Bering Strait Oceanic Fluxes - the Pacific Gateway to the Arctic

Part of the NOAA RUSALCA Program

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1. Abstract

The oceanic fluxes through the Bering Strait (the only ocean gateway between the Pacific and the Arctic Oceans) are major sources of heat, freshwater and nutrients for the Arctic Ocean, dominate the highly productive Chukchi Sea, and are an integrated measure of Bering Sea change. Oceanic heat entering the Arctic through the Bering Strait has been identified as a trigger of the 2007 anomalous Arctic sea ice retreat, and freshwater fluxes are recognized to have impacts on the meridional overturning circulation of the Atlantic Ocean. Quantifying and understanding Bering Strait oceanic fluxes is thus critical to local, Arctic, and climate studies. A measurement program started in 1990 has been taking year-round observations of velocity, temperature, salinity, and some biological parameters from moorings installed at several sites in the strait, although in many years failure to get permission to work in Russian waters limited these measurements only to the US half of the strait. In 2004, the NOAA-RUSALCA (Russian US Long-term Census of the Arctic) program established a joint US-Russian collaboration that now measures the entire strait with year-round moorings and annual hydrographic sections. The mooring data time-series is the longest record of oceanic fluxes into the Arctic. The now almost 2-decade long data set allows us to assess seasonal and interannual change, including quantifying the anomalous 2007 heat flux and its impacts on the Arctic, and the high variability in freshwater fluxes. Our work aims to understand the mechanisms driving variability in the strait and thus guide an optimal measurement system design for the strait. Our results are published and widely cited in leading journals. Bering Strait data are in demand for an astonishingly wide range of studies, from regional and global climate work, to ecosystem and fisheries studies and even global engineering projects. Bering Strait mooring and hydrographic data are freely available via the internet http://psc.apl.washington.edu/BeringStraitl.html and the National Oceanographic

Data Center. The project provides topical input to university classes and public science-outreach events, including the Polar Science Weekend at Seattle's top science museum.

2. Project Summary

The narrow (~ 85 km wide), shallow (~ 50 m deep) Bering Strait is the only ocean gateway between the Pacific and the Arctic Ocean. The throughflow, although small in volume (~ 0.8 Sv northwards in the annual mean), has a startlingly strong impact on the Arctic system:

- It provides ~ 1/5th of the oceanic heat input to the Arctic, is a driver of the seasonal melt-back of ice in the Chukchi/western Arctic, and is a subsurface heat source for over half the Arctic Ocean [Woodgate et al., 2010b];

- It is a highly variable source of freshwater, contributing 1/3rd of the freshwater input to the Arctic [Woodgate and Aagaard, 2005]; and

- It carries the most nutrient-rich waters entering the Arctic Ocean, fueling Arctic ecosystems.

Draining the Bering Sea Shelf to the south, the throughflow provides an integrated measure of Bering Sea change, dominates the hydrography of the highly productive Chukchi Sea, and (models suggest) influences the North Atlantic overturning circulation and possibly world climate.

Recent measurements of the Bering Strait fluxes find strong seasonal and interannual variability, so far unpredictable – the heat flux increase from 2001 to 2004 is enough to melt an 800 km by 800 km area of 1 m thick ice, and the internannual variability in freshwater is likely ~ 30% [*Woodgate et al.*, 2006]. Moreover, in 2007, both annual mean transport and temperatures were at record-length highs. Heat fluxes increased from 2001 to a 2007 maximum, 5-6x10^{20}J/yr. This is twice the 2001 heat flux, comparable to the annual shortwave radiative flux into the Chukchi Sea, and enough to melt 1/3rd of the 2007 seasonal Arctic sea-ice loss. This suggest the Bering Strait inflow influences sea-ice by providing a trigger for the onset of solar-driven melt, a conduit for oceanic heat into the Arctic, and (due to long transit times) a subsurface heat source within the Arctic in winter [*Woodgate et al.*, 2010b].

Yet, our understanding of what sets the properties and variability of the throughflow is still rudimentary, and our ability to measure these fluxes accurately is constrained by lack of data, both from the most nutrient-rich western half of the strait (which lies in Russian waters), and from the upper water column (due to potential ice-keel damage to instrumentation), where stratification and coastal boundary currents (especially the Alaskan Coastal Current in the eastern channel) contribute significantly to freshwater and heat fluxes.

Given the significant role of Pacific waters in the Arctic, quantifying the Bering Strait throughflow and its properties is essential to understanding the present functioning of the Arctic

system, and the causes and prediction of present and future Arctic change. This makes a Bering Strait measuring system a vital component of the Arctic Observing Network (AON).
Moorings have been in place in the Bering Strait region almost continuously since 1990 supported by a variety of funding sources. Access to the Russian half of the strait ceased in the early 1990s. However, in 2004, the NOAA RUSALCA (Russian US Long-term Census of the Arctic) program established a Russian-US joint scientific venture which has supported moorings and hydrographic measurements in the Russian side of the strait ever since. Together with a National Science Foundation International Polar Year grant, RUSALCA has supported a high resolution (i.e., 8 mooring) array in the strait region since 2007. The array includes upper and lower layer temperature, salinity and velocity measurements in both channels of the strait and at one "climate" site to the north, across-strait pressure measurements, and some bio-optic measurements (fluorescence, nitrate and turbidity).

