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Editorial

The Western Arctic Shelf-Basin Interactions (SBI) Project: An Overview

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An increasing body of research indicates that climate change will significantly impact the physical and biological linkages between the Arctic shelves and adjacent ocean basins. In 1998 the National Science Foundation (NSF) and the Office of Naval Research (ONR) responded to the need for a better fundamental information of these linkages through support for an interdisciplinary global change research study, Western Arctic Shelf-Basin Interactions (SBI). Initiated under the Ocean-Atmosphere-Ice Interactions component of NSF's Arctic System Science Program, the goal was to improve our understanding of the impacts of global change on the physical and biogeochemical connections among the western Arctic shelves, slopes, and deep basins (Grebmeier et al. 1998, 2001, Grebmeier 2003). The SBI project has a focus on water mass and ecosystem modifications, material fluxes and biogeochemical cycles in the Chukchi and Beaufort seas with work extending into the central Arctic basin (Figure 1 a). The SBI field efforts have centered on the outer shelf, shelf break and upper slope, where it is thought that key processes control water mass exchange and biogeochemical cycles, and where rapid and significant responses to climate change are expected to occur.

The SBI project is comprised of three phases extending over a 10-year period. Projects in Phase I (1998-2001) involved analyses of historical data, opportunistic field investigations, and modeling of specific regions and processes. The intensive field program constitutes SBI Phase II (2002-2006). The major goals of the field project are to investigate: 1) physical modifications of North Pacific and other waters on the Chukchi shelf and slope, and exchanges of these waters across the shelf and slope; 2) biogeochemical modifications of North Pacific and other waters over the Chukchi and Beaufort shelf and slope areas, with an emphasis on carbon, nutrients, and key organisms that represent a suite of trophic levels; and 3) comparative studies over the wide Chukchi and narrow Beaufort shelves and adjacent slopes to facilitate extrapolation and integration of the Western Ameriasian Arctic to a Pan-Arctic perspective. Integrated process and modeling studies of shelf-basin exchange mechanisms and their sensitivity to global change will continue to be a focal point of planned SBI Phase III (2007-2009) activities, which will develop Pan-Arctic models suitable for simulating scenarios of the impacts of climate change on shelf-basin interactions.

This special issue of Deep-Sea Research II includes both retrospective synthesis papers from the SBI Phase I component and field data results from the Phase II process, survey and mooring cruises in 2002 and 2003. Year-long continuous data from moorings and high resolution transect lines facilitated understanding the input function of water types entering the Arctic Ocean through Bering Strait and at the shelf break. Five key transect lines were reoccupied seasonally during the SBI study: the Herald Valley (HV) line in the western Chukchi Sea, then moving eastward, the West Hanna Shoal (WHS) line, East Hanna Shoal (EHS) line, the Barrow Canyon (BC) line, and the East Barrow (EB) line (Figure 1b). Ice conditions were highly variable during 2002, from 100% ice coverage in the spring from Nome, Alaska northward (except in portions of Barrow Canyon) to an extreme northerly ice retreat from all shelf/slope SBI lines by fall. A similar, near-record level of ice retreat continued in the western Arctic in 2003 and 2004 (Stroeve et al. 2005). Ship support for the SBI field program has been provided by the US Coast Guard icebreakers *Healy* and *Polar Star* and the RV *Nathaniel B. Palmer*, and the ice-strengthened ship RV *Alpha Helix.*

In support of the extensive data sets generated by the SBI field program, the Joint Office of Science Support (JOSS) of the University Corporation for Atmospheric Research maintained a shipboard field catalog during cruises on the USCGC Healy that provided real-time data to scientists on the ship as well as to onshore scientists following the progress of the cruise. Field products included satellite images, ship tracking, weather, CTD data from the hydrographic group as well as associated bottle data, and shipboard event logs. The SBI field catalog (with maps and event information) can be found at http://www.joss.ucar.edu/sbi/catalog/. Websites for the 2003 survey cruise and the annual SBI mooring cruises are linked from home institutions to the SBI websites maintained at JOSS (http://www.joss.ucar.edu/sbi/) and the SBI project office (http://sbi.utk.edu). In addition to the research information available through the JOSS and SBI websites, additional public outreach was provided through participation of local residents of Alaskan coastal communities and secondary school teachers on the research cruises, as well as television and broadcast news teams who provided information on the research effort to mass communication outlets. Further information about these activities and the SBI project in general can be found on the SBI Project Office website.

