An Extended Analysis of Time Series and Hydrographic Data with Reference to Shelf-Basin Interactions
and
Time Series Measurements in Bering Strait: 2001-2002
An Interim Contribution to SBI

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LONG-TERM GOALS

Our long-term research goals are to understand the physics of the high-latitude ocean mechanistically and quantitatively with respect to both its structure and circulation. We also seek to understand the links between physical mechanisms, including those affecting the ice cover, and the biology and chemistry of the high-latitude marine environment. The variability of the marine environment is a special focus and concern.

OBJECTIVES

Our first objective is to analyze existing data from the western Arctic Ocean and its adjacent seas in order to:

1) provide an observationally based measure of the variability of the shelf-basin system;

2) identify, and where possible quantify, the important physical mechanisms controlling this system;

3) contribute to focusing and refining the field programs planned under Phase II of the Shelf-Basin Interaction initiative (SBI), particularly as these depend upon an understanding of the mechanisms of shelf-basin exchange, and upon the climatology and variability of the shelf-slope-basin system; and

4) promote further improvements in the rapidly growing array of models of arctic circulation and hydrographic structures and their variability, including providing patterns and statistics against which to test the fidelity of these models.

Our second objective is to extend direct measurements of transport, temperature, and salinity in Bering Strait. This is vital upstream information for Phase II of the SBI initiative. An related undertaking is acquiring time series measurements of ice-thickness and of *in situ* nutrients, by incorporating upward-looking sonars and a nutrient analyzer into our array. The influx of Pacific waters provides a key forcing for the western Arctic shelf-slope-basin system, including its biogeochemistry. A particularly important dynamical aspect of the Pacific presence in the Arctic Ocean is its contribution to stabilizing the upper ocean, thereby influencing ice thickness and upper ocean mixing.

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14. ABSTRACT
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APPROACH

Together with T. Weingartner, University of Alaska, we are analyzing and synthesizing a historic set of moored time series and other measurements (primarily of velocity, temperature, and salinity) from the western Arctic shelves, slopes, and adjacent deep basin. While the focus is on high-resolution time series, we are also taking advantage of the large hydrographic data base now available. The synthesis addresses the circulation and its variability, together with water properties, with an emphasis on the dominant dynamics of the system and the statistics of the measured flows. In addition to refereed manuscripts and presentations at meetings, we are making this data set accessible via our web site and through the National Snow and Ice Data Center, Boulder, via JOSS.

We are also maintaining instrumented moorings in Bering Strait. In conjunction with earlier measurements, these will provide near-continuity in the record of flow and water properties in the strait over more than a decade. Velocity, temperature, and salinity are the core physical measurements at each mooring, supplemented with ice thickness measurements using upward-looking sonar and *in situ* nutrient analysis (cf., the related project section). Flow through both channels of Bering Strait is being measured. One mooring is placed in the center of the eastern channel, while a second is to be deployed mid-channel on the western side (which lies within the Russian Exclusive Economic Zone [EEZ]). A third mooring is placed north of the Diomede Islands, just outside the Russian EEZ, at a location which serves as a surrogate for the western channel. Deployment of the western channel mooring is subject to approval of our active EEZ application, and in the event that permission is denied this year, the mooring will instead be deployed in the eastern channel, between the established mid-channel mooring and Cape Prince of Wales. This alternative array would provide information on cross-stream variability and spatial scales, both of the flow and of the water properties in the strait.

WORK COMPLETED

We have continued the analysis of time series from the western Arctic shelf and slope, together with a variety of hydrographic data from the area. Completed data sets have been archived by submittal to JOSS, as per SBI guidelines. Two papers have been published in refereed journals, two more are in preparation, and several presentations have been made at national meetings and overseas.

The three new Bering Strait moorings have been built and shipped for deployment this fall from the *R/V Alpha Helix*. The two 2000-2001 moorings presently deployed in the strait are scheduled for recovery on the same cruise. The 1999-2000 time series recovered last fall have been processed and combined with earlier ones to provide a long-term perspective on the variability of flow and water properties in Bering Strait. Additionally, CTD and ADCP sections were taken in and north of the strait in 2000, and repeat sections are planned for the fall 2001 cruise.

We have also established a web site (http://psc.apl.washington.edu/HLD that incorporates research results and data displays.

RESULTS

We have nearly completed a synthesis of the western Arctic shelf circulation and its connection with the adjacent slope and basin, which is the SBI initiative focus. This work has been done together with T. Weingartner, University of Alaska. The synthesis provides a detailed description of the flow over the Chukchi shelf, including the region within the Russian EEZ. It shows that there are two principal modes of variability in the shelf circulation, and it quantifies the contribution of the wind, which is the dominant forcing mechanism in the system. The wind forcing, however, cannot solely explain the characteristics of the variable outflow from the Chukchi into the Arctic Ocean. A prime example is the flow through Herald Canyon, which shows pronounced seasonal variability (strong in summer, weak in winter) and little coherence with upstream events. A combination of time series and hydrographic data is being used to address these issues, with an emphasis on the temperature and salinity variability of the whole Chukchi system.