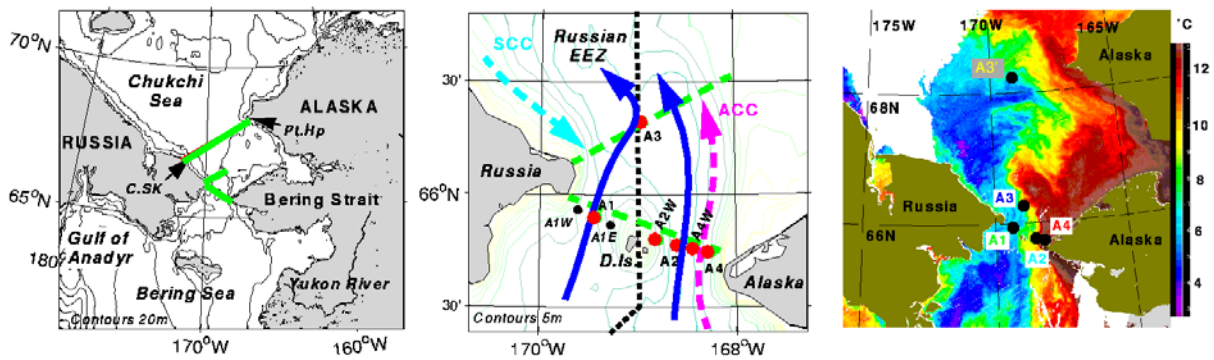


Figure 1: Bering Strait Maps: Left: *The Bering Strait, with annual target hydrographic lines (green).* ***Middle:*** *Detail of Bering Strait, with schematic flows, mooring locations (red and black dots) and CTD lines (green). The main northward flow passes through both channels (dark blue arrows). Topography diverts the western channel flow eastward near site A3. The warm, fresh Alaskan Coastal Current (ACC) (pink dotted arrow) is present seasonally in the east. The cold, fresh Siberian Coastal Current (SCC) (light blue dotted arrow) is present in some years seasonally in the west. All these currents reverse on time scales of days to weeks.* ***Right:*** *MODIS sea surface temperature image from 26th August 2004, with historic mooring locations (A1, A2, A3, A3' and A4), occupied variously since 1990. C.SK=Cape Serdtse Kamen. Pt.Hp=Point Hope. D.Is.= Diomede Islands. Black dotted line = EEZ (Exclusive Economic Zone).*

The current measurement program undertaken includes year-round moored measurements of water velocity and properties at several sites in the Bering Strait region, supported by satellite data and numerical weather prediction atmospheric forcing data, and hydrographic section data taken across the strait. The aim is to quantify and understand oceanic fluxes of volume, freshwater, heat and nutrients through the strait on daily to interannual timescales, with the view to designing an optimum observing network for the strait.

Mooring and hydrography data are freely available once calibration and quality control is complete (typically months after mooring recovery). Since the region is seasonally ice-covered, the moorings have to be entirely subsurface, and thus real-time data transfer is not possible. The

data are posted on our website http://psc.apl.washington.edu/BeringStrait.html and are submitted to the National Oceanographic Data Center (NODC) for permanent archiving. Metadata are also submitted to the National Science Foundation's CADIS (Cooperative Arctic Data and Information Service) site, and the AOOS (Alaskan Ocean Observing System) archives. Links to the data are also held in various international programs, such as the International Polar Year.

Quantification of the Bering Strait oceanic fluxes is vital to local, regional and global multidisciplinary observational, theoretical and modeling studies, and cited in over 100 recent publications. Bering Strait data have been used in various research areas including non-physical oceanography and areas beyond oceanography, such as biological studies of sea-birds and mammals. Voluntary registration at our data site shows the data is in demand for work ranging from climate modeling to King Crab fishing, including a wide variety of studies covering local, Arctic and global subjects (North Pacific, Gulf of Alaska, Bering Sea, Chukchi Sea, Arctic Ocean, Arctic Ocean outflows, North Atlantic), with topics including ocean circulation; multidisciplinary shelf-basin exchange; eddy processes; benthic-pelagic coupling; ocean sedimentation; hydrology; heat, freshwater and nitrogen budgets; biogeochemistry, including CDOM, POC, and PIC; modeling and observational studies of present-day, future and paleo conditions, including analysis of sediment cores; future climate predictions (including Arctic and Atlantic meridional overturning circulation investigations); present-day and paleo climate stability; recent studies of accelerated retreat of Arctic sea-ice; changes in the fate of Pacific water in the Arctic; and ecosystems and ecosystem change, including effects on algae, plankton, euphasiids, seabirds, grey and bowhead whales.

The moorings also provide a potential logistics platform for other projects. In the past the moorings have carried water sampling devices and various bio-optics systems. We currently carry whale acoustic sensors and in the future will carry pH and pCO2 sensors on the moorings.