This Deep-Sea Research II SBI special issue is the first of several anticipated special volumes on SBI project results. We have divided this issue into four chapters representing the major themes of the project. In the next sections we briefly highlight several findings of the investigators and their results from the SBI project to date.

Chapter 1. Hydrography and Ice Conditions

Physical forcing mechanisms and hydrographic characteristics of the waters transiting through Bering Strait and over the Chukchi and Beaufort shelves to the Arctic Basin are essential drivers of the productivity of this ecosystem. Woodgate et al. (2005) describe the atmospheric interactions and seawater input passing northward through Bering Strait to the Chukchi Sea, forced primarily by local winds and sea level change. Transit time for water from Bering Strait to the Arctic slope area ranges from 1-6 months, with residence time greatest in the winter when the velocity of flow through Bering Strait diminishes. As the water moves over the wide Chukchi shelf it transits through Herald Valley (in the west) and Barrow Canyon (in the east) in the northern Chukchi Sea. A third “Central Channel” branch also spreads northward onto the outer shelf and it varies seasonally in phase with Bering Strait transport, as described by Weingartner et al. (2005). A portion of the Central Channel outflow also moves eastward and converges with the Alaskan Coastal Current at the head of Barrow Canyon. Pickart et al. (2005) discuss the flow densities of winter-transformed Bering water that transits the Chukchi Sea and subsequently drains northward into the Arctic Ocean proper. The mechanisms responsible for this mode of shelf-basin exchange include cyclonic relative vorticity and internal mixing caused by shear instabilities, which lead to baroclinic instability and eddy formation. During most of the year, a prominent feature of the current system is an eastward flowing shelf break jet, observed in both physical and nutrient profiles. Kadko and Muench (2005) report on water column analyses of $^{228}Ra/^{226}Ra$ ratios and also provide the first measurements of the short-lived ^{224}Ra in the Arctic. Their findings indicate that the Bering Strait inflow is constrained by Coriolis forces to follow local isobaths and does not easily move into deeper waters.

A key goal of the SBI project is to understand how physical and biological processes together impact shelf-basin exchange of biological, chemical, and physical properties. Codispoti et al. (2005) summarize the data from the 2002 SBI process cruises using temperature-salinity relationships and hydrographic characteristics to evaluate shelf-to-basin mixing processes and their interactions with the upper halocline of the Arctic Ocean. The advection of dissolved inorganic nitrogen (DIN), primarily nitrate and ammonium, originating from Bering Strait was found to be a key factor in the high productivity values observed on the shelf and Barrow Canyon region, and a limiting factor in supporting offshore basin productivity. Studies by Mathis et al. (2005) of dissolved organic carbon (DOC) distributions in the western Arctic showed that concentrations of DOC highest in the surface waters, and a high degree of variability on spatial, seasonal, and even annual scales. There was a strong relationship between DOC and salinity, with the highest DOC in waters influenced by freshwater sources (the Mackenzie and Yukon Rivers). Ashjian et al. (2005) reports on the vertical distributions of plankton and particles via high-resolution observations with a Video Plankton Recorder during the summer 2002 cruise. These data corroborate the hydrographic data that nutrients and particulate material were moving along shelf to the east rather than northwards towards the basin. Visual observations of the vertical movement of particulate carbon in marine snow indicate that a large amount of this material settles to the benthos of the Chukchi Sea prior to being advected from the shelf into deeper waters.

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The field program was well-positioned in 2002 to observe the most extensive Arctic sea ice retreat in the satellite record, which afforded an unprecedented opportunity to investigate the impact of sea ice on biogeochemical processes and the ecosystem response to significant ice retreat. Recent changes in the Chukchi and Beaufort Sea ice regimes (reduced summer minimum ice extent and thickness, altered drift paths and winter break out events of landfast ice) have likely resulted in an increase of sediment-laden ice in the area. Eicken et al. (2005) report their observations of ice cover and sediment content over the Chukchi and Beaufort shelves in 2001, prior to the first SBI field season, and during the spring of 2002, which revealed the widespread occurrence of sediment-laden ice. Their results estimated that the total amount of sediment transported by sea ice over the entire Chukchi and Beaufort shelves in 2001/02 represented a significant sediment input to the western Arctic Ocean.