A particular focus of this work is the transformation of waters on the Chukchi shelf, between their entry through Bering Strait and their exit onto the continental slope bordering the Arctic Ocean. Figure 1 shows the temperature-salinity distribution by month at all the mooring sites in the Chukchi Sea during 1990-1991. Data from Bering Strait are shown in red (eastern channel, MA2), green (north of the Diomedes, MA3), and blue (western channel, MA1). Data from all other locations (5 moorings in the central Chukchi, one in Barrow Canyon, two in Herald Canyon and one on the northern side of Long Strait) are denoted in gray. Note that the flow through Bering Strait was as dense as any winter water found in the Chukchi Sea, except in February, when active salinization of the water column occurred along the Alaskan coast, most probably in wind-driven polynyas. Comparison of these dense waters entering through Bering Strait with observations over the Beaufort slope, suggest that the Pacific waters are capable of ventilating the Arctic Ocean halocline down to about 160 m. We are now combining these measurements with simultaneous velocity observations to estimate the flux in different salinity classes, thus quantifying both the net effect on the Pacific inflow waters of processes on the Chukchi shelf and the variable properties of the outflow from the shelf to the Arctic Ocean.

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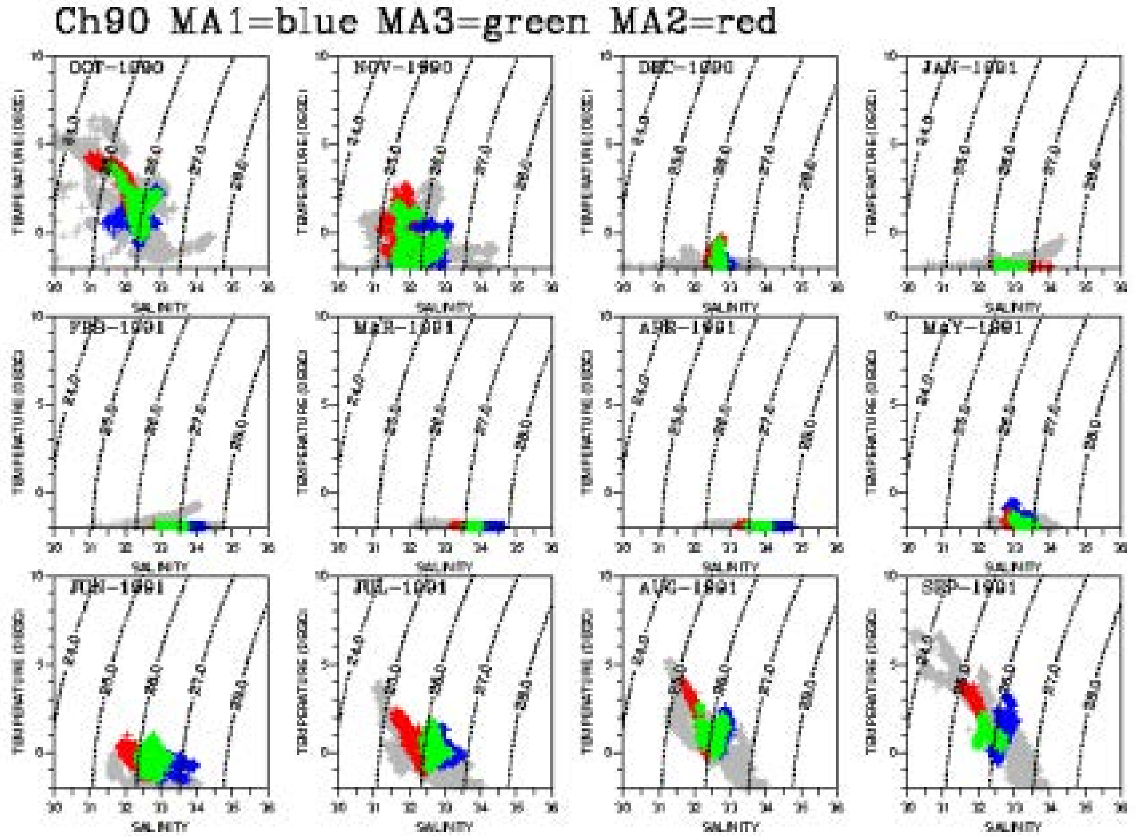

Figure 1: Monthly temperature-salinity (T-S) distributions in the Chukchi Sea and Bering Strait. [Twelve scatter plots, one for each month from October 1990 to September 1991, of the T-S correlation at 12 mooring sites in the Chukchi Sea. The range of T-S is greatest in October 1990 (c.30 to 34.5 psu and c. -2 to 7ºC), and decreases through November and December. By January, all the water is at the freezing point, with salinity ranging from c.30 to 35 psu. In May 1991, the waters start to warm, and the range of T-S increases to c.30 to 34 psu and c. -2 to 7ºC by September 1991. The scatter plots for Bering Strait are superimposed in color. The T-S at the western channel proxy site (MA3) always lies between the T-S of the western (colder and saltier) channel and that of the eastern (warmer and fresher) channel.]