3. Scientific Accomplishments

We report preliminary results from the new mooring data (still under data quality control/calibration, as the cruise only just ended), and on recent results from the entire time-series.

Mooring deployments and recoveries and 2010 cruise activities

Eight NOAA moorings were deployed on the RUSALCA 2009 mooring cruise on the Russian vessel Khromov [*Woodgate*, 2009], see Figures 1 and 2. Three moorings were deployed across the western (Russian) channel of the strait. Four moorings were deployed across the eastern (US) channel of the strait. A final 8th mooring was deployed ~ 30 nm north of the strait at a "climate site" occupied since 1990 and hypothesized to be a useful average of the flow through the strait. The 8 sites are a combination of 3 sites established in the 1990s, 3 sites established since 2001/2004 and 2 new sites established in 2007. Together they give the highest resolution to date in the Bering Strait.

These moorings include 6 upward looking ADCP (Acoustic Doppler Current Profilers) to measure water velocity in ~ 2 m bins to the surface, bottom pressure sensors, and lower and upper-layer temperature salinity sensors, the latter in ice-resistant housings (ISCATs). The moorings also carry optical sensors for nutrients (one site in each channel), and fluorescence and turbidity, these latter measurements now being made at 4 sites across the strait. In collaboration with Kate Stafford and Carter Esch, two moorings also carry whale acoustic recorders.

These eight moorings were successfully recovered on the RUSALCA 2010 mooring cruise in August also on the Khromov [*Woodgate et al.*, 2010a]. (The 8 moorings were redeployed under NSF funding.) High (~3km) resolution hydrographic sections were also taken across both channels of the Bering Strait, both in the Strait proper and through the mooring site A3. In addition, a US-Russia section was run across the central Chukchi Sea with high resolution near the coasts. Exceptionally good working conditions over the 10 days cruise allowed us to complete an extra 4 high resolution lines each approximately perpendicular to the Russian coast crossing the Siberian Coastal Current, the 4th being a rerun of the Russian half of the Bering Strait line (see Figure 2). This detailed high resolution survey of the Siberian Coastal Current is exceptional, since our estimation of the importance of this current is only rudimentary – there has been only one such campaign (to our knowledge) in the past. Our new data will assist considerably in understanding the role of this current, especially in terms of freshwater flux.

All stations were sampled for nutrients and (with the exception of the repeat of the Bering Strait line) chlorophyll. The Bering Strait line was also sampled for dissolved inorganic carbon (for Nick Bates). On many of the lines (all of the initial lines and some of the extra lines) water samples were also taken for dissolved organic nitrogen (for Terry Whitledge) and phytoplankton (for the Shirshov Institute). One set of water samples were taken in the Siberian Coastal Current for analysis of O18 isotopes. Eighteen zooplankton net tows were taken on the various lines (for Russ Hopcroft).
During the cruise, marine mammal and bird observations were made from the bridge (by Kate Stafford and Carter Esch), with the focus on whales. Unusually, a small area of sea ice was found on the Russian coast just off Cape Serdtse Kamen, and this was supporting polar bears and walrus. This appears to be the last remnants of a tongue of ice advected south with the Siberian Coastal Current (see Figure 3 satellite images from ~ 1 month before the cruise).

