Summertime Circulation and Water Mass Transformation in the Eastern Chukchi Sea

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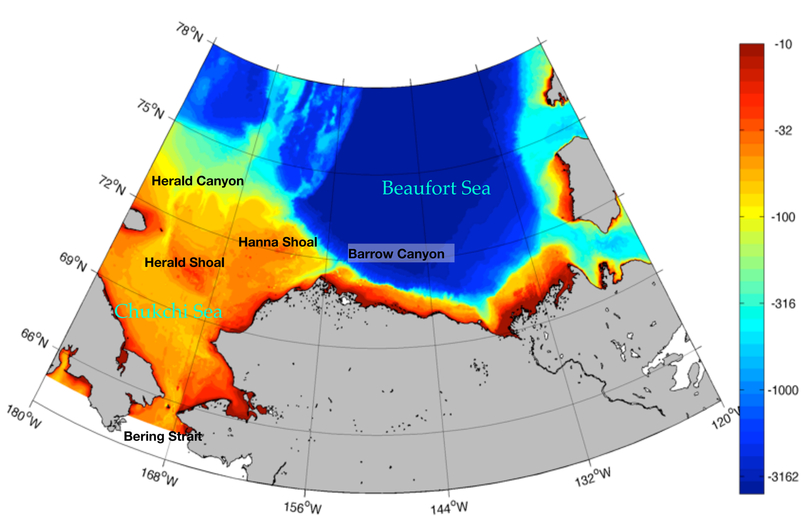
Mean Flow Structure & Transport of the Alaska Coastal Current

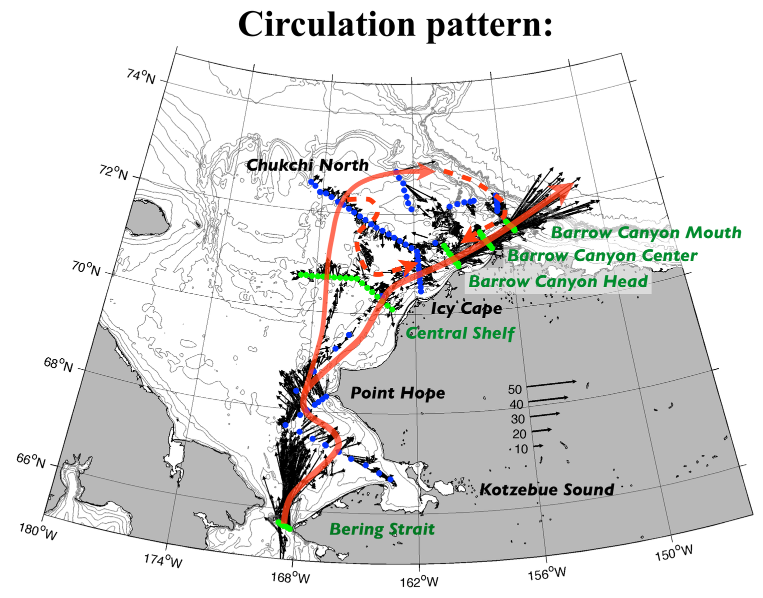
Background: Pacific water entering the Arctic Ocean through Bering Strait is transported across the shallow and expansive Chukchi Sea through one of three major transport pathways. Two of the pathways are in the Eastern Chukchi Sea: one is steered by the Central Channel through Herald Shoal and Hanna Shoal, and the other is the Alaska Coastal Current (ACC) which flows into Barrow Canyon (Coachman 1975, Weingartner et al. 2005). Despite previous observational efforts, the mean summertime hydrographic and current structure of the ACC in the eastern Chukchi Sea has not been fully characterized. This study uses shipboard CTD and ADCP survey data collected over the past decade to quantify the mean state of the ACC by focusing on five key sections: Bering Strait, Central Shelf, Barrow Canyon Head, Barrow Canyon Center (also known as the DBO line), and Barrow Canyon Mouth. The left side of the poster characterizes the mean condition in the mid- to late-summer period. The right side of the poster presents a comparison between an early-summer survey conducted during the ICESCAPE program and data from the mid-summer period.

