies can move directly across isobaths, carrying their water masses (and any associated biogeochemicals, etc.) with them. Most of the exchange processes are highly variable in both space and time, suggesting that shelf-basin exchange will also be spatially variable and episodic in nature. Examples of both the strong tendency for flows to follow topography and the effectiveness of dense-water eddies in breaking this constraint will be presented.

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WIND-DRIVEN CIRCULATION, WATER TYPES AND SHELF-SLOPE UPWELLING IN THE LATE-SUMMER CHUKCHI SEA

John P. Christensen, Bigelow Laboratory for Ocean Sciences, 180 McKown Point, West Boothbay Harbor ME 04575 USA; jchristensen @ bigelow.org
Koji Shimada, Institute of Ocean Sciences, 9860 W. Saanich Road, Sidney, B.C., V8L, 4B2, Canada, and JAMSTEC
Patricia A. Wheeler, College of Ocean and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331, USA

In September 1996, we surveyed the U.S. portion of the Chukchi Sea with 200 CTD casts and nearly continuous shipboard ADCP current measurements, covering the region from the Bering Strait in the south to the edge of the pack ice in the north and from the U.S. - Russian Boundary Line to Point Barrow. Following September 7, a series of Arctic gales ensued where strong and relatively continuous winds (averaging 10 m/s as measured on the ship) were from the north. As a result of the winds, waters near Bering Strait were altered from typical conditions, as found in early September, to conditions in the last week of September where Chukchi Sea water was intruding southward along the U.S.-Russian boundary line. In the northern portion of the Chukchi Sea after Sept. 7, upwelling of waters identical in temperature and salinity with upper halocline (UHC) waters were observed within the Barrow Canyon. These waters spilled over much of the shelf west and south of the Canyon. Also, the northeastward flow of the Alaskan Coastal Current was reversed. In addition, along an east-west transect at 72.6^{o}N at the edge of the ice-pack, the waters consisted of three layers, low salinity surface waters, mid-column Chukchi Sea waters, and bottom waters with substantial proportions of UHC waters. Silicate and nitrate plus nitrite (NO_3^-+NO_2^-) concentrations in the waters containing substantial proportions of UHC water were high. All but one nutrient sample with silicate concentrations greater than 20 mmol/m^3 and NO_3^-+NO_2^- concentrations greater than 7 mmol/m^3 were either those of UHC waters on the shelf or those from offshore sites with depths at or deeper than the UHC. In contrast to these cold intruding waters, most of the northern Chukchi Sea waters had <8 mmol/m^3 of silicate and <2 mmol/m^3 of NO_3^-+NO_2^-. We calculated an upwelling transport of 0.35 Sverdrup (1 Sv = 10^6 m/s) associated with the Barrow Canyon plume. Comparing this to the annual average flow through the Bering Strait for the same duration of time, this event was equivalent to 44% of the salt flux, 102% loss of heat, and 106% and 76% of the NO_3^-+NO_2^- and silicate fluxes through the Bering Strait. These estimates would be a minimum for the entire sampling region because both the intrusions along the northern boundary and the mixtures of shelf and upper halocline waters were not included. These results suggest that the shelf break of the Chukchi Sea represents an open boundary with potential for important exchanges with the central Arctic Ocean.

APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEM (GIS) TECHNIQUES TO ASSESSING BENTHIC BIOLOGICAL CHANGE IN THE BERING SEA

Jackie Clement, Lee W. Cooper, and Jackie M. Grebmeier, Department of Ecology and Evolutionary Biology, 569 Dabney Hall, The University of Tennessee, Knoxville, TN 37996 USA; jlc@utk.edu

In the northern Bering Sea, there exists a region of historically high benthic biomass and abundance. This region is located on shallow continental shelves southwest of St. Lawrence Island. During winter, a polynya forms just south of the island while surrounding water is covered by more than 90 percent ice. From the early 1990's to the late 1990's a decline in bivalve abundance and biomass is apparent. Diving sea ducks, which feed on bivalves, have also undergone a dramatic decline. Primary production, benthic biomass and abundance, bivalve size classes, percent ice cover, ice extent, sediment grain sizing, Beryllium-7, conductivity, temperature, and depth have all been measured in this region over the previous decade.

Using GIS (Geographic Information System) software, I will try to determine which factors are important in causing this decline. Data from multiple cruises will be placed in a GIS for further analysis using two software products, ArcView 3.2 and ArcInfo 8. Using the same projection and basemap will allow for the standardization of various years. Because station data only gives information for one point, interpolation between stations is necessary to produce a continuous view of each parameter.

Many important questions arise in regard to this benthic decline. What caused the decline? Is it a cyclic event? In order to understand biological change in the Bering Sea, one must face the challenge of differentiating between interannual and seasonal processes. Benthic macroinvertebrates are not only affected by multiple processes within the sediments, but are also greatly affected by processes in the overlying water column, such as sedimentation. With the help of GIS technology I plan to uncover patterns and create a model for the northwest Bering Sea benthos.

ROLE OF ECHINODERMS IN BENTHIC REMINERALIZATION INTHE CHUKCHI SEA

Lisa Clough, Dept. of Biology, East Carolina University, Greenville, NC 27858, USA; cloughl@mail.ecu.edu
Wil Ambrose, Bates College

The role of large, epibenthic organisms in carbon cycling at high latitudes is difficult to assess using standard ship-board collection techniques. We instead used a remotely operated vehicle equipped with video imaging to examine the distribution and abundance of epibenthic organisms in the northeast Chukchi Sea during June 1998. At each site we collected between 25 and 50 images from a minimum of 20 minutes of video. We observed 15 different epibenthic taxa, with the echinoderms (*Ophiura sarsia, Ophiura maculata, Ophiopholis aculeata, Stegophiura nodosa, and Echinarachinus parma*) overwhelmingly dominating the epibenthos. Epifaunal density was highly variable, ranging from 0.2 to 256.6 individuals m^{-2} (median16.3), and epifaunal biomass varied between <0.5 to 4988 mg C m^{-2} (median 737). Using a relationship between biomass and respiration developed for deep-sea organisms living at cold temperatures, we estimated respiration rates from <0.1 to 15.0 mg C m^{-2} da^{-1} (median = 1.9). Respiration rates measured on-board were several orders of magnitude higher than those obtained from the predictive equation. Further work is needed to accurately assess echinoderm respiration rates under *in situ* conditions. Even with calculated minimal values for respiration rates, a comparison of epifaunal and infaunal respiration at 4 stations revealed that echinoderm respiration accounted for as much as 25% of total respiration. High epifaunal respiration rates and biomass values are probably supported by high concentrations of particulate organic carbon carried by Bering Sea Water flowing through the eastern Chukchi Sea. Concentrations of plant pigments were greatest at the base of Barrow Canyon, suggesting that the large size, high biomass and high respiration rates of ophiuroids at this location were supported by organic material carried down the canyon from the shelf. Our observations support observations from the Eurasian arctic that echinoderms dominate the epibenthos of arctic shelves and that the role of these organisms in carbon remineralization must be considered if we are to generate accurate models of carbon cycling in the arctic.

INDICES OF ARCTIC SHELF-BASIN PRODUCTIVITY

Glenn F. Cota, Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA 23508, USA; cota@ccpo.odu.edu.
Larwrence R. Pomeroy, Institute of Ecology, University of Georgia, Athens, GA, 30602, USA

Our Phase I SBI project, Arctic Shelf and Basin Productivity, incorporates A) historical data analyses, B) opportunistic field investigations, C) modeling, and D) related NASA bio-optics and remote sensing studies. Part A is complete, but data are always welcome. Part B involved a cruise in the Chukchi and Beaufort Seas on the USCG Polar Star in August 2000, and included property profiles, photosynthesis vs. irradiance, primary production, and nitrogen uptake experiments. Surface chlorophyll and production explained >95% of the variability for integrated chlorophyll and production, respectively. Part C involves: 1) biochemical property distributions for "bottom-up" models, and 2) irradiance-based "top-down" models of primary production. Results require further evaluation. Property-distribution estimates of production in the Amerasian Arctic will be presented. Part D has shown that 1) tuned arctic bio-optical algorithms explain 80 to >90% of the variance in chlorophyll, 2) similar algorithms for production account for 70% of the variability in net daily primary production, and 3) SeaWiFS monthly chlorophyll climatologies encompass most of the SBI study area from June through September. The SeaWiFS global chlorophyll algorithm underestimates biomass >1.5X compared with our panarctic chlorophyll algorithm, but overestimates a similar amount compared with our new regional algorithm for the SBI study area. Sediments and runoff interfere with chlorophyll retrievals in certain areas, and corrections or alternative algorithms will be necessary.