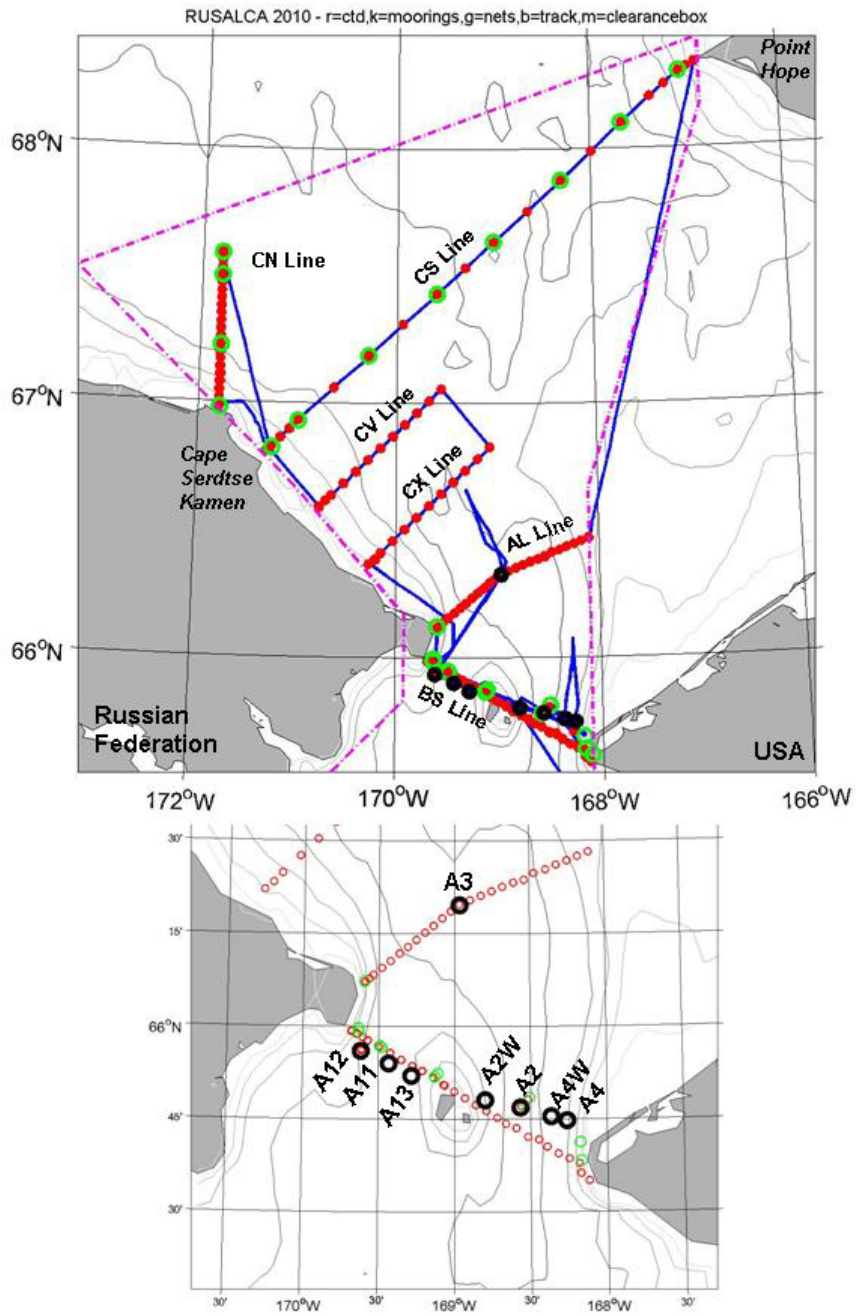
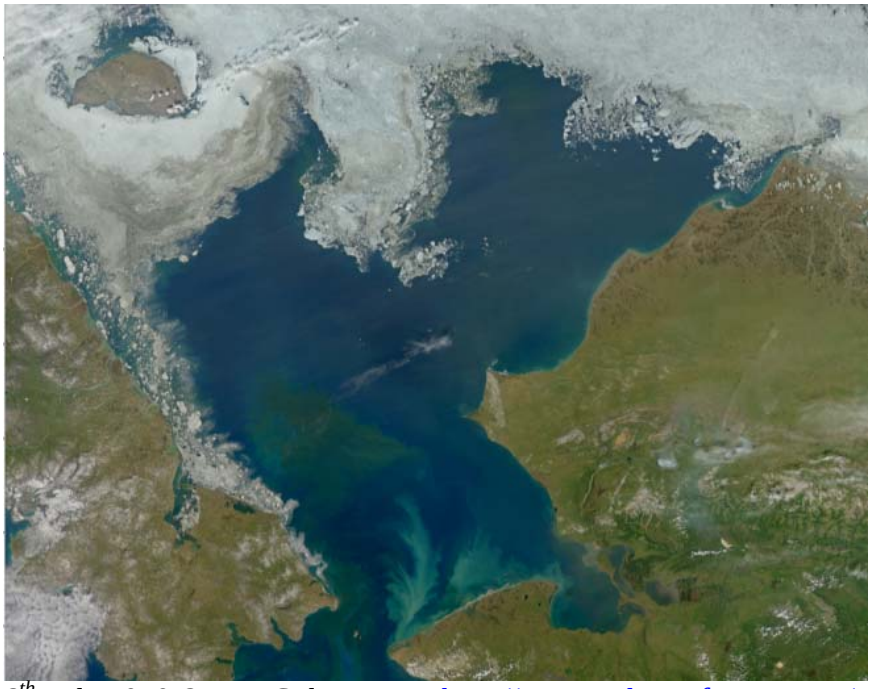
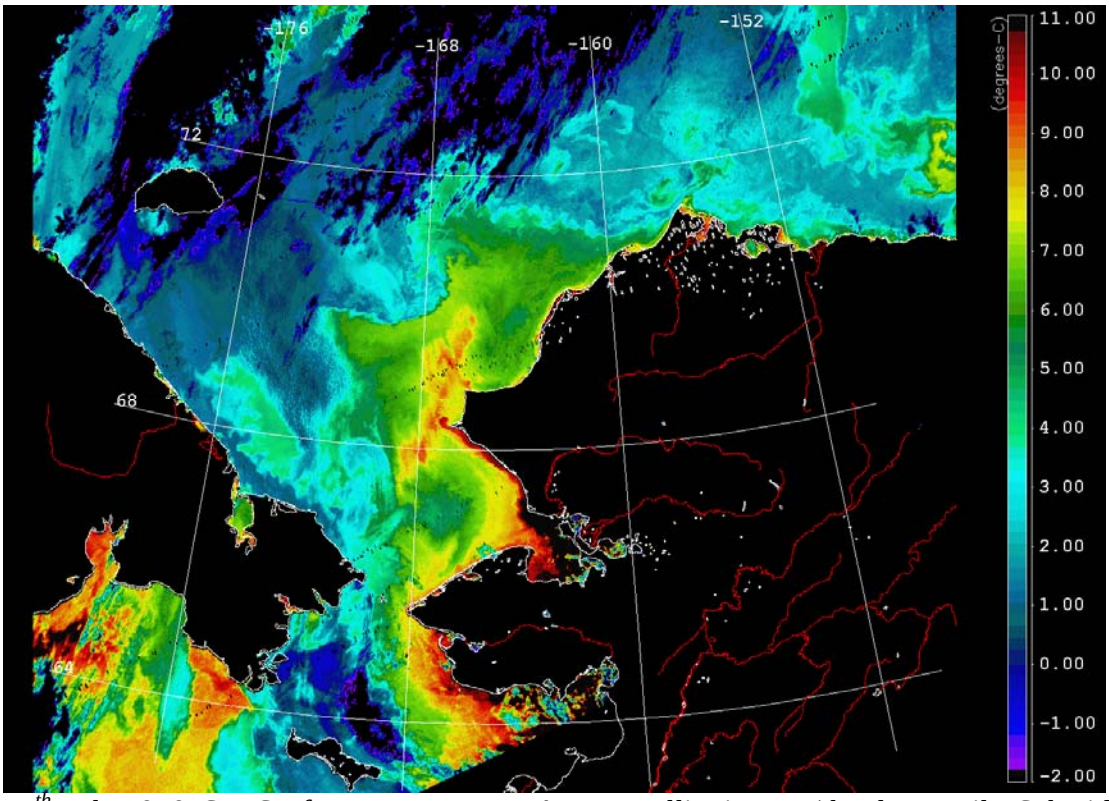


