The Bering Sea/Bering Strait Relationship

From Stabeno, Schumacher & Ohtani, 1999

Alaskan Coastal Current (warm, fresh, seasonal)

Siberian Coastal Current (cold, fresh, seasonal)

Stagnation Zones over Herald and Hanna Shoals

By providing an exit, Bering Strait influences flow over the Bering Sea Shelf (although the deep Bering Sea Basin may not care)

Bering Strait and the Chukchi Sea

To first order, except for cooling - input from coastal polynyas,

Chukchi dominated by input through Bering Strait

Export to Arctic ~ Input through Bering Strait

Bering Strait dominates the Chukchi Sea

Woodgate et al., 2005, DSR and via http://psc.apl.washington.edu/HLD

The role of Pacific waters in the Arctic

Important for Marine Life
Pacific waters are the most nutrient-rich waters entering the Arctic (Walsh et al. 1989)

Primary Productivity \( gC \text{ m}^{-2} \text{ yr}^{-1} \)

Courtesy of (and adapted from) Codispoti, Stein, Macdonald, and others, 2005

Bering Strait good proxy of Arctic inflow
The role of Pacific waters in the Arctic

Implicated in the seasonal melt-back of ice
In summer, Pacific waters are a source of near-surface heat to the Arctic
(Paquette & Bourke, 1981; Ahlén & Garrison, 1984; Woodgate et al., 2006)

Important for Arctic Stratification
In winter, Pacific waters (fresher than Atlantic waters) form a cold (halocline) layer, which insulates the ice from the warm Atlantic water beneath
(Shimada et al., 2001; Steele et al., 2004)

The role of Pacific waters in the Arctic

Significant part of Arctic Freshwater Budget
Bering Strait throughflow
~ 1/3rd of Arctic Freshwater
(Wijffels et al., 1992; Aagaard & Carmack, 1989; Woodgate & Aagaard, 2005; Serreze et al., 2006)

Important for Marine Life
Pacific waters are the most nutrient-rich waters entering the Arctic
(Walsh et al., 1989)

The role of Pacific waters in the Arctic

Chlorophyll from SeaWiFS Satellite from NASA/Goddard Space Flight Center and Orbimage

Sea ice concentration from SSMI (IABP)

ARCTIC FRESHWATER FLUXES
Bering Strait ~ 2500 km$^3$/yr
(0.08 Sv)
Arctic Rivers ~ 3300 km$^3$/yr
P-E ~ 900 km$^3$/yr
Fram Strait water ~ 820 km$^3$/yr
Fram Strait ice ~ 2790 km$^3$/yr
Canadian Archipelago ~ 920 km$^3$/yr

Important for Arctic Stratification
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(Paquette & Bourke, 1981; Ahlén & Garrison, 1984; Woodgate et al., 2006)
Global role of Bering Strait

A Freshwater source for the Atlantic Ocean

Freshwater inhibits deep convection, slowing the Atlantic Ocean overturning circulation (see Wadley & Bigg, 2002; for a discussion)

Models suggest the Bering Strait throughflow also influences the deep western boundary currents & the Gulf stream separation (Huang & Schmidt, 1993)

Seasonal cycle in water properties (Woodgate et al, 2005)

Salinity
31.9 to 33 psu

Temperature
-1.8 to 2.3 deg C

Transport
0.4 to 1.2 Sv

(30 day means)

Why care?
Seasonally varying input to the Arctic Ocean
- temperature
- salinity
- volume
- equilibrium depth (~50m in summer ~120m in winter)
- nutrient loading

Bering Strait Basics

- annual mean flow ~0.8 Sv northwards, with an annual cycle of 0.3 to 1.3 Sv
- weekly flow reversals common (~2 Sv to +3 Sv)
- 1 hourly flow can be over 100 cm/s
- Alaskan Coastal Current (ACC) velocities can be 50-100 cm/s stronger than midchannel flow
- flow strongly rectilinear
- tides are weak (Roach et al, 1995; Woodgate et al, 2005)

- away from boundary currents, flow dominantly barotropic (Roach et al, 1995)
- flow in east and west channel highly correlated (0.95; Woodgate et al, 2005)

Paleo role of Bering Strait

Stabilizer for World Climate?
- if Bering Strait is open, excess freshwater in the Atlantic (from, for example, ice sheet collapse) can “vent” through the Bering Strait, allowing a speedy return to deep convection in the Atlantic.

Land Bridge for migration of mammals and people?

Note: in modern times, people have swum, driven and walked across!
What Drives the Bering Strait Throughflow?

**Velocity** = 
- "Pacific-Arctic Pressure Head" + "Wind Effects"

10° sea surface slope gives rise to pressure gradient between Pacific and Arctic Oceans (Coachman & Aagaard, 1966; Siggaard, 1984)

- across-strait atmospheric pressure gradient (Coachman & Aagaard, 1981)
  - local wind (Aagaard et al., 1985 and others)
  - set-up against topography (same ref.)

Wind explains ca. 60% of the variance and the seasonal cycle (Roach et al., 2005, DSR)

**But WHY?**
- freshwater transport from Atlantic by atmosphere?
- steric height difference?
- global winds? (Nof)

**ASSUMED constant**
- but why should it be?
(Woodgate et al, 2005, DSR)

In the mean, the winds oppose the pressure head forcing. Thus, in winter, when winds are strongest, the northward flow is weakest.