Considerable work on biochemical property distribution has been completed, including: 1) pan-Arctic data reclamation of ~20,000 profiles of oxygen, nutrients and/or chlorophyll from public and private databases in the US, Canada, and a few European sources, 2) a relational database has been established, 3) editing and quality control selection has been completed (but user beware), 4) programs to compute a) derived parameters (e.g. nutrient ratios, NO, PO, N*), b) integrated values, and c) primary production based on oxygen supersaturation, nutrient depletion, and/or chlorophyll accumulation, 5) predicted bottom depths from the new International Bathymetric Chart of the Arctic Ocean, and 6) summary figures of data distributions seasonally and regionally. Current efforts are focused on interpretation of results. Data distribution will be via JOSS/NSIDC with summaries at http://www.ccpo.odu.edu/~orca/sbi.htm .

Irradiance-based "top-down" models of primary production in sea ice and the water column are being developed with climatologies of sea ice cover, cloud cover, and albedo from Comiso. Stamnes and Chen have estimated spectral and PAR transmission for a series of seasonal cases and scenarios designated by us. Alternate production models are being examined.

THE BIO-OPTICAL PROPERTIES OF ARCTIC SEAS

Glenn Cota, Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA, USA; cota@ccpo.odu.edu

The bio-optical properties of Arctic and Subarctic Seas show regional variations and often differ markedly from lower latitude ecosystems. Bio-optical properties have been observed on 12 recent cruises. Large, shade-acclimated phytoplankton with highly packaged pigments often dominate in nutrient-rich waters at low light and temperature. Packaging was typically >90% for diatom-dominated populations near Resolute (74.5N) (Cota et al. 2001b). Mean chlorophyll-specific absorption by phytoplankton was two to threefold lower at Resolute than in the Chukchi and Beaufort Seas (Arctic; 70-72.5N) and the Labrador Sea (51-62N). Diatoms had higher reflectance ratios at lower biomass levels (<3 mg chlorophyll m^{-3}) and ~twofold lower chlorophyll-specific absorption than prymnesiophytes in the Labrador Sea (Cota et al. 2001a, Sathyendranath et al. 2000). Nonpigmented particulates (nonliving organic and inorganic particles, bacteria, microzooplankton, and extracted phytoplankton cells) contribute a third to one half of the total particulate absorption in the blue-green, whereas soluble materials represent about half to two thirds of average particulate absorption.

Phytoplankton absorption dominates total particulate absorption at 443 nm, but both are closely related to chlorophyll; which suggests that the phytoplankton anabolic processes dominate their dynamics. Slightly more than a quarter of the variability is explained between nonpigmented particulates and chlorophyll, but much less for soluble materials. Catabolic activities and abiotic processes (e.g. sedimentation, photolysis) presumably control the net fluxes of nonpigmented particulate and soluble materials. Regional comparisons show that total particulate and phytoplankton absorption in the Labrador, Chukchi and Beaufort Seas are quite similar to a temperate compilation (Bricaud et al. 1998), whereas absorption is lower for large, highly-packaged diatoms at Resolute. The most striking difference between temperate data and ours is the relatively low nonpigmented contribution at 443 nm for bloom concentrations in most regions. Soluble absorption is relatively high for oceanic waters but not eutrophic coastal ecosystems (Kirk 1994). The Chukchi and Beaufort Sea (Arc00) data may be influenced by river runoff, dirty ice, and resuspension more than other regions (see adjacent Wang et al. poster).

The latest "global" SeaWiFS algorithm (OC4V4) now includes >300 of our high latitude observations (O'Reilly et al. 2000), but still underestimates chlorophyll by >1.5-fold over most of the range of biomass. Global algorithms should be used with caution at high latitude. Regionally-tuned algorithms improve chlorophyll retrievals, and polar algorithms are in general agreement, except for the diatom plus prymnesiophyte (D+P) algorithm of Arrigo et al. (1998). Small cell size may explain part of this discrepancy. Given limited ranges, small sample sizes (n = 26), and overlapping reflectance ratios, taxon-specific algorithms seem premature (Cota et al. 2001a). A maximum band-ratio algorithm for net daily primary production explains 70% of the variance in two study regions, and shows considerable promise for productivity retrievals albeit with broad confidence limits. Larger, more comprehensive data sets encompassing natural variability are needed to clarify differences within and between ecosystems, and to tune algorithms regionally, and perhaps seasonally. This research was sponsored by NASA and NASDA.

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PALEOCEANOGRAPHIC RECORD OF THE HOLOCENE AT THE CHUKCHI SHELF EDGE

G. A. Cutter, Dept. of Ocean, Earth, and Atmospheric Sciences, Old Dominion University, Norfolk, VA 23529, USA; gcutter@odu.edu
D. Darby, J. Bischof, A. deVernal, G. Dwyer, C. Hillaire-Marcel, J. McManus, L. Osterman, L. Polyak, R. Poore

In order to provide a detailed record of oceanographic conditions (e.g., temperature, ice cover, circulation, biogenic and terrigenous fluxes) over the last ~10,000 years in the SBI study region, we have analyzed piston and companion box cores for a suite of mineralogical, micropaleontological, and geochemical tracers. ^{14}C age dates on calcareous tests, and ^{210}Pb data, indicate a 4 cm-smoothing window, and thus our 5cm sections provide a 100-300 year resolution for the Holocene. Four different intervals of paleoceanographic conditions during the Holocene are indicated by benthic foraminifer and ostracodes results: **1**) the first 2 kyrs. were dominated by melt-water and dissolution of calcareous tests. Org C, N, and S rise from very low levels in the late Pleistocene, and elevated C/S ratios are consistent with lowered salinities from melt-water. This early Holocene interval also contains unique coarse-grained ice-rafted detritus from Tertiary rocks outcropping on the Chukchi Shelf, eroded and transported to the shelf edge when sea level was still rising rapidly and currents across this shelf were probably stronger than today. **2**) The interval from ~8 to 4.5 kyrs. had relatively stable marine conditions with warmer surface waters. During this period, elevated org C and a pronounced biogenic Si maximum are present, consistent with a large flux of siliceous organisms. The highest Mo/Ti ratios are also found within the organic matter maximum, indicating anoxic sediments near the surface. **3**) The next 3.5 kyrs (4.5-1 kyrs) had more stable water and pack ice conditions. Organic C, N, and C/N ratios are relatively constant and indicate the steady input of marine organic matter, while biogenic Si values slowly increase with decreasing age (diagenetic alterations). **4**) The last millennium is dominated by bottom waters that dissolve calcareous tests and by variable pack ice and water conditions. Pulses of biogenic Si, elevated org C, and lowered C/N ratios suggest large inputs of marine organic matter, with a drop in the last 300 yrs.

Overall, the flora and the benthic and planktonic fauna indicate that warmer conditions prevailed throughout most of the last 9,000 to 10,000 years with gradual cooling beginning around 4-5 kyrs followed by a rapid decrease in temperature and increase in seasonal sea ice cover in the last few centuries. August sea surface temperature (SST) reconstructed on the basis of dinocyst transfer functions varied between 4 and 8°C in the middle Holocene before dropping in the last few centuries to the current 1.8°C. Mg/Ca ratios in ostracode shells indicate highly variable bottom water temperatures (-0.6 to 3.0°C) superimposed on an overall decrease of 2°C in the last 8,000 years with the coldest temperatures occurring during the last millennium. Periodic fluctuations in August SST and salinity, detrital smectite clay (< 2 m), as well as oxygen isotope values in benthic foraminifers, amongst others, suggest millennial scale oscillations during the Holocene. The apparent covariance of some of these parameters (e.g., smectite clay content and surface and bottom water conditions) suggests that sea ice conditions and surface ocean drift control transport from potential sources in East Siberian Kolyma or southwest Alaska volcanic areas, with deposition in the Chukchi shelf-edge area. More generally, this observed frequency of these oscillations of around 1.5 kyrs is possibly related to the Dansgaard-Oeschger-like cycles recently noted in the Holocene from the North Atlantic region, and thus could be due to changes in large-scale climatic and atmosphere wind patterns.

ARCTIC BENTHIC BIOTA: LINKS TO GLOBAL CHANGE

Ken Dunton, and Susan Schonberg, Marine Science Institute, University of Texas at Austin, 750 Channel View Dr., Port Aransas, TX 78373, USA; dunton@utmsi.utexas.edu
Jackie Grebmeier, Department of Ecology and Evolutionary Biology 569 Dabney Hall, The University of Tennessee, Knoxville, TN 37996 USA
David Maidment, University of Texas at Austin, Center for Research in Water Resources, Austin, TX, 78712, USA

Project description

The ultimate goal of our research is to link patterns of benthic community structure and biomass in the Chukchi and Beaufort seas to associated physical and biological processes that can be identified as key determinants of global change. Benthic organisms integrate elements in the adjacent water column and therefore can be used as indicators of long-term change. We used Geographical Information Systems (GIS) software as a tool to map the biomass and distribution of benthic organisms for comparison to other features (eg. ocean depth, seasonal ice extent, currents, water column chlorophyll, etc.). Benthic data were assembled in an Access relational database and analyzed with the GIS programs ArcView and Arc/Info. A Geostatistical Analyst extension to ArcMap was used to interpolate the data with kriging techniques to produce probability estimates of benthic biomass across the study area.