Chukchi Sea:



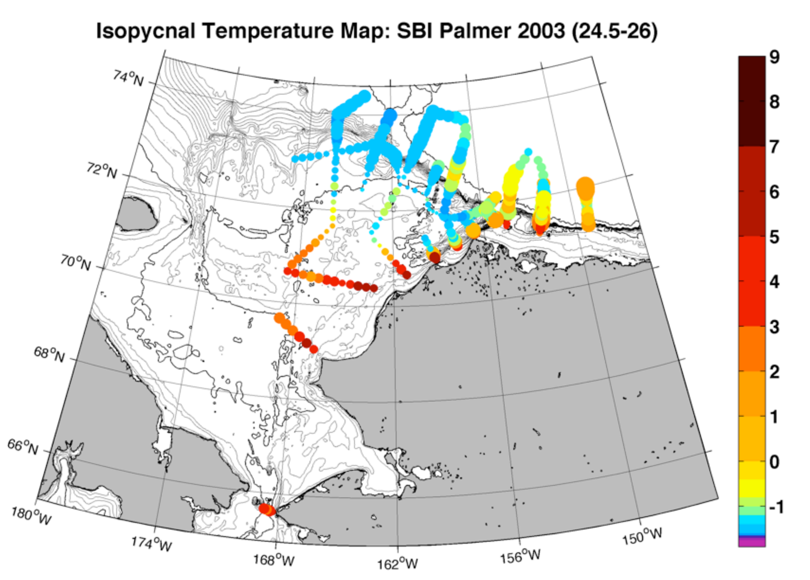
The Chukchi Sea has a mean depth of 50 m and an along flow distance scale of 1000 km. Two major canyons cut into the shelf: Herald Canyon to the west and Barrow Canyon to the east. They are separated by Herald and Hanna Shoals in the middle. In between the two shoals is a topographic depression called Central Channel.

Circulation pattern:



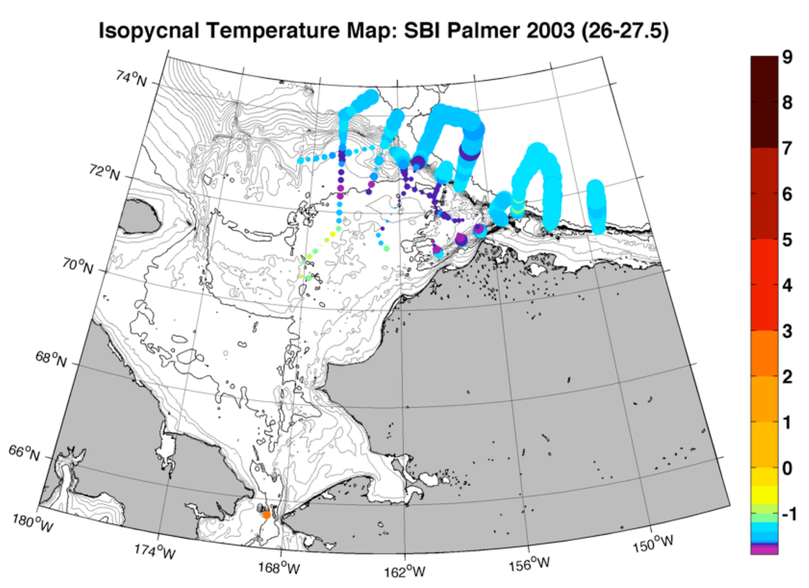
- ✧ The northward flow from Bering Strait separates at Point Hope into the Central Channel branch and the ACC.
- ✧ Flow from the Central branch progresses around both sides of Hanna Shoal into the head of Barrow Canyon.
- ✧ The outflow from Barrow Canyon forms part of the Beaufort shelfbreak jet at BCM.

Distribution of light summer water masses:



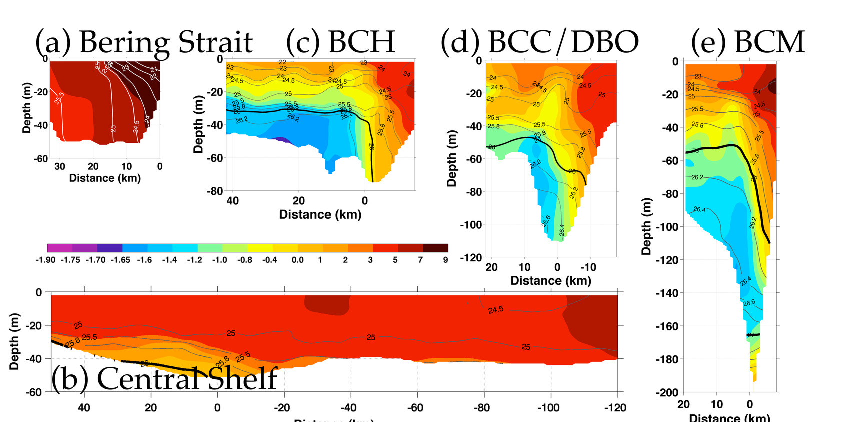
Warm and fresh surface water originating from the Pacific (T > 0 C) permeates the southern Chukchi Sea by mid-summer. The warmest and freshest water is the Alaska Coastal Water (ACW) transported by the ACC, which exits Barrow Canyon into the Beaufort Sea. At mid-summer winter remnant water and ice-melt water (T < -1 C) still fills the northern portion of the Chukchi Sea. The shelf and shelfbreak region west of Barrow Canyon remains significantly cooler than the shelf and shelfbreak region east of Barrow Canyon.

Distribution of dense winter water masses:



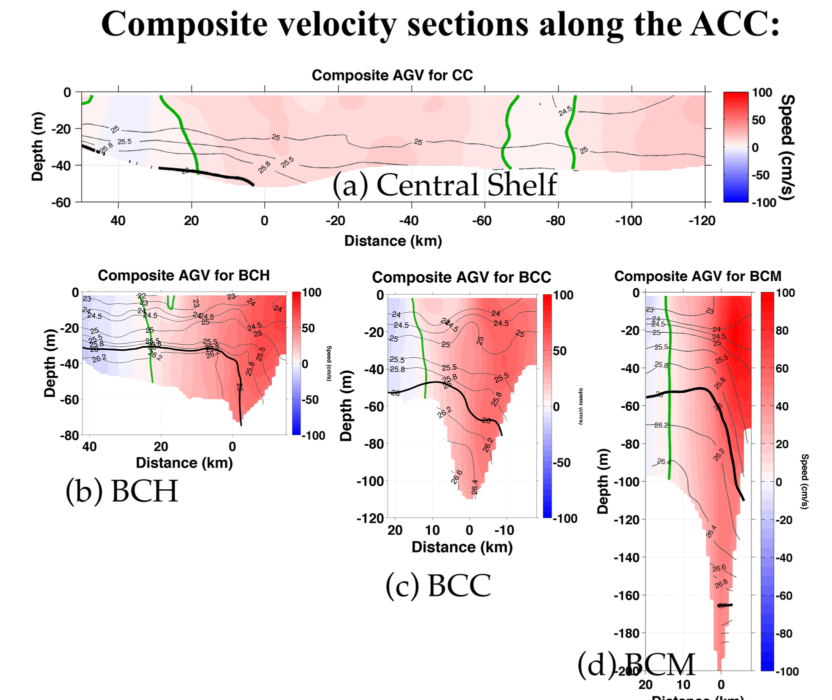
Cold and saltier water resides at depth in the northern Chukchi Sea in mid-summer. The coldest of which (T < -1.6 C) is the newly ventilated Pacific winter water (NVWW). As the summer progresses, the dense winter water advects northward and is replaced by the warm Pacific water inflow through Bering Strait. The last vestiges of winter water flows along the slower Central Channel pathway around Hanna Shoal. This water drains through Barrow Canyon and is dense enough to ventilate the upper halocline of the western Arctic basin.

Composite temperature sections along the ACC:



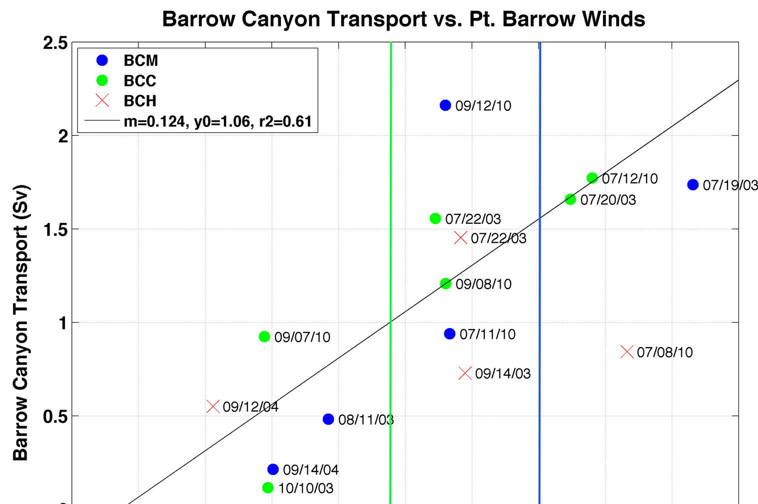
- ✧ **Bering Strait**: Highest ACW temperature (T > 7 C), strongly stratified ACW core to the east, weakly stratified to the west.
- ✧ **Central Shelf**: Weakly stratified water column throughout the section (note: the near coastal segment is missing). Remnant signature of colder winter water is seen in Central Channel to the west.
- ✧ **Barrow Canyon Head**: Winter water is still present on the western side of the canyon. ACW is confined to the eastern portion of the canyon with relatively weak stratification.
- ✧ **Barrow Canyon Center**: Dense winter remnant water sinks and ACC is still present on the eastern side of the canyon. There is evidence of upwelling near the canyon axis at depths of 20-40 m, where the isotherms are.
- ✧ **Barrow Canyon Mouth**: Winter water layer sinks further, stretches, and moves laterally towards the eastern canyon wall.

Composite velocity sections along the ACC:



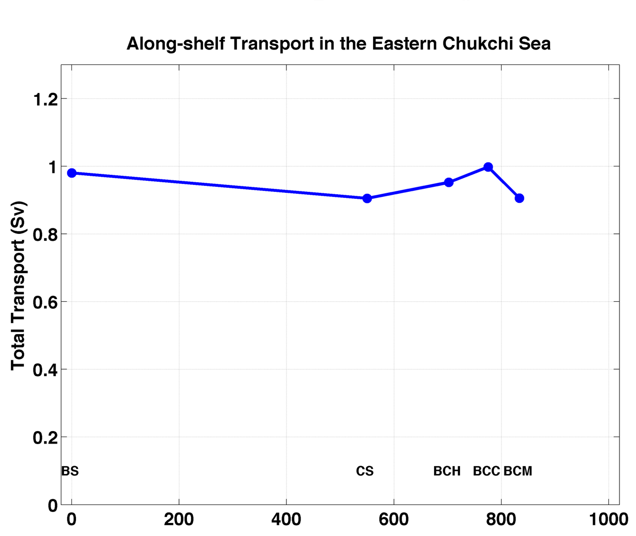
The ACC extends to the bottom and is weakly baroclinic. Green lines delineate the region of northward flow of 5 cm/s or higher. The velocity and hydrographic sections indicate that the ACC simultaneously transports both warm and fresh summer ACW water as well as cold and salty Pacific winter water. The ACC thus ventilates both the surface water in the Beaufort Sea as well as the upper halocline during the summer.

Effect of winds on Barrow Canyon transport:



- ✧ Transport in Barrow Canyon is significantly correlated with the along canyon winds ($R^2 = 0.61$).
- ✧ Southerly wind enhances poleward flow while northerly winds impedes the flow.
- ✧ The linear relationship can be used to remove the effect of along-canyon wind forcing from the transport measurements for individual sections at BCC and BCM.

De-winded transport along the ACC:



- ✧ The poleward transport along each composite section from Bering Strait to the mouth of Barrow Canyon is calculated from the absolute geostrophic sections referenced using shipboard ADCP.
- ✧ The summertime Bering Strait transport is estimated from published figures by Woodgate et al. (2006).
- ✧ The mean along canyon wind speed is calculated for BCC and BCM and the transport values are then de-winded using the linear relationship on the left.
- ✧ Remarkably, the average poleward transport across each sections north of Bering Strait are the same within +/- 10%. This implies that most of the transport flowing through the eastern side of Bering Strait eventually ends at up Barrow Canyon.

References:

Coachman, L. K., Aagaard, K., and Tripp, R. B. Bering Strait: The Regional Physical Oceanography. University of Washington Press, 1975.