Chapter 2 Water Column Processes

The production of organic carbon and its recycling are important variables in understanding shelf-basin exchange and the impact of climate. Measurements of dissolved inorganic carbon (DIC) by Bates et al. (2005a) were used to determine rates of net community production for the Chukchi and western Beaufort Sea shelf and slope region from spring to fall in 2002. During the summer months high rates of phytoplankton production resulted in a large draw down of inorganic nutrients and DIC in the polar mixed layer and in the shallow depths of the upper halocline layer. Measures of particulate organic carbon (POC) and nitrogen (PON) were also used by Bates et al. (2005b) to follow the large accumulation of carbon and nitrogen between spring and summer in the surface mixed layer due to phytoplankton productivity. Hill and Cota (2005) measured seasonal primary production in the SBI shelf and continental slope areas into deep water over the Canada Basin. An average estimated annual production of 80 g C m^{-2} yr^{-1} was measured over the outer shelf, dropping to <20 g C m^{-2} yr^{-1} in the offshore basin regions.

Very high rates were observed in Barrow Canyon (>400 g C m^{-2} yr^{-1}) seasonally, comparable to rates >800 g C m^{-2} yr^{-1} in the high production zones in the southern Bering Sea (Springer et al. 1993), which are among the highest in any ocean. Within the high production regions in the leads and ice margin, Hill et al. (2005) observed that >50% of production occurs in particles greater than 5 µm in size during the spring, and cluster analysis of pigment ratios revealed different assemblages over the shelf, slope and basin regions, with large diatoms dominating the shelf in spring. Variability in environmental conditions supporting productivity in the SBI regions were also evaluated by time-series of remotely sensed distributions of phytoplankton, sea ice, surface temperature, albedo, and clouds from April 1998-September 2002 (Wang et al. 2005). Phytoplankton pigment and ice concentrations derived from SeaWiFS, SSM/I, and AVHRR imagery were used in the analysis. These data suggest that seasonal variation of ice cover is the dominant environmental factor influencing productivity by ice edge blooms.

The recycling of dissolved organic materials was examined by Kirchman et al (2005) who found the role of temperature in controlling bacterial growth in the western Arctic was similar to that in low latitude oceans. The level of dissolved organic matter (DOM) was equally as important in controlling bacterial growth. These results suggest that the low water temperatures of the Arctic (-1.7 to 5 °C) may inhibit heterotrophic microbial activity and allow more primary production to be directed to higher trophic levels than observed in low latitude waters. Corroborating this finding, Davis et al. (2005) report the range of sources and bioactivity of organic matter in the SBI region. This study determined that POM concentrations in shelf waters are strongly correlated with chlorophyll a biomass from phytoplankton, and increased by a factor of 10 between spring and summer in surface waters. By comparison, DOC/DON only showed minor seasonal variations.

Lower trophic consumers were studied by Plourde et al. (2005) who report that copepod egg production is an indicator of food limitation for the mesozooplankton community in the Chukchi and Beaufort Seas. Zooplankton are also associated with specific water mass types, and this study showed that a transition region of older-aged Pacific water was located at the shelfbreak, separating nutrient-rich Pacific-origin shelf water from the low nutrient waters of the deep Arctic basin.