Study area

The study area of this research extends from 62° to 75° North and from 160° East to 128° West, encompassing the northern part of the Bering Sea, the Bering Strait, and the coastal shelves along the Chukchi and the Beaufort seas.

Benthic data mapping

Biological data was collected from numerous sources and organized as a relational database in Microsoft Access then mapped onto a base map. Three sources of gridded bathymetry/elevation maps were used to create the base map. Portions of all three sources were merged because not a single map encompassed the entire study area with both land and ocean data coverage.

Geostatistical analysis

Benthic data were sampled at point (station) locations and ESRI's beta product, the Geostatistical Analyst Arc/Info extension was used to interpolate the benthic data to model continuous coverage. Geostatistical methods, based on statistics, have two major tasks; creating a prediction surface and creating an error of prediction. The techniques are referred to as kriging or co-kriging for a multivariate analysis. The kriging technique evaluates the spatial autocorrelation of the data and assigns weights based on the distance from a measured location to the prediction locations. Changes in organism distribution or composition over time and space, as well as development of some basic "if…then" models to study cause and effect relationships, are being explored using this approach.

Preliminary results & future studies

Plotted benthic data reveal areas of high biomass (>250 g/m^2) north of the Bering Strait in the Chukchi Sea and south of the Bering Strait in Gulf of Anadyr waters. In contrast, benthic biomass along the nearshore Alaskan Beaufort Sea shelf is less than 30 g/m^2 except along the regions of the western Beaufort and east of the Mackenzie River delta. The high benthic biomass in the Bering-Chukchi parallels the abundance of benthic feeding marine mammals in this region in comparison to the Beaufort Sea. We are conducting further studies to examine the linkages between chlorophyll standing stocks and the productivity of overlying shelf waters with the physical forcing processes that regulate the advection of carbon to these benthic communities.

ABUNDANCE, BIOMASS, COMPOSITION AND GRAZING IMPACT OF THE SEA-ICE MEIOFAUNA IN THE NORTH WATER, NORTHERN BAFFIN BAY

M. Gosselin, Institut des sciences de la mer de Rimouski (ISMER), Université du Québec à Rimouski, 310 Allée des Ursulines, Rimouski (Québec), Canada G5L 3A1; michel_gosselin@uqar.uquebec.ca
C. Michel, G. Tita, G., C. Nozais

The abundance, biomass, composition and grazing impact of the bottom sea-ice meiofauna were investigated in the North Water during April-May 1998. Sampling was conducted on both pack ice and land fast ice. At the lowermost 2-4 cm of the sea ice, chlorophyll *a* reached a maximum concentration of 55.7 mg m^{-2}. Sea-ice meiofauna were observed only at the ice bottom, and were composed of nematodes, copepods (harpacticoids and cyclopoids), crustacean nauplii, polychaete larvae and turbellarians. Total abundance of sea-ice meiofauna ranged from 0 to 34 500 ind. m^{-2} at the sampling stations. Nematodes were the most abundant taxon in the ice with highest densities at a land fast ice station. Highest abundances of copepods as well as crustacean nauplii were observed in the pack ice. The total sea-ice meiofauna biomass varied between 0 and 19.4 mg C m^{-2}. Potential ingestion rates, determined using allometric equations, indicated that sea-ice meiofauna never consumed more than 0.9% of the ice-algal standing stock and 5.7% of the daily ice-algal production. These calculations strongly suggest that the grazing impact of sea-ice meiofauna on ice algae was negligible in the North Water in early spring. The low standing stock of ice meiofauna also precludes their potential as an important food source for higher trophic levels. Meiofauna, therefore, appear to be a minor contributor to the overall carbon flow in the sea-ice biota of the North Water during spring.

ORGANIC-WALLED MICROFOSSILS AND GEOCHEMICAL TRACERS: SEDIMENTARY INDICATORS OF PRODUCTIVITY CHANGES IN THE NORTH WATER AND NORTHERN BAFFIN BAY (HIGH ARCTIC) DURING THE LAST CENTURIES

M. Gosselin, Institut des sciences de la mer de Rimouski (ISMER), Université du Québec à Rimouski, 310 Allée des Ursulines, Rimouski (Québec), Canada G5L 3A1; michel_gosselin@uqar.uquebec.ca
D. Hamel, A. de Vernal, A., and C. Hillaire-Marcel

Analyses performed in 26 surface sediment samples collected with a box corer at 17 stations throughout the North Water and the northern Baffin Bay (75º-79º N; 66º-80º W) reveal abundant organic-walled microfossils, including principally cysts of dinoflagellates (10^3 to 10^4 cysts g^{-1}) and organic linings (OL) of benthic foraminifers (10^2 to 10^3 OL g^{-1}) as well as high organic carbon concentrations (0.87 to 2.81 dry weight %). These data indicate high productivity in both pelagic and benthic environments of the North Water, and slightly lower productivity in the northern Baffin Bay. The data also indicate calcium carbonate and biogenic silica dissolution throughout the study area. The dinocyst assemblages are relatively uniform in the North Water and are dominated by the heterotrophic taxa *Algidasphaeridium*? *minutum* and *Brigantedinium* spp., whereas the northern Baffin Bay assemblages are dominated by autotrophic taxa, notably *Operculodinium centrocarpum* and *Spiniferites elongatus*. The difference between these two assemblages may be related to higher diatomaceous primary production in the North Water than in the northern Baffin Bay. The biogeographical boundary between the North Water and the northern Baffin Bay were maintained at least during the last few centuries as shown by analyses of microfossils and geochemical tracers in two sediment cores taken respectively in the southeastern part of the North Water (76º17'N, 72º02'W) and in the northeastern Baffin Bay (75º35'N, 70º48'W). The analyses of the North Water core reveal relatively uniform microfossil assemblages and organic carbon fluxes ranging 1-1.5 mg C_{org} cm^{-2} yr^{-1} for the last centuries, suggesting a high productivity and relatively stable conditions in the polynya on a decadal-secular time scale. In the northeastern Baffin Bay core, the analyses indicate generally lower organic carbon fluxes ranging 0.3-0.6 mg C_{org} cm^{-2} yr^{-1}, and the microfossil data suggest significant variations in sea-surface conditions over the last centuries.

U.S. NAVY SBI POTENTIAL COOPERATIVE OPPORTUNITIES

Jeffrey Gossett, Operations, COMSUBDEVRON FIVE DET AL, 140 Sylvester Road, San Diego, CA 92106-3521, USA; gossett@nosc.mil

Throughout most of the 1990s, the U.S. Navy provided submarines on a recurring basis for dedicated SCICEX research cruises. Now that dedicated cruises have ended, SCICEX has entered a new phase with "Accommodation" cruises, the first of which was conducted in late 2000. Some of these could potentially support SBI. In addition, there is the possibility for the Navy and SBI to time-share an ice camp in early 2003.

WESTERN ARCTIC SHELF-BASIN INTERACTIONS (SBI)
PROJECT OVERVIEW AND PHASE II FIELD IMPLEMENTATION PLAN

Jacqueline M. Grebmeier, SBI Project Office, Department of Ecology and Evolutionary Biology, The University of Tennessee, Knoxville, TN 37996, USA: jgrebmei@utk.edu
and SBI Science Steering Committee

The Western Arctic Shelf-Basin Interactions (SBI) project is a contribution of the Ocean-Atmosphere-Ice Interactions (OAII) component of the National Science Foundation (NSF) Arctic System Science (ARCSS) program that is investigating the Arctic marine ecosystem in an effort to improve our capacity to predict environmental change. The overarching hypothesis underlying the Western Arctic SBI project is that climate change will significantly and preferentially impact the physical and biological linkages between arctic shelves and the adjacent ocean basins. SBI will therefore focus on the outer shelf, shelf break and upper slope, where it is believed that key processes control water mass exchange and biogeochemical cycles, and where the greatest responses to climate change are expected to occur. The geographical focus is on the Chukchi and Beaufort seas and adjacent upper slopes.

The SBI Phase II field project is centered around three research foci in the core study area in the Chukchi and Beaufort seas: 1) northward fluxes of water and bioactive elements through the Bering Strait input region; 2) seasonal and spatial variability in the production and recycling of biogenic matter on the shelf-slope area; and 3) temporal and spatial variability of exchanges across the shelf/slope region into the Canada Basin.

The SBI project is going forward in three phases. Currently Phase I is in progress (1998-2001) and involves regional historical data analysis, opportunistic field investigations, and modeling. Phase II (2002-2006) will constitute the core regional field investigations in the Chukchi and Beaufort Seas, along with continued regional modeling efforts. The SBI Phase II Field Implementation Plan (Grebmeier et al., 2001) outlines a combination of moorings, seasonal survey and process studies, as well as modeling efforts, at various time and space scales. A special concern is that physical and biogeochemical process studies be well coordinated. Moored arrays will allow investigations of the flow into the study area through Bering Strait as well as the exchanges at the shelf-slope interface to document the influence of this highly productive region on the Arctic ecosystem. Mesoscale, interdisciplinary survey and process studies conducted across the shelf and slope regions during various seasons will be critical to understand biogeochemical processes occurring over time and space scales relevant to interpreting annual and interannual change in the system. Phase II sampling program (with required platforms) includes integration with both national and international programs.