Figure 2: RUSALCA 2010 Cruise Map: *Ship-track in blue, Mooring sites in black, CTD stations in red, and Zooplankton nets in green. Mauve dashed lines indicate area with working permission. Depth contours are every 10m from the International Bathymetric Chart of the Arctic Ocean [Jakobsson et al., 2000].*

Figure 3: RUSALCA 2010 Satellite images



8th July 2010 Ocean Color Image http://oceancolor.gsfc.nasa.gov/_ (found by Bill Crawford)



24th July 2010 Sea Surface Temperature Aqua-satellite image (thanks to Mike Schmidt) from http://mather.sfos.uaf.edu/~mschmidt/ak_chukchi_sea_2010/A2010205230000_AQUA_LAC_sub1_sst_map.png

Bering Strait heat flux as a trigger of the 2007 anomalous Arctic sea ice retreat

Recent work [*Woodgate et al.*, 2010b] suggests that the Bering Strait heat flux was anomalously high in 2007, and this acted as a trigger for the remarkable Arctic sea-ice retreat that year. In 2007, both annual mean transport and temperatures are at record-length highs. Heat fluxes increase from 2001 to a 2007 maximum, 5-6x10^{20}J/yr. This is twice the 2001 Bering Strait heat flux, comparable to the annual shortwave radiative flux into the Chukchi Sea, and enough to melt 1/3rd of the 2007 seasonal Arctic sea-ice loss. These results suggest the Bering Strait inflow influences sea-ice by providing a trigger for the onset of solar-driven melt, a conduit for oceanic heat into the Arctic, and (due to long transit times) a subsurface heat source within the Arctic in winter. The substantial interannual variability reflects temperature and transport changes, the latter (especially recently) being significantly affected by variability (> 0.2Sv equivalent) in the Pacific-Arctic pressure-head driving the flow.

This latter point is especially interesting for climate studies. It was long assumed that the variability of the flow through the Bering Strait was driven predominantly by local winds. However, recent work is suggesting increasingly there is a variable far-field driving to the flow [*Woodgate et al.*, 2005b; *Woodgate et al.*, 2010b], which is presumably linked to larger scale climate change.

Bering Strait interannual variability

The now almost 2 decades of mooring data from the strait region allow us to study long-term variations in the fluxes [see e.g., *Woodgate et al.*, 2006]. The time-series updated to include preliminary versions of the most recent data are given in Figure 4.

Recent years show significant increases in velocity and transport since 2001. We estimate the 2001 transport at 0.6 Sv (1 Sv = 1,000,000 m^3/s), whereas the 2009 transport is around 1 Sv. The terms of heat flux, the years 2004 and 2007 still remain the largest in the record, with 2007 being the greater of the two. Interestingly, annual mean temperatures have decreased in the central strait and in the Alaskan Coastal Current in the last 2 years (2008 and 2009). Recently salinities have also decreased (in 2009), while still remaining higher than in the early 2000s.

Future Work

Our immediate goals are to quantify volume, heat and freshwater fluxes taking into account the contributions from stratification and the Alaskan and Siberian Coastal Currents. The data shown below are only from near bottom measurements made in the strait, and thus underestimate both the magnitude and the variability of the total fluxes. The upper level instruments deployed on the moorings and satellite data [e.g., as per *Woodgate et al.*, 2010b] will allow us to quantify, or at least bound, the sizeable effects of stratification on the fluxes.