Estimating Heat Flux

2007 Bering Strait Heat is 5-6 x 10^{20} Jyr (20 TW)

- 2 x the 2001 Bering Strait heat
- could melt 2 x 10^8 km^2 (2 MSK) of 1m thick ice
- winter extent ~ 10 MSK
- 2006 Sept min ~ 6 MSK
- 2007 Sept min ~ 4 MSK
- ~ 4 W/m^2 over ½ the Arctic (ERA-40 2 to + 10 W/m^2; Simeone et al., 2007)
- greater than incoming solar into Chukchi ~ 3 to 4.5 x 10^{20} Jyr (data, B.Light)
- ~ 1/3rd of Fram Strait Heat ~30-50TW net, (Schauer et al., 2008)

- Errors ~ 0.1 Sv, 10^{20} J

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**Getting the 4-dimensional picture**

Bering Strait and Chukchi Sea 2003

**Convection line Fluorescence**

Chlorophyll from SeaWifs Satellite
from NASA/Goddard Space Flight Center & Orbimage

Sea surface temperature and altimeter satellite data too

**OUTFLOW FROM ARCTIC**
- PW (Polar Water)
- MAW (Modified Atlantic Water)
- KB (Knipovich Branch)
- DW (Deep Water)

**INFLOW TO ARCTIC**
- SVB (Svalbard Branch)
- YPB (Yermak Plateau Branch)
- KB+ (Knopovich Branch)
- MAW+ (Modified Atlantic Water)
- DW+ (Deep Water)

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Figure 2. Potential temperature distribution across Fram Strait from the CTD section taken in (a) 1997, (b) 1998, and (c) 1999 together with the instrumental coverage of the mooring period (a) 1997–1998, (b) 1998–1999, and (c) 1999–2000. Large triangles on top of the section mark the positions of measured velocity and temperature. Data note full record length data, triangles note partly synthesized data, crosses denote that all data were synthesized. For more explanation see section 2. CTD station positions are given above the section. Figure 2b shows the division into subsections for which the transport was calculated (see section 3). Schauer et al., 2002
Nordic Seas
(European VEINS project)

Fram Strait
- NORTHWARD
  West Spitsbergen Current
  - warm, salty
  - estimated 0-7 Sv (Rudels, 1989)
  - large barotropic component
  - lots of eddies
  - varies seasonally
  - T min in winter, Vol max in winter
    - splits into several branches
    - topographically steered
    - wind driven?
- SOUTHWARD
  East Greenland Current
  - significant velocity shear
  - lower kinetic energy
  - eddies more dominant than wind
  - NOT seasonal

NB East Greenland Current in Greenland Sea MUCH stronger (~ 20Sv), recirculating, wind driven, seasonal

FRAM STRAIT Transports in Sv for period 1997-2000

Atlantic Water?

Heat flux through Fram Strait
- based on moorings
Annual Mean ~ 25 - 50 TW
~ 8 to 16 x 10^20 J/yr

What does heat flux MEAN if there is a non zero mass flux?

Estimates?
Pathways?
Getting heat up?

Barents Sea facts
- strong modification
- important fisheries

Barents Sea Outflow
(Schauer et al, 2002, DSR)

Inflow from Greenland Sea ~ 2 Sv
Blindheim, 1989; Ingvaldsen et al., 2002
Outflow St Anna ~ 2 Sv (varies seasonally)
(1Sv summer, 3 Sv winter)
Loeng et al, 1993
Cooled and freshened from AW
Deep flow little seasonal variability, but interannual variability, esp in salinity?
Schauer et al, 2002 (and others)

Loeng & Drinkwater, 2007
### CAA and Nares Strait Challenges

**Measurements Issues:**
- Remote, ice-covered, small-scale variability, strong tides, strong winds, compass issues, simultaneous measurements

**Science Issues:**
- Friction (ice, tides)
- Hydraulic Control
- Pressure Head forcing Mediated by wind

~ 2 Sv, likely seasonal

**Lancaster Sound** ~ 68 km wide ~ 285 m deep ~ 0.7 Sv
  - (seasonal: 0.45 Sv winter, 1.05 Sv summer) ice-covered ~ 10 months
  - Ice bridges, very strong winds

**Nares Strait** ~ 38 km wide ~ 380 m deep ~ 0.85 Sv (SNAPSHOT)
  - Ice bridges, very strong winds
  - Ice-covered, strong tides

**Cardigan Strait and Hell Gate** ~ 12 km wide ~ 180 m deep ~ 0.3 Sv
  - Very variable, seasonal not clear, VERY strong (2 m/s) tides

~ 2 Sv, likely seasonal

**Davis Strait** ~ 360 km wide ~ 1000 m deep ~ 25 Sv NET
  - also northward inflow from Atlantic (~ 25 Sv northward, 45 Sv southward)

### Arctic Precipitation & Precipitation-Evapotranspiration (P-ET)

- Arctic ~ 12-36 cm/year
- Much ~ desert (~ < 25 cm/yr)
- Seattle ~ 38 cm/year

**Arctic Freshwater revised (km³/yr)**

Serreze et al, JGR, 2006

<table>
<thead>
<tr>
<th>INFLOW</th>
<th>OUTFLOW</th>
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<tbody>
<tr>
<td>- Rivers 38%</td>
<td>- CAA 35%</td>
</tr>
<tr>
<td>- Bering Strait 30%</td>
<td>- Fram St water 26%</td>
</tr>
<tr>
<td>- P-E 24%</td>
<td>- Fram St ice 25%</td>
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All relative to mean Arctic salinity of 34.8 pS