An Announcement of Opportunity for SBI Phase II field program is anticipated at the end of February 2001, with proposals due at the end of April 2001, and proposals funded by October 2001. The first field program will be initiated in spring 2002. Further information on the SBI project and the updated (Feb. 2001) SBI Phase II Implementation Plan can be found on the SBI webpage <http://www.utk-biogw.bio.utk.edu/SBI.nsf>.

MOLECULAR MARKERS OF ORGANIC MATTER SOURCES AND FATE IN THE ARCTIC OCEAN

H. Rodger Harvey and Laura Belicka, Chesapeake Biological Laboratory, UMCES, 1 Williams Street, Box 38, Solomons, MD, USA; harvey@cbl.umces.edu
Mark B. Yunker, 17137 Wallace Dr., Brentwood Bay, B.C., Canada
Robie W. Macdonald, Institute of Occean Sciences 9860 West Saanich Road, Sidney, B.C., V8L 4B2, Canada

Some of the highest global levels of primary production occur on the wide shelves of the Arctic Ocean, yet can be accompanied by large amounts of terrestrial material eroded from the land and transported by rivers and ice. In this complex system, the carbon cycle is complicated by organic pools of vastly different recycling times under the influence of strong physical and temporal gradients. This project is defining the suite of molecular organic markers most useful for tracking the fate of primary production in the marine dominated the Chukchi Sea verses the Beaufort Sea which receives substantial terrestrial material via rivers and ice transport. Multivariate approaches are being integrated with composition analysis to validate the most appropriate molecular markers and to construct preliminary budgets for carbon export from the Chukchi and Beaufort shelves. Core records are also being studied to follow historical changes in community structure and productivity across the contrasting shelves.

Samples analyzed include a set of surface sediments (0-2cm) collected during the 1994 Arctic transect cruise which spanned the entire Arctic Ocean. The molecular markers present in these sediments provide a snapshot of material reaching the underlying shelf and basin sediments and thus a survey of the amount and distribution of organic matter either produced or transported into the Arctic Ocean. For most biomarkers examined, both the dry weight and organic carbon normalized concentrations are highest in the Chukchi Sea, intermediate in the Eurasian Basin and Greenland Sea and lowest in the Canadian Basin. Arctic basin locations influenced by the Transpolar Drift have higher organic biomarker concentrations than locations influenced by the Beaufort Gyre. Alkane hydrocarbon profiles suggest a significant yet varied input of higher plant material throughout the Arctic Basins, which may reflect the transport of low-density peat particles exported by rivers and transport by drifting sea-ice. This implies that differences in both sources and/or transport mechanisms must occur, which in turn affect available nutrients and ultimately the amount of primary production reaching the underlying sediments. It also highlights the need for close coordination with physical and geochemical measures in any planned field activities.

Additional analyses are being conducted on intact cores collected from the Chukchi shelf and Beaufort Sea together with particles collected during a ship of opportunity cruise during the summer of 2000. Downcore concentrations of several important biogeneic markers in Chukchi shelf sediments show a sharp increase at the 4-5 cm horizon, and include the appearance of highly labile algal fatty acids and sterols which are absent in sediments above and below this depth. Such a peak in labile marine derived organic matter at depth suggests that the Chukchi shelf experienced a strong episodic pulse in total primary production in the recent past which was not accompanied by enhanced water column or benthic consumption.

ADVECTION AND FOOD WEBS IN THE WESTERN ARCTIC: RETROSPECTIVE SAMPLE AND DATA ANALYSIS AND MODELLING

Idrisi Nasseer, Peter Lane, and Sharon L. Smith, Rosenstiel School of Marine and Atmospheric Science, Marine Biology and Fisheries Division, University of Miami, 4600 Rickenbacker Causeway, Miami FL 33149, USA; nidrisi@rsmas.miami.edu, plane@rsmas.miami.edu.

Global warming, although much debated, is presently a widely accepted phenomenon that is expected to have a wide range of impacts on Earth's ecosystems. It is anticipated that Polar Regions will be more susceptible than temperate regions to ecological changes brought on by climate change. As part of the Phase I of the Shelf Basin Interactions (SBI) program, we are utilizing historical plankton data and samples from previous studies in the western Arctic to examine potential impacts of changing climate on pelagic plankton ecology in the Chukchi and Beaufort Seas. The emphasis of our work is on the northern shelf-break and Alaskan coastal regions. Our focus is on large bodied calanoid copepods that have been shown to dominate zooplankton populations in the western Arctic. *Calanus hyperboreus* is a large species which exhibits a multi-year life cycle, requiring overwintering at various juvenile stages in relatively deep water in the Arctic. *Neocalanus* spp. are large sub-arctic species that exhibit one-year life cycles in the North Pacific Ocean. These species also require relatively deep water for overwintering. Observations of these pelagic copepods over the northern shelves of the Chukchi and Beaufort Seas allow us to study their impact on regional ecology as they are advected on and off the shelves by prevailing currents and transitory circulation. Our retrospective analyses here focus on the abundance of these large-bodied copepods collected during the summers of 1950 and 1951, relatively cool and relatively warm years respectively in terms of observed sea surface temperatures.

Copepod growth is generally controlled by temperature and food resources, two environmental factors that would likely change with global warming. Our modelling efforts focus on the direct effect of temperature on metabolic processes that include differential synthesis and utilization of proteins and lipids. By examining changes in the respiratory quotient (RQ) with temperature, it is possible to predict the proportional utilization of these two substrates during the course of the copepod's life cycle. In general, relatively higher temperatures lead to proportionately greater protein catabolism and relatively lower temperatures lead to proportionately greater lipid catabolism. A higher RQ, resulting from exposure to temperatures exceeding the optimum, would require more energy because catabolized protein has a lower energy density than lipid. Such a shift would leave less energy for growth and reproduction. The implications are potential shifts in energy and material transport over the shelf, slope, and the deep basin as a result of seasonal migrations between the upper layers where these species feed and deep basin layers where they overwinter.

INVESTIGATION OF THE RATE OF SHELF-BASIN INTERACTION IN THE WESTERN ARCTIC OCEAN USING RADIUM ISOTOPES

David Kadko, University of Miami, RSMAS-MAC, 4600 Rickenbacker Causeway, Miami, Fl 33149 USA; dkadko@rsmas.miami.edu

The largely landlocked Arctic Ocean receives input from the Pacific and Atlantic Ocean, and from rivers draining the surrounding continents. These inflows are important sources of salt, heat, nutrients, sediment and organisms to the central basin. With the exception of a portion of the Atlantic contribution, these inputs must cross continental shelves where they are significantly modified by benthic, water column, air/sea and sea/ice interactions. There are therefore significant biogeochemical exchanges between the shelves and basins, but we currently lack the information necessary to quantify these exchanges. A better understanding of the processes and rate of exchange with the central basin is clearly needed. To trace the shelf-water interaction with and transport to the central basin we have, as part of the NSF SBI program, been measuring the ratio of two isotopes of radium, ^{228}Ra ($T_{1/2}$ =5.77y) and ^{226}Ra ($T_{1/2}$= 1620 y) in the water column extending from the shelf into the central basin. Radium is derived from the decay of thorium in the sediments; Radium-228 is produced from the decay of ^{232}Th, and ^{226}Ra from the decay of ^{232}Th. Because radium is mobile in the porewaters of sediment, a fraction of the radium produced there diffuses into the overlying water. Therefore, enrichment of Ra isotopes occurs in marine waters when they are in contact with sediment. Waters crossing shelves will therefore pick up radium diffusing from the underlying sediments. The ^{228}Ra/^{226}Ra ratio over the shelves will be high, because the newly injected ^{228}Ra will not have decayed to a great extent. However, because of the short half-life of ^{228}Ra (5.77 years), as the water is transported offshore, the ^{228}Ra/^{226}Ra will decrease because of radioactive decay (radioactive loss of the long-lived ^{226}Ra in the relevant timescales is negligible). Note that the use of the isotopic *ratio* precludes complications arising from possible biological or particle uptake of the radium. We have collected and are analyzing samples from three sources 1) the SHEBA floating ice station in the Beaufort Sea (summer/fall 1998) 2) Ship-of-opportunity samples from the USCG ice breaker Polar Sea in the summer of 2000 mainly in the Chukchi Sea and 3) a pan-Arctic collection from the USN submarine Mendel Rivers as part of SCICEX 2000. Results indicate that 1) off the narrow Barrow Shelf, the highest ^{228}Ra/^{226}Ra ratios (R) were nearshore (0.85-1.0) and decreased to R=0.35 at a distance of 530 km from shore. 2) Off the wider Chukchi Shelf higher values were found further offshore reflecting continued input from the underlying sediments and perhaps the existence of eddy transport.