The Bering Strait records from 1999-2000 show that summer water temperatures have remained cool for the past two years. The recent temperatures are comparable to those at the beginning of the decade, and they are much lower than during the extremely warm period of 1997-1998, a year that saw a dramatic ecosystem shift on the Bering and Chukchi shelves. Furthermore, the salinity of the Bering Strait throughflow during 1999-2000 has increased from the very low values prevailing during most of the 1990s, although it has not yet reached the high levels that began the decade. The ADCP sections run last fall show that the flow follows the isobaths, and, when combined with CTD sections, it is clear that in the eastern channel a coastal jet is concentrated over the steepest topography, inshore from the mid-channel mooring location.

IMPACT/APPLICATIONS

This work quantifies the large variability found in the Pacific-origin waters that flush the western Arctic shelves. Much of this variability is generated in the Bering Sea, and the waters are further modified in the Chukchi, particularly along the Alaskan coast in winter. They are then discharged into the Arctic Ocean, where their seasonal and interannual variability is propagated within the Arctic Ocean, probably predominantly by the boundary current. This in turn leads to variability in regions far from the originating shelves. An understanding of these effects and processes will be vital to future conceptualizations of the Arctic Ocean.

The accumulating time series from Bering Strait, now more than a decade long, provides a remarkable record of the upstream shelf forcing of the Pacific sector of the Arctic Ocean. For example, the salinity measurements point to a regime shift to lower salinities in the early 1990s, with likely implications for both the stratification of the upper Arctic Ocean and the injection depth in that ocean of the nutrient-rich Pacific waters. We note also that the coastal jet in the eastern channel of Bering Strait is likely one of several narrow flow features that will require attention in future studies.

This project provides a framework for the analysis of chemical and biological data. It also promotes further improvements in modeling arctic circulation and hydrographic structures and their variability, and it provides observations against which to test the fidelity of these models.

TRANSITIONS

Major goals of the SBI initiative are to understand the physical processes responsible for water mass modification over the arctic shelves and slopes and the exchanges with the interior ocean, as well as to understand the variability of this system. Our work addresses this directly. Furthermore, our description of the time-dependent shelf circulation provides important guidance to investigations of shelf productivity and biochemical cycling, since water parcels following different trajectories, and at different times of the year, will evolve differently during their transit of the shelf. This will, for example, result in different carbon and nutrient loading of these water parcels.

The extended time series measurements from Bering Strait will be used in a variety of physical and biochemical studies on the western arctic shelves, including:
1) the flux and processing of freshwater on the western Arctic shelves;
2) the variability of shelf sources for the interior ocean and the causes of that variability; and
3) the needs of a variety of arctic simulations for accurate long-term boundary conditions and forcing.

To facilitate the work of other SBI investigators we are making results available through refereed publications, various presentations, and our web site. The underlying time series data set is also being archived and made widely available through the National Snow and Ice Data Center, Boulder, via JOSS.

RELATED PROJECTS

Our ongoing analysis of the western arctic data set is coordinated with complementary work by T. Weingartner, University of Alaska, who is working on the Chukchi shelf and slope under ONR sponsorship and in the Beaufort Sea under a Department of the Interior grant. In the first effort, Dr. Weingartner is concentrating on shelf-basin exchange in the northeastern Chukchi Sea, while our own emphasis is on the larger-scale shelf circulation and the exchanges through Herald Canyon and Bering Strait. In the Beaufort study we are also cooperating with investigators from the Japan Marine Science and Technology Center (T. Takizawa and K. Shimada), who are building extended time series from measurements over the shelf and slope, and with investigators at the Institute of Ocean Sciences, Canada (E. Carmack, R. Macdonald, and F. McLaughlin), who have gathered a multi-disciplinary suite of data extending over a decade.

The deployment of an *in situ* nitrate analyzer during 2000-2001, and again this fall for a second year, is on behalf of T. Whitledge, University of Alaska. The data from this instrument are prototypes of a new generation of time series measurements that will be required to illuminate biogeochemical cycles in the high-latitude ocean. On behalf of R. Moritz, the University of Washington, we have also deployed upward-looking sonars on the Bering Strait moorings. These deployments address the need for circumpolar time series measurements of ice thickness, both to illuminate issues of ice mechanics and thermodynamics and to track changes in ice thickness that may accompany those observed within the Arctic Ocean by submarines.

PUBLICATIONS

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