Our next focus will be on the freshwater fluxes. Even the bottom data show remarkably large interannual variability (from ~ 1400 km^3/yr to ~ 2100 km_3/yr), which appears to be larger than reported changes in river and atmospheric inputs to the Arctic [*Serreze et al.*, 2006]. Bering Strait fluxes contribute ~ 1/3rd of the freshwater entering the Arctic Ocean, with impacts on

stratification (and thus heat flux to the surface). Dramatic changes are being seen in the Arctic freshwater storage, and thus a rigorous quantification of variability in the freshwater inputs to the Arctic is urgently required for observational and modeling projects.

We will also study the flow and water property structure of the strait, with a view to understanding the dominant driving mechanisms, calibrating our long-term measurements and designing an optimum observing system for the strait.

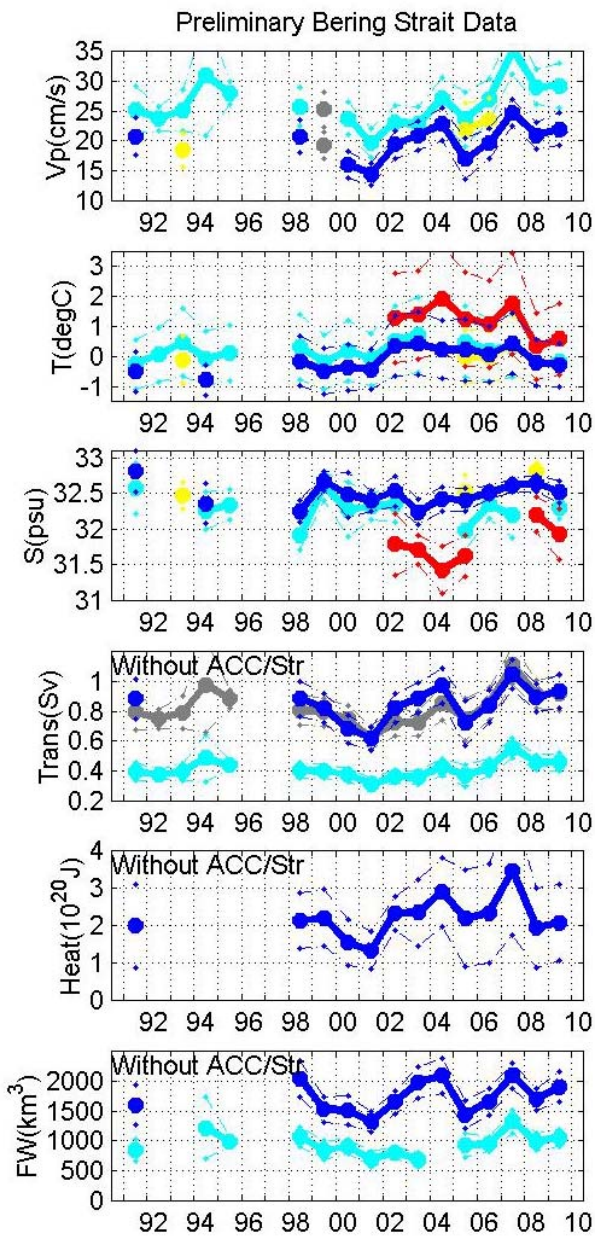


Figure 4: Bering Strait Annual Means *(A1-yellow; A2-cyan; A3-blue; A4-red) of near-bottom principal component (~ northward) of velocity (Vp), temperature (T) and salinity (S) (top three panels); and estimates of transport, heat flux and freshwater flux (panels 3-6). For transport and flux estimates, blue (from A3) are for the entire strait and cyan (from A2) are only for the eastern channel. For transport, gray line is the entire strait transport as estimated from A2 only. Corrections for stratification and the ACC (not included) are ~ 1 - 2x10^{20} J/yr (heat) and 800 - 1000 km^3/yr (freshwater). Dashed lines indicate estimated errors in the means. Grey dots in Vp indicate results from partial years (used for flux estimates).*

Data Archiving and Availability

Mooring and hydrography data are freely available once calibration and quality control is complete (typically months after mooring recovery). Since the region is seasonally ice-covered, the moorings have to be entirely subsurface, and thus real-time data transfer is not possible. The data are posted on our website http://psc.apl.washington.edu/BeringStrait.html and are submitted to the National Oceanographic Data Center (NODC) for permanent archiving. Metadata are also submitted to the National Science Foundation's CADIS (Cooperative Arctic Data and Information Service) site, and the AOOS (Alaskan Ocean Observing System) archives. Links to the data are also held in various international programs, such as the International Polar Year.

4. Education and Outreach

Our website - http://psc.apl.washington.edu/BeringStrait.html – gives an overview of Bering Strait activities. Our outreach activities on this project are many-fold:

1) To the Science Community – our website includes data access, and links to journal publications. We also present results at national and international conferences. Woodgate was an invited speaker at the International Polar Year meeting in Oslo in 2010, and at various meetings requesting information on the Bering Strait throughflow, including an invited talk at the European DAMOCLES (Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies) meeting in 2009. Results and data are in popular demand for other Arctic and international projects, including biological studies, model intercomparisons, the ASOF (Arctic SubArctic Ocean Fluxes) studies, ESSAS (Ecosystem Studies of Arctic and Sub-Arctic Seas), freshwater and heat budgets studies, and the annual Arctic Report Card. The work is part of the Arctic Observing Network, and contributes to International Polar Year projects Bering Strait, iAOOS (international Arctic Ocean Observing System), and C3O (Canada's three oceans).