Chapter 3. Carbon Export and Sediment Processes

The high spatial and temporal carbon production and advective transport regime of the SBI study area is intimately related to the export flux of POC in the upper waters of the Chukchi Sea. Moran et al. (2005) used $^{234}Th/^{238}U$ disequilibrium and POC/^{234}Th ratios and show enhanced particle export in the shelf and slope waters with a marked seasonal increase during the summer relative to spring. A key finding of this study was the general close agreement between POC export and benthic carbon respiration in the spring, with an imbalance between POC export and benthic respiration in the summer. This suggests that enhanced summertime production was not fully consumed over the shelf, leading to offshore particulate carbon transport. Cooper et al. (2005) also found patterns of short-term export of particulate matter to the sediments using the short-lived ($t_{1/2}$ = 53 d) natural isotope, ^{7}Beryllium (^{7}Be), which is solely derived from atmospheric deposition. Although ^{7}Be is present in snow over ice, no ^{7}Be was detected in sediments under ice-covered conditions in May-June 2002. By comparison, ^{7}Be was present in surface sediments during the summer cruise, indicating rapid transport to the benthos both on the shelf and in waters as deep as 945 m in Barrow Canyon. Additional deposition tracers including the inventories of sediment chlorophyll and sediment oxygen respiration rates also supported rapid deposition of materials following sea ice melt.

Dunton et al. (2005) provide a 20-year retrospective analysis of faunal populations and biomass, along with water column integrated chlorophyll a (chl *a*), which are used as integrators of water column productivities. This study examines the ultimate fate and northward transport of carbon produced in the Bering and southern Chukchi seas. Spatial analyses document areas of high benthic biomass (>300 g m^{-2}) and water column chlorophyll (>150 mg m^{-2}) on both the southern and northern Chukchi shelf in known depositional centers. Strong benthic-pelagic coupling occurs in the shallow southern Chukchi Sea system, an area utilized heavily by benthic-feeding marine mammals. In contrast, there was no significant correlation between biomass and chlorophyll in the less productive Beaufort Sea (<75 g m^{-2} benthic biomass and <50 mg m^{-2} integrated chl *a*, respectively). Further evaluation of preserved organic carbon in Arctic sediments is reported by Yunker et al. (2005), who used organic biomarkers of terrigenous and marine carbon sources to investigate removal mechanisms during burial and provide insight into shelf-to-basin transport and preservation processes. Despite the large production and supply of marine organic carbon in the region, sediment composition and organic carbon budgets suggest that most of the marine component is utilized, with a far larger fraction of terrigenous organic carbon being preserved in Arctic Ocean sediments.

Ch. 4 Coupled Biophysical Modeling

Biophysical coupled models are important research tools to evaluate field results and processes influencing shelf-basin dynamics. Clement et al. (2005) used a high resolution (~9 km with 45 levels), large spatial domain model to simulate the flow through straits in the northern Bering Sea in order to investigate ocean circulation, and water mass and property exchanges between the Pacific and Arctic oceans. Model results indicate that ocean circulation is variable at seasonal to interdecadal scales as well as being responsive to short-term atmospheric forcing. . The model results for the northern Bering Sea provide important insights into the ocean circulation and fluxes in the Bering Strait region and into the Chukchi/Beaufort seas, ultimately providing a useful frame of reference for the more limited spatial and temporal field observations that are available. In the main SBI study region, Walsh et al. (2005) utilized the results from the SBI 2002 field season in a three-dimensional coupled circulation and ecological model to evaluate daily carbon/nitrogen cycling by planktonic and benthic components. Seasonal model budget results for the shelf regime of the Chukchi/Beaufort Seas indicated that productivity in the spring was limited most by light penetration, whereas summer productivity was limited most by nutrient availability, although overall production was higher in summer versus spring. One particular objective of this study was to investigate possible consequences of future global climatic changes at high latitudes. A key finding was that even with retreating ice cover, if there is no mechanism for nutrient replenishment to surface waters, climate change may have little impact on carbon sequestration within these high latitude ecosystems.

A Dedication

The authors and co-authors of this SBI special issue of Deep-Sea Research II dedicate this journal issue to the memory of three colleagues who passed away in 2004: Ryan Schrawder/Woods Hole Oceanographic Institution (SBI Phase II, 8 May 2004); Dr. Glenn Cota/Old Dominion University (SBI Phase I and II, 2 June 2004), and Dr. David Chapman/Woods Hole Oceanographic Institution (SBI Phase I, 20 July 2004). Their personal contributions of creative ideas, constructive comments, involvement in science planning and field, computational and laboratory work during the SBI project were significant and they each are missed.