THE ARCTIC AND ANTARCTIC RESEARCH CENTER: A UNIQUE RESOURCE FOR POLAR REMOTE SENSING

Dan Lubin, Scripps Institution of Oceanography University of California, San Diego, 9500 Gilman Drive La Jolla, CA 92093-0221, USA; dlubin@ucsd.edu

The Arctic and Antarctic Research Center (AARC) at the Scripps Institution of Oceanography serves as one of the world's major repositories of satellite data covering the Earth's polar regions. In contrast to the National Snow and Ice Data Center (NSIDC), whose charter is that of a final archive of all polar data, the AARC maintains an interactive "front-end" role with numerous researchers, by (1) providing hands-on training in the use of satellite remote sensing data for polar navigation, cruise planning, and support of individual field products, and (2) providing specially tailored remote sensing services for individual polar expeditions. As an example of the latter, the AARC has routinely provided sea-ice mapping support at moderate spatial resolution (12.5 km, using the Special Sensor Microwave Imager 85.5 GHz channels) to research vessels operating in Antarctic waters. The AARC's Manager, Mr. Robert Whritner, has in recent years participated in several Arctic shipboard field campaigns, serving as a satellite meteorologist and sea-ice expert. The AARC can offer these services to SBI. The AARC is supported by the National Science Foundation Office of Polar Programs, and SBI participants are invited to visit the AARC's web site at http://arcane.ucsd.edu.

TOWARDS A REALISTIC MODELING OF PHYSICAL PROCESSES AND LARGE-SCALE CIRCULATION IN THE ARCTIC OCEAN

Wieslaw Maslowski, Department of Oceanography, Naval Postgraduate School, Monterey, CA 93943, USA; maslowsk@ucar.edu
W. Walczowski, D. Marble

Modeling studies of the Arctic Ocean have focused on either the large-scale ocean-ice circulation, at an expense of detailed representation of physics, or on small-scale processes but with specified simplified forcing and initial and boundary conditions to represent the outside environment. In addition, such models have covered geographically separated regions permitting no or limited exchanges with other domains (e.g. Bering Strait in the Pacific Ocean or the Canadian Archipelago and Fram, Denmark, and Davis Straits in the Atlantic Ocean). Advancements in computer technologies and in ability of scientific communities to employ them for solving complex applications have opened new opportunities for adequate modeling of the Arctic Ocean and its marginal seas. As a result, high-resolution models of basin-wide extent have begun to more realistically represent physical processes, many of which occur in the Arctic Ocean at relatively small scales.

By combining high resolution with improved parameterizations of sub-grid physical processes, numerical models have become a powerful tool in investigations of basin-wide ocean dynamics, shelf and basin circulation, water mass modification, cross-shelf transport, shelf-basin and inter-basin communication. Development and use of such tools satisfies two main objectives of physical modeling part of the Shelf Basin Interaction program. First, it provides a big picture of the large-scale circulation of ocean and sea ice in the Western Arctic and the pan-Arctic region. Second, through the use of field observations and results from process-oriented studies it allows comprehensive studies of shelf-basin exchanges, biogeochemical cycles, and their role in the large scale interannual variability of the Arctic Ocean system.

We present results from two coupled ice-ocean models, at increasingly high resolution, with emphasis on their ability to help in better understanding processes crucial in shelf-basin communication, ice-ocean interactions, boundary current dynamics, and maintenance of halocline. The role of physical regimes and their variability in the Arctic Ocean is emphasized in context of their importance to studies of biogeochemical cycles and the ecosystem response to basin and global change. An importance of high resolution and domain size is evaluated by comparison of two model outputs.

DIFFERENTIAL EXPORT OF BIOGENIC SILICA IN THE NORTH WATER POLYNYA

Christine Michel, Department of Fisheries and Oceans, Freshwater Institute, 501 University Crescent, Winnipeg, Manitoba, R3T 2N6, Canada
Michelc@dfo-mpo.gc.ca

Michel Gosselin, Institut des Sciences de la mer, Université du Québec à Rimouski, 310 Allée des Ursulines, Rimouski, Québec, G5L 3A1, Canada
Michel_gosselin@uqar.uquebec.ca

Jean-Éric Tremblay, Biology Department, McGill University, 1205 Dr. Penfield, Montréal, Québec, H3A 1B1, Canada
Jett@globetrotter.qc.ca

Short-term free-drifting sediment traps were deployed at 19 stations during June and July 1998, in the North Water polynya. The traps were moored at three depths (50, 100, and 150m), and the material collected was analyzed for pigments, particulate organic carbon and nitrogen (POC, PON), biogenic silica, and cell and feces enumeration. Highest sinking fluxes were observed in June. The composition of the sinking material revealed seasonal trends that included an increase in diatom resting spores and zooplankton feces in July. Pennate diatoms dominated the sinking assemblage until mid-June, after which centric diatoms took over.

Two independent budget estimates showed higher sinking export of silica (Si) compared to carbon (C). Export of Si balanced new Si production, while ca. half of the new carbon (C) production sank out of the euphotic layer. As the material sank to greater depth, additional loss of C (ca. 30%), but no significant loss of Si, were observed. These results provide evidence for differential export of Si in the polynya, and high C recycling in the surface layer.

MEAN HYDROGRAPHIC STRUCTURE OF THE BEAUFORT SHELF AND SLOPE

Robert S. Pickart, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA; rpickart@whoi.edu

Historical hydrographic data, spanning the period 1951-1987, have been compiled in the region of the Beaufort shelf and slope to investigate the water properties and circulation of the southern Canada Basin. The purpose of the study is to determine the nature and scales of the boundary current system east of Barrow Canyon, in part to determine the fate of Bering Strait Water that has exited the Chukchi Sea eastward along the continental shelfbreak. Of particular interest is the question of whether the basic structure of the flow is conducive for baroclinic instability, and hence eddy formation. This has ramifications regarding the ventilation of the interior Canada Basin via boundary-origin water.

The domain of interest extends from Point Barrow to the MacKenzie slope, a distance of 600km, and from the inner shelf to the 3000m isobath, a distance of 250km. The maximum depth of significant data coverage is 1500m, which includes the Atlantic layer. The methodology employed is as follows. First, all synoptic hydrographic sections were identified and extracted from the historical database---there are 45 such sections, occupied predominantly in summer and fall. Next, using the IBCAO bathymetric data set, an average cross-stream bottom profile was constructed for the region. Each section was then mapped onto this average bathymetric coordinate system, and objectively interpolated on a uniform grid. Finally, the interpolated synoptic sections were combined to form mean sections of various hydrographic variables. Standard deviation fields were also produced.

The average sections constructed as such reveal the unique nature of the region near the Beaufort continental shelfbreak and upper slope. Distributions of temperature, salinity, and density---from the surface through the Atlantic layer---are indicative of significant advection along the boundary. The variable nature of the water masses and the implied geostrophic circulation remain to be sorted out. For example the large standard deviation in temperature at the shelfbreak is indicative of the intermittent presence of buoyant Bering Strait summer water. Future work will include Empirical Orthogonal Function analysis to quantify the space/time variability, calculation of the velocity field (with the aid of historical current meter data), and comparison of the boundary water masses to bserved interior basin eddies in order to investigate the origin of the eddies.

PHYSICAL AND DYNAMICAL PROPERTIES OF ARCTIC EDDIES

Al Plueddemann, Woods Hole Oceanographic Institution, 360 Woods Hole Rd., Woods Hole, MA 02543-1541 USA; aplueddemann@whoi.edu
Krishfield, R.

The Arctic Ice Dynamics Joint Experiment (AIDJEX) provided the first clear evidence that isolated baroclinic eddies exist in the Arctic Ocean. Interestingly, only a few detailed eddy observations have been reported since AIDJEX. We use new observations of velocity in the upper Arctic Ocean (25-300 m depth) made with Acoustic Doppler Current Profilers (ADCPs) to detect eddies and determine their properties. The ADCPs were deployed on Ice Ocean Environmental Buoys (IOEBs) which drifted within the Beaufort Gyre between 1992 and 1998. Ninety-five probable eddy encounters were identified during four IOEB deployments, which included 44 months of buoy drift. Physical properties were determined for 62 encounters in a series of steps, the most important of which was estimating the eddy center. The majority of center depths were between 70 and 180 m and typical vertical extents were 90-180 m. Thus, eddies were found predominantly in the cold halocline. Maximum rotation speeds were typically 15-35 cm/s, with some greater than 40 cm/s. Typical radii were 3-8 km. Faster rotation speeds were associated with larger vertical extent and larger radius. The sense of rotation was predominantly anticyclonic. The typical eddy encounter rate was 1 per 100 km of drift. The highest encounter rate was in the Canada Basin, but a significant number of eddies were also found to the west of the basin, over the Chukchi Plateau. Dynamical properties were determined for 22 eddies. Relative vorticity was maximum in the eddy cores, whereas strain was largest outside the radius of maximum velocity. These results are consistent with isolated eddy cores in approximate solid body rotation.