2) Providing a science platform for other studies – in 2010, we collaborated with Kate Stafford to add Whale Acoustic listening sensors to the Bering Strait moorings. In 2011 we will work with Kelly Falkner to add pH and pCO2 sensors to the moorings. As part of the interdisciplinary RUSALCA (Russian-US Long-term Census of the Arctic) program, in addition to sampling directly related to the goals of our project, we collaborate with biological and ocean acidification programs in the hydrographic program at sea, and these programs will also utilize mooring data results.

3) Verification of Arctic Models – Woodgate is also involved in a model-data comparison study organized by AOMIP (Arctic Ocean Model Intercomparison Project) to assess how well models represent the Bering Strait oceanic fluxes, and provide data for various data assimilation studies.

4) To students – results of this project are part of an interdisciplinary course "The Changing Arctic Ocean" taught by Woodgate and Deming at the University of Washington School

of Oceanography, and feature in other invited lectures given by Woodgate for UW oceanography and engineering courses (see list below).

5) To the general public – the importance of the Pacific input to the Arctic is one message brought to the public via various outreach activities, including the Polar Science Weekend, held in spring each year at the Pacific Science Center, Seattle's major science museum. This 4-day event (with 2 days focused on school visits) typically draws over 10,000 visitors over the weekend. We exhibit a mooring, anchored to the museum floor, suspended from the museum ceiling, with real floatation, instruments, releases, and anchor. We demonstrate (and with training allow the public to operate) the acoustics which release the mooring from the anchor, and allow us to recover subsurface instrumentation. The forum provides excellent interactions with adults, children, teachers, and school classes on Arctic issues, oceanography, science in general, climate change, and the role and careers of women in these endeavors.

Woodgate serves on ASOF science steering committee, the WCRP Arctic Climate Panel of the CliC (Climate and Cryosphere) program, and the advisory board for the University of Washington's Program on Climate Change, and is a guest editor for a special Arctic edition of Oceanography.

By providing input to student classes and field work opportunities, this project aids in the training and development of new oceanographers and technicians. Students and new technicians (Chase Stoudt, Jonathan Whitefield and Brian Svabik) received at-sea training in hydrographic and mooring operations. The latter is particularly important, since there is remarkably little new intake into the community of sea-going mooring technicians.

Examples of outreach talks

Woodgate, R.A., 2009, Research at the Frozen Poles, invited lecture as part of the Ocean 500 graduate class, Oct 2009

Woodgate, R.A., 2009, Moorings in ice-covered waters, all for the want of an isolator, invited lecture as part of the EE 500 graduate class on ocean technology, Oct 2009

Woodgate, R.A, et al., 2009, What's New in the Bering Strait?, invited presentation for the ASOF (Arctic Sub-Arctic Ocean Fluxes) steering committee meeting. Brussels, Nov 2009.

Woodgate, R.A., 2009, Pacific Influences in the Western Arctic, invited presentation for the European DAMOCLES (Developing Arctic Modeling and Observational Capabilities for Long-term Environmental Studies) project, European IPY research, Brussels, Nov 2009.

Bering Strait contribution to Proshutinsky et al., 2010, Arctic Report Card, BAMS State of the Climate Report.

Woodgate, R.A., 2010, Arctic Influences of Bering Strait heat, talk in UW Polar Lunch series.

Woodgate, R.A., 2010, Getting into the Arctic Ocean – talk to new graduate students.

Woodgate, R.A., T.Weingartner and R.Lindsay, 2010, Changes and Impacts of the Pacific Inflow to the Arctic: 1990 – present, invited talk at IPY Conference in Oslo, June 2010.

5. Publications and Reports

5.1. Publications by Principal Investigators

Journal Publications

Woodgate, R. A., and K. Aagaard (2005), Revising the Bering Strait freshwater flux into the Arctic Ocean, *Geophys. Res. Lett.*, *32*, L02602, doi:10.1029/2004GL021747.
(September 2010 - Cited 61 times, Source: ISI Web of Knowledge)

Woodgate, R. A., K. Aagaard, and T. J. Weingartner (2005a), Monthly temperature, salinity, and transport variability of the Bering Strait throughflow, *Geophys. Res. Lett.*, *32*, L04601, doi:10.1029/2004GL021880.
(September 2010 - Cited 45 times, Source: ISI Web of Knowledge)

Woodgate, R. A., K. Aagaard, and T. J. Weingartner (2005b), A year in the physical oceanography of the Chukchi Sea: Moored measurements from autumn 1990-1991, *Deep-Sea Res., Part II*, *52*, 3116-3149, 10.1016/j.dsr2.2005.10.016.
(September 2010 - Cited 44 times, Source: ISI Web of Knowledge)

