On the Role of Advection on the Interaction between Arctic and Subarctic Seas: Comparing the Atlantic and Pacific Sectors

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Advection between the Arctic and Subarctic

- **Inflow**: Bering Strait and CAA flows are mostly one way and shallow.
- **Outflow**: Fram Strait and Barents Sea are two-way and deep.

Note: Bering Strait and CAA flows are mostly one way and shallow while Fram Strait and Barents Sea are two-way and deep.
Bering Strait Inflow

Western Arctic Shelf
Chukchi & Bering Sea

3 major inflows from the North Pacific

- **Anadyr Water**: Cold, Saline, Nutrient rich
- **Bering Shelf Water**: Cold, saline
- **Alaska Coastal Water**: Warm, less saline

Seasonally ice covered
- Oct–Jun (Chukchi Sea)
- Nov–May (Bering Sea)

Advection of Warm Water

Bering and Chukchi Seas
SST 26 August 2004, Woodgate et al., 2005
...but not in winter.

Barents Sea
SST 15 August 2007, Våge et al., 2011
...warm water comes in year around.
Inflow Bering Strait: Warm waters, near Surface

Inflow Fram Strait: Warm, High Saline waters, intermediate depths (200 m)
Summer (JAS) observed height of freshwater relative to salinity of 35.

1992-1999

2006-2008

Increase in recent years due to increased ice melt, river runoff and inflow through Bering Strait.

Source of FW through Bering Strait and from Russian rivers and little from Atlantic.

Rabe et al., DSRII, 2011
Woodgate et al., GRL, 2012
Freshwater Outflows

Fram Strait: 160 mSv

Canadian Archipelago: 82 mSv

Dickson et al., 2008
Freshwater from Arctic has been traced from the Arctic through the Canadian Archipelago into the NW Atlantic where it has affected zooplankton distributions.

Greene et al., Ecology, 2008
Advected Effect on Recent Sea-Ice Decline

Decreasing Arctic sea ice attributed to heat advected through Bering Strait (Woodgate et al., 2010).

Atlantic heat input not as effective in melting sea ice due to being mainly subsurface.

(Perovich & Ritcher-Menge, 2009)
Ice advection out of the Arctic

Little to no ice transported out through Bering Strait.

Mean annual sea ice area flux averaged for the period 1979-2006 (10^3 km²)

Annual ice-associated biomass export from the Arctic Ocean:
Fram Strait: $922 \times 10^3$ t wet weight ($106 \times 10^3$ t C)
Barents Sea: $99 \times 10^3$ t wet weight ($12 \times 10^3$ t C)

Fronts Move in Response to Advection

Modelled currents and Polar Front (thick black line) in the Barents Sea. Such movements have also been observed in response to variability of Atlantic inflow.  

Huse & Ellingsen, 2008
The front separating Atlantic and Pacific waters shifted from Lomonosov Ridge to the Mendeleyev-Alpha Ridge in mid-1990s due to greater advection of Atlantic Water into the Arctic.

Morison et al. 2000
Carbon Budget: Nordic Seas

Adveective C fluxes are 2 orders of magnitude larger than the CO$_2$ uptake from the atmosphere. Small changes in advective fluxes can have a big effect on the carbon budget within the Nordic Seas.

Jeansson et al., 2011, GCB
Advection and zooplankton biomass

North of Iceland

$y = 0.0773x + 0.4691$
$R^2 = 0.2359$
$p<0.01$

From Astthorsson et al., 2007

Increased Atlantic Water input ➔ Elevated PP ➔ Elevated Zooplankton Biomass

Greater influx of zooplankton

Higher growth rates at warmer temperatures
Simulated annual production of the Atlantic species *C. finmarchicus* (g C m$^{-2}$) in the Arctic Ocean under different climate change scenarios. Note that it is advected into the Arctic but does not survive (negative production).

Slagstad et al., 2011
The high benthic biomass (>300 g m\(^{-2}\)) and chlorophyll (>150 mg m\(^{-2}\)) on both the southern and northern Chukchi shelf are known as depositional centers for reduced organic matter that originates on the Bering Sea shelf and is advected northward in Anadyr and Bering shelf water masses.

Dunton et al., DSRII, 2005
Off West Svalbard, comparison of benthos prior to the 1930s with those of the 1950s indicated that Atlantic species spread northward by approximately 500 km under increased Atlantic flows.

Blacker, 1957
In the 1920s cod larvae drifted from Iceland to West Greenland and there was good survival once there.

Increased abundance of cod through to the 1960s resulted in the development of a cod fishery that dominated the Greenland economy.
Hotspot for Predators Foraging on Krill

Shearwaters feeding with ~ 100 humpback whales in Unimak Pass.

Photo: Mike Brittain
Source of the Euphausiids?

Modified from Ladd et al., 2005 Fish. Oceanogr.
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Conclusions

• Advection plays an important role in the interaction of Arctic and Subarctic Seas, both in terms of physical properties and the ecology.
• Ecological effects are both direct and indirect
• Effects range from carbon to marine mammals and seabirds
Thank you for your Attention!
Larval Drift

Wilderbuer et al., 2002

Bering Sea

NEA Cod

Vikebø et al., 2011

Flatfish

Good Recruitment

1980-89

1990-97

Poor Recruitment

2009

2010
Polynyas Forced by Wind-induced Advection

Many of these areas are also regions of increased tidal mixing (Hannah et al., 2009). These polynyas are regions of high biological production.
Still....

Thanks for your attention.
Biogeographic boundaries for zoobenthos in the Barents Sea in 20th century: I – maximal western penetration of Arctic species in cold periods; II – line of 50% average relation between boreal and arctic species; III – maximal eastern penetration of boreal species in warm periods; IV – transitional zone.

Loeng et al., 2005, ACIA Zoobenthos Results related to penetration of Atlantic waters.
Atlantic cod moved northward by 1500 km in response to warming.

Based on Hansen, 1940
Effects of Advection

In this talk I will provide some examples of advective effects from both the Pacific and Atlantic.

Indirect effects of advection through:
- Water mass properties (heat, freshwater)
- Nutrients
- Sea ice
- Turbulence

Direct effects of advection on
- Plankton (Phytoplankton, Zooplankton, Benthos)
- Fish Larvae
Riverine Input to the Arctic Ocean

Major input from the Siberian Rivers.
Influence of advection on zooplankton community composition

- Chukchi Sea zooplankton is dominated by Bering Sea fauna during summer

- Pacific species are generally confined to shelves, but the larger more oceanic members have been observed as distant as the northern boundary of the Canada Basin

Observed (black) & niche-modeled probabilities (fills) of encountering Pacific species: Rutzen & Hopcroft, unpublished