CARBON CYCLING IN THE ARCTIC OCEAN: MOLECULAR LEVEL STUDIES

Annelie Skoog, Department of Marine Sciences, University of Connecticut at Avery Point, 1084 Shennecossett Road, Groton, CT 06340-6097, USA; skoog@uconnvm.uconn.edu

A key unknown in the Arctic is the transformation and fate of variable levels of production and forms of dissolved and particulate organic carbon (SBI Science Plan, Grebmeier *et al.,* 1998). An intriguing characteristic of the Arctic ocean has been suggested in unusually high OC concentrations found in several studies (Anderson *et al.,* 1994; Rich *et al.,* 1997; Wheeler *et al.,* 1997; Gordon and Cranford, 1985) suggesting the potential for a central and important role of OC in the Arctic ecosystem. Explanations for the apparently high DOM and substrate concentrations in the Arctic Ocean could be found by studying DOM on a molecular level. Some microbes need higher substrate concentrations to grow at low temperatures, which has become known as the "Pomeroy hypothesis" (Pomeroy *et al*. 1990, 1991; Wiebe *et al.,* 1993). A result of the inability of heterotrophs to utilize low substrate concentrations at low temperatures would be a higher background substrate concentration. This theory could be tested by determining concentrations of biologically labile compounds in the Arctic. Preliminary results from DOC and neutral aldose (a group of sugars) analysis from our laboratory indicate that DOC and carbohydrate concentrations on the Chuckchi shelf are higher than in the Pacific Ocean, which would support the Pomeroy theory.

LIGHT AND LIFE IN HIGH-LATITUDE WATERS

Knut Stamnes, Department of Physics and Engineering Physics, Stevens Institute of Technology, Hoboken, NJ 07030; kstamnes@stevens-tech.edu
Jiang, S., Chen, B., and Li, W., Stevens Institute of Technology; Hamre, B. and Stamnes, J.J., University of Bergen; Cota, G., Old Dominion University.

Abstract

Simulations aimed at determining the underwater radiation environment have been carried out by use of a comprehensive radiative transfer model (RTM) for the coupled atmosphere-sea ice-ocean system in conjunction with a 1-D phytoplankton biomass model (PBM). The RTM consists of the following components: (i) Atmosphere: including all radiatively important gases, clouds, and aerosols. (ii) Snow: the optical properties of snow are parameterized in terms of snow density, grain size, and impurities. (iii) Sea ice: the optical properties of the first-year ice and the multi-year ice are based on detailed measurements of ice salinity and temperature as well as air bubble and brine pocket distributions. (iv) Sea water: a standard bio-optical model in which optical properties are described in terms of the chlorophyll concentration. The PBM is a basic 1-D phytoplankton model that describes the temporal evolution of phytoplankton biomass with depth: $\frac{\partial B}{\partial t} = \frac{\partial}{\partial z}\left(K_z \frac{\partial B}{\partial z}\right) - w\frac{\partial B}{\partial z} + (p - \phi)B$. Here B is the phytoplankton concentration, P the growth rate given by $P = \left(\frac{Chl}{C}\right) P^B(1 - e^{-\frac{\epsilon I}{P^B}})$, K_z the vertical mixing coefficient, w the sinking rate, ϕ the loss rate, P^B the maximum photosynthetic rate, and ϵ the photosynthetic efficiency. The photosynthetically active radiation (PAR) at depth z is calculated from the radiative transfer equation $cos\theta\frac{dI(z,\theta)}{dz} = -[\alpha(z) + \sigma(z)]I(z,\theta) + \frac{\sigma(z)}{2}\int_{-1}^{1} d(cos\theta')p(\theta',\theta)I(z,\theta')$, where α and σ are absorption and scattering coefficients, and $p(\theta',\theta)$ is the phase function.

Comparisons of the computed light fields with measurements taken in Lofoten (Northern Norway, at 68°18'N, 14°43'E) in March-May 2000 show very good agreement between simulated and measured irradiance profiles. The studies also show that use of a realistic light field is essential for the phytoplankton evolution in the PBM.

We also studied the light propagation in the atmosphere-snow-sea ice-ocean system for typical Arctic conditions given in the following table:

Medium	April	May	June	July	Aug	Sept
Snow (cm)	20 dry	20 dry	0	0	0	0
MY Ice (m)	3	3	3	2.5	2	2
Snow (cm)	10 dry	10 dry	0	0	0	0
FY Ice (m)	1.75	1.75	1.5	1	0.5	0
Open Water	> 50m	same				

Based on the input in this table, we have computed: (i) incident surface spectral and PAR irradiance E_{0+} under clear sky conditions; (ii) albedo for each type of surface; (iii) transmitted PAR irradiance E_{z0-} just below the ice or water; (iv) Euphotic zone irradiances in sea water with different chlorophyll concentrations. The computed albedo for each type of surface agrees well with measurements. We find that the downward irradiance is significantly enhanced just below the atmosphere-sea ice interface. The radiation model is available to other PIs of the SBI program on a collaborative basis.

BIO-OPTICAL OBSERVATIONS IN THE BEAUFORT AND CHUKCHI SEAS

Jian Wang, Glenn Cota, and David Ruble, all at: Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA, USA; cota@ccpo.odu.edu

Bio-optical observations were made during August, 2000 in the Beaufort and Chukchi Seas, mostly within the marginal ice zone. Much of the shelf is nearly ice-free or <50% ice-covered by late August. Ocean color signatures in shelf waters can be complicated by runoff from the Colville and Mackenzie Rivers, melting "dirty" (sediment-laden) sea ice, and sediment resuspension in shallow areas. Remote-sensing reflectance (R_{rs}) spectra were sometimes elevated in the blue-green at sites rich in nonpigmented particulates. Above-water reflectance in the blue-green tended to be slightly higher than in-water estimates, but maximum band-ratios of R_{rs} from above-water were, on average, very similar to in-water observations here and in the Labrador Sea. Secchi depths ranged from 4.5 to 30m in the Beaufort and Chukchi Seas, while phytoplankton biomass ranged from <0.1 to 20 mg chlorophyll m^{-3}. Bio-optical algorithms based on reflectance ratios explain >93% of the variance in surface chlorophyll concentrations, which are similarly correlated with integrated chlorophyll. This algorithm data set has a limited range (~0.1 to 9 mg chlorophyll m^{-3}), and decreases the minimum biomass values for existing polar algorithms. Under these conditions, the current operational algorithm for SeaWiFS (OC4V4) overestimated chlorophyll concentrations almost 1.5X at most stations. Absorption spectra in the euphotic zone (>1% incident irradiance) suggest that phytoplankton represent about two thirds of the total particulate absorption in the blue-green, and have relatively low chlorophyll-specific absorption. Power functions for constituent absorption at 443nm versus chlorophyll concentration show strong relationships for total particulate and phytoplankton. Phytoplankton absorption dominates total particulate absorption at 443 nm except at low biomass, where it is highly variable and analytical signal to noise ratios degrade. Over 40% of the variability is explained between nonpigmented particulates and chlorophyll, but <20% for soluble materials. Soluble absorption is relatively high for oceanic waters but not eutrophic coastal ecosystems (see adjacent Cota poster). Shelf waters of the Chukchi and Beaufort Seas can be influenced by river runoff (e.g. sediments and colored dissolved organic material), sediment from melting dirty sea ice, and sediment resuspension in shallow areas. Constituent retrievals should be improved with absorption-based inversion algorithms. A better understanding of the continuum of conditions in highly variable regions is required. This research was supported by NASA and NASDA

CIRCULATION AND WATER MASS MODIFICATION IN THE CHUKCHI SEA

Thomas Weingartner, Institute of Marine Science, University of Alaska, Fairbanks, AK 99775 USA; weingart@ims.uaf.edu
Knut Aagaard and Rebecca Woodgate, Applied Physics Laboratory, University of Washington, 1013 NE 40th Street, Seattle, Washington 98015, USA
Koji Shimada, Institute of Ocean Sciences, 9860 W. Saanich Road, Sidney, B.C., V8L, 4B2, Canada, and JAMSTEC

We describe circulation and water mass modification processes in the Chukchi Sea using shipboard hydrographic and ADCP data and moored velocity, temperature, and salinity time series. The long time-averaged Bering Strait transport of 0.8 Sv crosses the Chukchi along three main branches: Herald Valley (western Chukchi; ~0.3 Sv), Hanna Trough (central Chukchi; <~0.2 Sv), and Barrow Canyon. A 6-year transport time series for Barrow Canyon suggests a mean annual transport of ~0.3 Sv, varying from a maximum in 1994-95 of ~0.4 Sv to a minimum in 1990-91 of ~0.2 Sv. The annual cycle in transport consists of a maximum in July (0.6 Sv) and a minimum in December (0 Sv), which is in-phase with the annual cycle of Bering Strait transport. We find that ~60% of the strait throughflow drains through Barrow Canyon in summer, while less than 30% does so in winter. This implies that much of the winter strait transport probably exits through Herald Valley. Our results also suggest that, over the long-term, most of the nutrient-rich Bering winter water flows through Herald Valley, while most of the fresher and nutrient-poor Bering summer water exits via Barrow Canyon in summer and fall.