Woodgate, R. A., K. Aagaard, and T. J. Weingartner (2006), Interannual Changes in the Bering Strait Fluxes of Volume, Heat and Freshwater between 1991 and 2004, *Geophys. Res. Lett.*, *33*, L15609, doi:10.1029/2006GL026931.
(September 2010 - Cited 31 times, Source: ISI Web of Knowledge)

Aagaard, K., T. J. Weingarter, S. Danielson, R. A. Woodgate, G. C. Johnson, and T. Whitledge (2006), Some controls on flow and salinity in Bering Strait, *Geophys. Res. Lett.*, *33*, L19602, doi:10.1029/2006GL026612.
(September 2010 - Cited 8 times, Source: ISI Web of Knowledge)

Serreze, M. C., A. P. Barrett, A. G. Slater, R. A. Woodgate, K. Aagaard, R. B. Lammers, M. Steele, R. Moritz, M. Meredith, and C. M. Lee (2006), The large-scale freshwater cycle of the Arctic, *J. Geophys. Res.*, *111*, C11010, doi:10.1029/2005JC003424.
(September 2010 - Cited 61 times, Source: ISI Web of Knowledge)

White, D., et al. (2007), The Arctic Freshwater System: changes and impacts, *J. Geophys. Res.*, *112*, G04S54, doi:10.1029/2006JG000353.
(September 2010 - Cited 18 times, Source: ISI Web of Knowledge)

Woodgate, R. A., T. J. Weingartner, and R. W. Lindsay (2010b), The 2007 Bering Strait Oceanic Heat Flux and anomalous Arctic Sea-ice Retreat, *Geophys. Res. Lett.*, *37*, L01602, doi:10.1029/2009GL041621.
(September 2010 - Cited 61 times, Source: ISI Web of Knowledge)

Rawlings, M.A., et al, 2010, Analysis of the Arctic System for Freshwater Cycle Intensification: Observations and Expectations. accepted *Journal of Climate.*

Recent Books or Other One-time Publications

Woodgate, R. A. (2009), Bering Strait Mooring Cruise Report - RUSALCA 2009 Leg 1, Professor Khromov, 28 pp, University of Washington, available at http://psc.apl.washington.edu/BeringStrait.html.

Woodgate, R. A., S. Hartz, M. Kong, E. Ershova, V. Sergeeva, and K. Stafford (2010a), Mooring Cruise report for RUSALCA Khromov cruise to the Bering Strait – July/August 2010, University of Washington, Seattle, available at http://psc.apl.washington.edu/BeringStrait.html.

Bering Strait contribution to Proshutinsky et al., 2010, Arctic Report Card, BAMS State of the Climate Report.

Recent Conference Proceedings

Rawlings et al, 2009, Analysis of the Arctic System for Freshwater Cycle Intensification: Observations and Expectations. Abstract for AGU 2009

Woodgate, R.A, et al., 2009, What's New in the Bering Strait?, invited presentation for the ASOF (Arctic Sub-Arctic Ocean Fluxes) steering committee meeting. Brussels, Nov 2009.

Woodgate, R.A., 2009, Pacific Influences in the Western Arctic, invited presentation for the European DAMOCLES (Developing Arctic Modeling and Observational Capabilities for Long-term Environmental Studies) project, European IPY research, Brussels, Nov 2009.

Clement et al, 2010, On the flow through Bering Strait and its potential impact on sea ice in the Chukchi Sea, invited talk Ocean Sciences 2010

Woodgate, R.A., T.Weingartner and R.Lindsay, 2010, Changes and Impacts of the Pacific Inflow to the Arctic: 1990 – present, invited talk at IPY Conference in Oslo, June 2010.

Web/Internet Site URL(s):
http://psc.apl.washington.edu/BeringStrait.html – overview of Bering Strait activities, including links to data access and cruise reports

5.2. Other Relevant Publications

Bering Strait data and results are in demand for a large variety of research areas, as is evident from the large number of citations of our papers. It is impractical to include a list, but citation numbers for our main references as tracked by the ISI Web of Knowledge are given in the publication list above.

Voluntary registration at our data site shows the data is in demand for work ranging from climate modeling to King Crab fishing, including a wide variety of studies covering local, Arctic and global subjects (North Pacific, Gulf of Alaska, Bering Sea, Chukchi Sea, Arctic Ocean, Arctic Ocean outflows, North Atlantic), with topics including ocean circulation; multidisciplinary shelf-basin exchange; eddy processes; benthic-pelagic coupling; ocean sedimentation; hydrology; heat, freshwater and nitrogen budgets; biogeochemistry, including CDOM, POC, and PIC; modeling and observational studies of present-day, future and paleo conditions, including analysis of sediment cores; future climate predictions (including Arctic and Atlantic meridional overturning circulation investigations); present-day and paleo climate stability; recent studies of accelerated retreat of Arctic sea-ice; changes in the fate of Pacific water in the Arctic; and ecosystems and ecosystem change, including effects on algae, plankton, euphasiids, seabirds, grey and bowhead whales.

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