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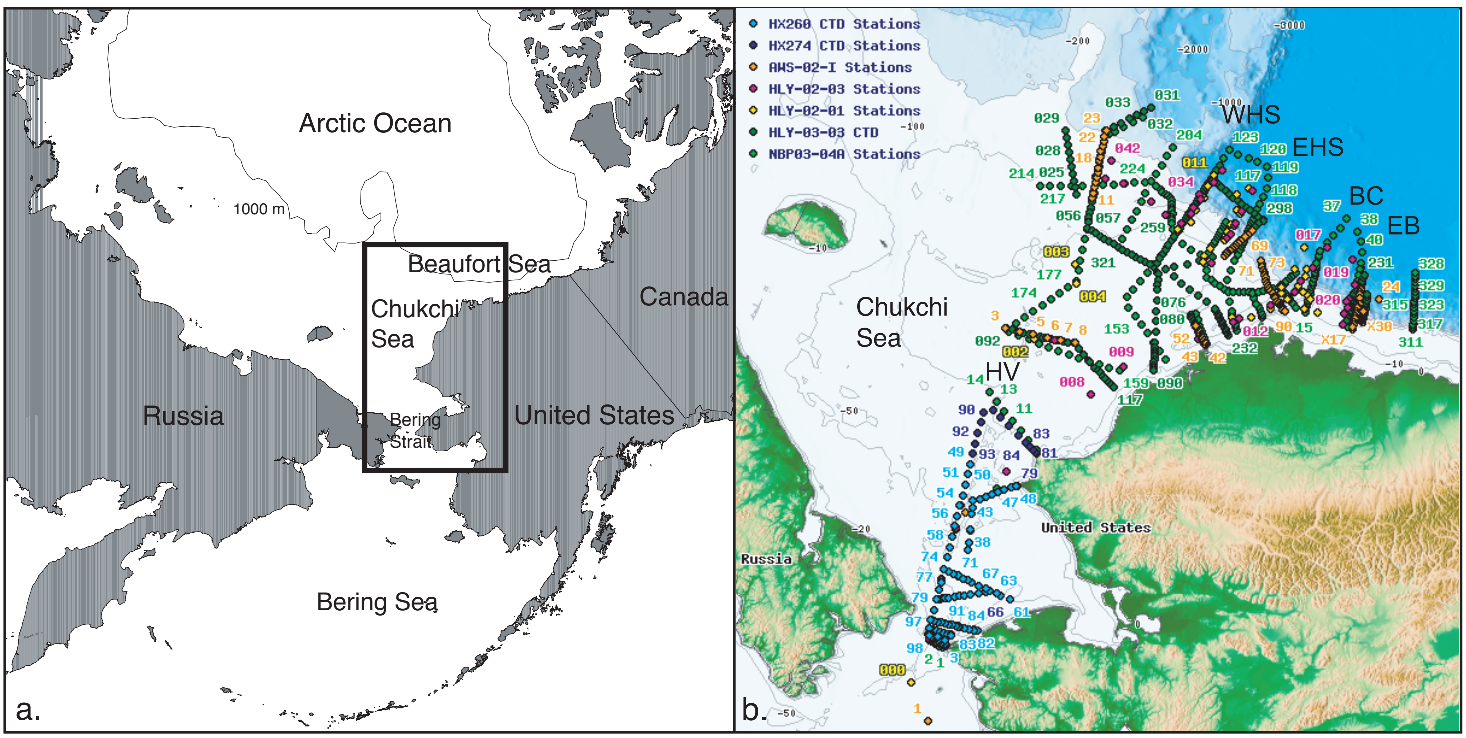

Figure 1. a. General location map for the Western Arctic Shelf-Basin Interactions (SBI) study (black box). b. Station locations for the SBI 2002 and 2003 process, survey and mooring cruises in the Bering Strait, Chukchi and Beaufort seas, and Arctic Ocean. Main SBI transect lines are indicated by HV=Herald Valley, WHS=West Hanna Shoal, EHS=East Hanna Shoal, BC=Barrow Canyon, and EB=East Barrow. Cruise identification by ship type: AWS=Arctic West Summer cruise on the USCGC Polar Star, HLY= USCGC Healy, HX=RV Alpha Helix, and NBP=RV Nathaniel B. Palmer.