Velocity shears in Barrow Canyon are generally cyclonic of O(0.2*f*). Large anticyclonic shears occur during upcanyon flows, consistent with the squashing of fluid columns moving into shallow water. The fate of the canyon outflow is not well resolved; some of it continues eastward above the subsurface Atlantic Water flowing southward around the Northwind Ridge and thence eastward along the Chukchi-Beaufort slope. However, Shimada et al. (submitted) suggest that in summer and fall some of the low-density outflow from Barrow Canyon is carried westward toward the Northwind Ridge by eddies and/or within the westward flowing, wind-driven surface layer over the slope.

Mean flow on the outer, central Chukchi shelf is northeastward, opposite the mean winds, but consistent with forcing by the Pacific - Arctic sea-level slope. Flow variations over the northeastern shelf are mainly wind-driven and coherent over spatial scales of O(300 km) but seasonal thermohaline processes can also influence the circulation. Horizontal density gradients form whose strength and sign vary due to the seasonal advection of different water masses from the Bering Sea and the formation/ablation of ice. In some winters, cold, hypersaline waters form within the coastal polynyi generated along the Alaskan coast. Most of this dense water drains through Barrow Canyon but some propagates across isobaths into the central Chukchi Sea as eddy-like features having swirl speeds of ~0.15 m s^{-1}. Large interannual variability characterizes the winter thermohaline structure and production of dense water on the Chukchi Sea shelf. This variability depends on the regional wind field that controls autumn ice extent on the shelf and the development of coastal polynyi in winter. Extensive, residual fall ice cover delays shelf water cooling and inhibits new ice growth, while light fall ice cover promotes early cooling and possibly heavy ice production. In years of extensive coastal polynyi along the Alaskan coast, substantial volumes of hypersaline water (S>34) form in winter and flow through Barrow Canyon. Water with these characteristics is absent from the northeast shelf in years when there is little polynya development. These large seasonal and interannual changes in transport and water properties on the Chukchi shelf and along the principal flow paths of Bering water are expected to play important roles on the circulation and mixing dynamics over the adjacent slope.

Reference

Shimada, K., T. Takizawa, K. Hatakeyama, T. Kikuchi, and S. Nishino, Circulation of Bering Summer Water in the Arctic Ocean: joint effects of seasonality and topography, (submitted to J. Geophys. Res.), 2001.

THE CIRCULATION IN THE CHUKCHI SEA FROM 1990 TO 1991: RESULTS FROM MOORED INSTRUMENTATION

Rebecca Woodgate and Knut Aagaard, Applied Physics Laboratory, University of Washington, 1013 NE 40th Street, Seattle, Washington 98015, USA; woodgate@apl.washington.edu
Weingartner, Thomas, Institute of Marine Science, University of Alaska Fairbanks, Fairbanks, AK 99775, USA

Between 1990 and 1991, eleven moorings, carrying current meters and CTD recorders, were deployed in the Chukchi Sea, and, combined with hydrographic surveys taken in autumn 1990 and 1991, these data give the best spatial coverage currently available for the region. Three lines of moorings were maintained: the first in Bering Strait, the second reaching across the Chukchi Sea from north of Kolyuchin Bay to Cape Lisburne, and the third covering Long Strait, Herald Canyon and Barrow Canyon.

At one site, north of Bering Strait, an upward-looking ADCP measured a predominantly barotropic structure to the principal component of the current and an ice velocity which was well correlated (r=0.9) with the water velocity. Simultaneous measurements of ice thickness show the ice transport northward through Bering Strait to be c.100 km^3/yr, although, surprisingly, for the first half of the winter, the net ice transport through Bering Strait is southward, even though the net transport of water is northwards.

The other current measurements indicate flow that is predominantly northwards throughout the Chukchi Sea, consistent with the mean northward transport via Bering Strait. In the western Chukchi Sea, near the coast, occasional southward reversals of the flow and freshening events in early winter show that the East Siberian Current can reach as far south as 68°N, but did not, in this year, extend far out from the coast. Outflows to the Arctic through Barrow Canyon and Herald Canyon are comparable in magnitude, with the western canyon carrying the far higher nutrient signal. To balance the volume transport through Bering Strait, a third outflow is required, which temperature data show to be via the gap between Herald and Hanna shoals.

Dominant in the records is a high spatial correlation of the currents and also a high correlation with the local wind. The latter is greatest in Bering Strait and the eastern Chukchi Sea, where the correlation is over 0.6. The spatial correlation is best visualized by horizontal EOFs. The first EOF, which explains 44% of the variance, gives a pattern of coherent flow from the Bering Strait to the northeast. The pattern of the second EOF, which explains 24% of the variance, is such that northward flow in the east correlates with southward flow in the west, and vice versa.

Large seasonal variability (cooling, salinization and weaker flow in winter) is present in most, but not all, the records (cf. Aagaard *et al.,* this volume). For example, in 1990-91, the flow through Herald Canyon showed a clear annual cycle in both salinity and speed, whilst the flow through Barrow Canyon did not. We can therefore expect that both the relative importance and the characteristics of the primary Chukchi shelf ventilation sources for the Arctic Ocean will shift seasonally, and, comparing to Weingartner *et al*., (this volume), also from year to year.

ATTENDEES ADDRESS LIST

Knut Aagaard
Polar Science Center - APL
Physics Laboratory - HN-10
University of Washington
1013 NE 40th St.
Seattle WA 98105-6698
phone: 206/543-8942
fax: 206/616-3142
email: aagaard@apl.washington.edu

Carin Ashjian
Woods Hole Oceanographic Institution
Redfield 246 MS #33
266 Woods Hole Road
Woods Hole, MA 02543
phone: 508/289-3457
fax: 508/457-2169
email: cashjian@whoi.edu

Arianne Balsom
Department of Ecology and Evolutionary Biology
569 Dabney/Buehler
University of Tennessee
Knoxville, TN 37996
phone: 865/974-6160
fax: 865/974-3067
email: abalsom.utk.edu

Jonathan M. Berkson
U.S. Coast Guard (G-OPN-1)
2100 2nd Street, SW
Washington, DC 20593
phone: 202/267-1457
fax: 202/267-4222
e-mail: jberkson@comdt.uscg.mil

Paul Bienhoff
Johns Hopkins University
Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel, MD 20723-6099
phone: 240/228-4323 (Wash./VA exch)
phone: 443/778-4323 (Balt./MD exch)
fax: 443/778-6864
email: Paul.Bienhoff@jhuapl.edu

Bodil Bluhm
1315 Spring Glade
Fairbanks, AK 99709
phone: 907/474-7407
fax: 907/474-7204
email: fsbab3@aurora.uaf.edu

Joseph W. Bodenstedt,
U. S. Coast Guard
Commandant (G-OPN-2)
Chief, Short Range Aids to Navigation Division
2100 2nd St. SW, Washington, DC, 20593
phone: 202/267-0344
fax: 202/267-4222
e-mail: jbodenstedt@comdt.uscg.mil

Lawson W. Brigham
PO Box 4577
Carmel, CA 93921-4577
phone: 831/622-7119
fax: 831/622-7119
email: lwb48@aol.com

Eddy C. Carmack
Institute of Ocean Sciences
Department of Fisheries and Oceans (Canada)
9860 West Saanich Road
Sidney, BC V8L 4B2 Canada
phone: 250/363-6585
fax: 250/363-6746
email: carmacke@dfo-mpo.gc.ca

Claudia Cenedese
Woods Hole Oceanographic Institution
MS #21
360 Woods Hole Rd.
Woods Hole, MA 02543
phone: 508/289-2696
fax: 508/457-2181
email: ccenedese@whoi.edu

David C. Chapman
Clark 316B, MS#21
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: 508/289-2792
fax: 508/457-2181
email: dchapman@whoi.edu

John P. Christensen
Arctic System Science Program
Office of Polar Programs
National Science Foundation
4201 Wilson Blvd. Room 740S
Arlington VA 22230
phone: 703/292-8029
fax: 703/292-9082
email: jchriste@nsf.gov

Barbara Clark
Department of Ecology and Evolutionary Biology
569 Dabney/Buehler
University of Tennessee
Knoxville TN 37996
phone: 865/974-2648
fax: 865/974-3067
email: bclark3@utk.edu

Jackie Clement
Department of Ecology and Evolutionary Biology
569 Dabney/Buehler
University of Tennessee
Knoxville, TN 37996
phone: 865/974-6160
fax: 865/974-3067
email: jlc@utk.edu

Lisa M. Clough
Dept of Biology
East Carolina University
Greenville, NC 27858
phone: 252/328-1834
fax: 252/328-4178
email: cloughl@mail.ecu.edu

Louis A. Codispoti
Horn Point Laboratory
P.O. Box 775
2020 Horns Point Road
Cambridge MD 21613-0775
phone: 410/221-8479
fax: 410/221-8490
email: codispot@hpl.umces.edu

Dennis M. Conlon
High Latitude Dynamics Program
Office of Naval Research, Code 322HL
800 N. Quincy St.
Arlington VA 22217
phone: 703/696-4720
fax: 703/696-2710
email: conlond@onr.navy.mil

Lee Cooper
Department of Ecology and Evolutionary Biology
569 Dabney/Buehler
University of Tennessee
Knoxville TN 37996
phone: 865/ 974-2990
fax: 865/974-3067
email: lcooper1@utk.edu

Glenn Cota
Center for Coastal Physical Oceanography
Crittenton Hall, 768 52nd Street
Old Dominion University
Norfolk , VA 23508 USA
phone: 757/683-5835
fax: 757/683-5550
email: cota@ccpo.odu.edu

Greg Cutter
Department of Ocean, Earth, and Atmospheric Sciences
Old Dominion University
4600 Elkhorn Ave.
Norfolk, VA 23529-0276 USA
phone: 757/683-4929
fax: 757/683-5303
email: gcutter@odu.edu

Dr. Ken Dunton
University of Texas at Austin
Marine Science Institute
750 Channel View Drive
Port Aransas, TX 78373
phone: 361/749-6744
fax: 361/749-6777
email: dunton@utmsi.utexas.edu

Mikhael Flint
P.P. Shirshov Institute of Oceanology
Russian Academy of Sciences
Nakhimovski prt. 36
Moscow 117851, RUSSIA
phone: +7 095 124 8515
fax: +7 095 124 5983
email: m_flint@orc.ru

Michel Gosselin
Institut des sciences de la mer
Universite du Quebec a Rimouski
310 Allee des Ursulines
Rimouski, (Quebec)
Canada G5L 3A1
phone: 418/723-1986 ext 1761
fax: 418/724-1842
email: michel_gosselin@uqar.uquebec.ca

Jeffrey Gossett
Operations
COMSUBDEVRON FIVE DET
140 Sylvester Road
San Diego, CA 92106-3521
phone: 619/553-7446
email: gossett@nosc.mil

Rolf Gradinger
Institute for Marine Science
University of Alaska Fairbanks
Fairbanks, AK 99775-7220
phone: 907 474 7407
fax: 907 474 7204
email: rgradinger@ims.uaf.edu

Jackie Grebmeier
Department of Ecology and Evolutionary
Biology
569 Dabney/Buehler
University of Tennessee
Knoxville, TN 37996
phone: 865/ 974-2592
fax: 865/974-3067
email: jgrebmei@utk.edu

H. Rodger Harvey
Chesapeake Biological Laboratory, UMCES
1 Williams Street, Box 38
Solomons, MD 20688
phone: 410/326-7206
fax: 410/326-7341
email: harvey@cbl.umces.edu

Benjamin Holt
Oceanography Element
Jet Propulsion Laboratory
(JPL) - California Institute of
Technology MS 330-323
4800 Oak Grove Drive
Pasadena, CA 91109
phone: 818/354-5473
fax: 818/393-6720
email: ben@pacific.jpl.nasa.gov

Idrisi Nasseer
Rosenstiel School of Marine
and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149
phone: 305/361-4817
fax: 305/361-4765
email: nidrisi@rsmas.miami.edu

David Kadko
University of Miami
RSMAS/MAC
4600 Rickenbacker Causeway
Miami, FL 33149
phone: 305/361-4721
fax: 305/361-4689
email: dkadko@rsmas.miami.edu

David L. Kirchman
700 Pilottown Road
College of Marine Studies
University of Delaware
Lewes, Delaware 19958 USA
phone: 302-645-4375
fax: 302-645-4028
e-mail: kirchman@udel.edu

Peter Lane
Marine Biology and Fisheries
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149
phone: 305/361-4818
fax: 305/361-4765
email: plane@rsmas.miami.edu

Michael T. Ledbetter
Office of Polar Programs
(OPP) - ARCSS Program
National Science Foundation
4201 Wilson Boulevard
Room 755 S
Arlington, VA 22230
phone: 703/292-8029
fax: 703/292-9082
email: mledbett@nsf.gov

Dan Lubin
Scripps Institution of Oceanography
University of California, San Diego
9500 Gilman Drive
La Jolla, CA 92093-0221 USA
phone: 858/534-6369
fax: 858/534-7452
email: dlubin@ucsd.edu

Wieslaw Maslowski
Department of Oceanography
Naval Postgraduate School
833 Dyer Road Room 331
Monterey, CA 93943-5122
phone: 831/656-3162
fax: 831/656-2712
email: maslowsk@ucar.edu

C. Peter McRoy
Institute of Marine Science
University of Alaska Fairbanks,
Fairbanks AK 99775 USA
phone: 907/474-7783
fax: 907/474-5863
e-mail: ffcpm@aurora.uaf.edu

Chris Measures
Department of Oceanography
University of Hawaii
1000 Pope Road
Honolulu, HI 96822
phone: 808/956-5924
fax: 808/956-7112
email: chrism@soest.hawaii.edu

Igor A. Melnikov
Shirshov Institute of Oceanology
Russian Academy of Sciences
Nakhimovsky pr 36
Moscow 117851 Russia
phone: +7-095/124-5996
fax: +7-095/124-5983
email: migor@online.ru

Dr. Christine Michel
Freshwater Institute
Arctic Science Division,
Fisheries and Oceans Canada
501 University Crescent,
Winnipeg, Manitoba R3T 2N6
phone: 204/984-8726
fax: 204/984-2403
email: MichelC@DFO-MPO.GC.CA

James Moore
Joint Office for Science Support (JOSS)
University Corporation
for Atmospheric Research (UCAR)
PO Box 3000
Boulder, CO 80307-3000
phone: 303/497-8635
fax: 303/497-8158
email: jmoore@ucar.edu

Mitch Ohiwa
Massachusetts Institute of Technology
Woods Hole Oceanographic Institution
54-1417 MIT 77 Massachusetts Ave.
Cambridge, MA 02139
phone: 617/225-9100
email: ohiwa@MIT.EDU

Scott Pegau
Oregon State University
104 Ocean Admin Bldg.
Corvallis OR 97331
phone: 541/737-5229
fax: 541/737-2064
email: spegau@oce.orst.edu

Robert Pickart
Department of Physical Oceanography
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: 508/289-2858
fax: 508/457-2181
email: rpickart@whoi.edu

Albert Plueddemann
Woods Hole Oceanographic
Institution
Department of Physical
Oceanography
202A Clark Laboratory - MS 29
360 Woods Hole Road
Woods Hole , MA 02543-1541
phone: 508/457-2000 x2789
fax: 508/457-2181
email: aplueddemann@whoi.edu

Annelie Skoog
Department of Marine Sciences
University of Connecticut at Avery Point
1084 Shennecossett Road
Groton, CT 06340-6097
phone: 860/405-9220
fax: 860/405-9153
email: skoog@uconnvm.uconn.edu

Yvette Spitz
College of Oceanic and
Atmospheric Sciences
Oregon State University
104 Ocean Admin Building
Corvallis, OR 97331
phone: 541/737-3227
fax: 541/737-2064
email: yvette@oce.orst.edu

Knut Stamnes
Department of Physics and
Engineering Physics
Stevens Institute of Technology
Castle Point on Hudson
Hoboken, NJ 07030
phone: 201/216-5587
fax: 201/216-5638
email: kstamnes@stevens-tech.edu

James H. Swift
Scripps Institution of Oceanography
University of California, San Diego, 0214
9500 Gilman Dr.
La Jolla, CA 92093-0214
phone: 858/534-3387
fax: 858/534-7383
email: jswift@ucsd.edu

CAPT Dave Visneski
Maintenance and Logistics Command Pacific
BLDG. 50-1, Coast Guard Island
Alameda, CA 94501-5110
phone: 510/427-3525
fax: 510/437-5695
email: dvisneski@d11.uscg.mil

Thomas Weingartner
Institute of Marine Science
University of Alaska Fairbanks
PO Box 757220
Fairbanks, AK 99775-7220
phone: 907/474-7993
fax: 907/474-7204
email: weingart@ims.uaf.edu

John A. Whitehead
Woods Hole Oceanographic Institution
Department of Physical
Oceanography
360 Woods Hole Road -
MS #21
Woods Hole, MA 02543
phone: 508/289-2793
fax: 508/457-2181
email: jwhitehead@whoi.edu

Terry Whitledge
Institute of Marine Science
University of Alaska Fairbanks
PO Box 757220
Fairbanks, AK 99775-7220
phone: 907/474-7229
fax: 907/474-5863
email: whitledge@ims.uaf.edu

Rebecca A. Woodgate
Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, Washington 98105-6698
phone: 206/221-3268
fax: 206/616-3142
email: woodgate@apl.washington.edu