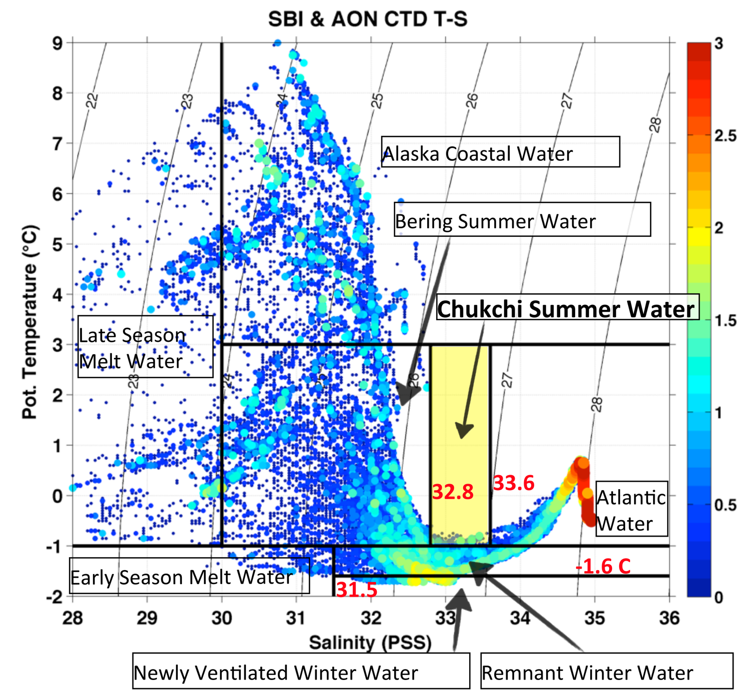
Weingartner, T., K. Aagaard, R. Woodgate, S. Danielson, Y. Sasaki, D. Cavalieri (2005), Circulation on the north central Chukchi Sea shelf, *Deep Sea Research Part II: Topical Studies in Oceanography*, 52, Issues 24–26, ISSN 0967-0645

Woodgate, R. A., Aagaard, K., Weingartner, T. J. (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

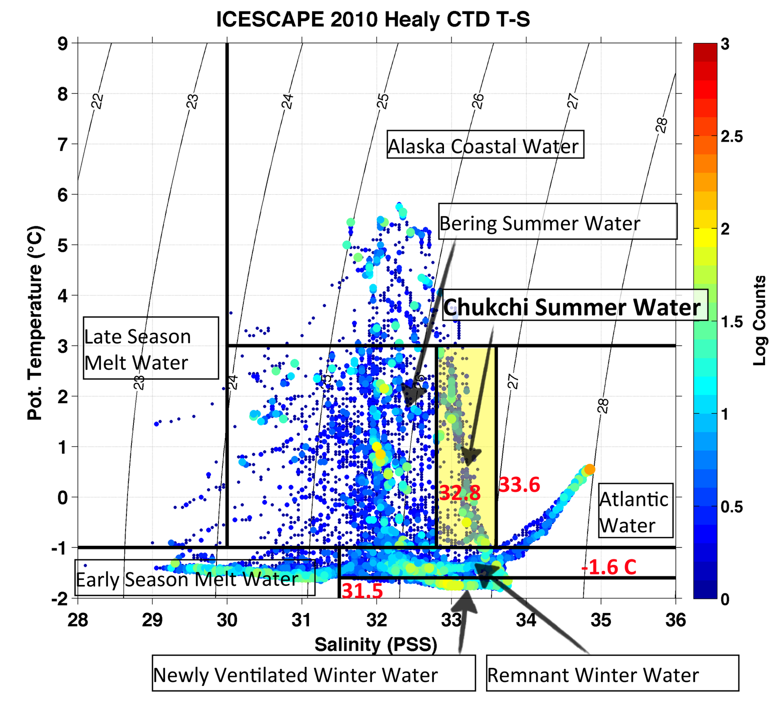
Formation of the Chukchi Summer Water (CSW)

We compare hydrographic observations inthe eastern Chukchi Sea between the typical mid- to late-summer state (characterized on the left side of the poster) with the early-summer ICESCAPE survey conducted in June-July 2010. During ICESCAPE, there was considerable amount of sea ice present, unlike the completely ice-free condition of late summer. A previously unobserved water mass was found on the shelf during ICESCAPE. Below we describe this "Chukchi Summer Water" (CSW) and present a possible formation mechanism.

T-S late summer (composite):



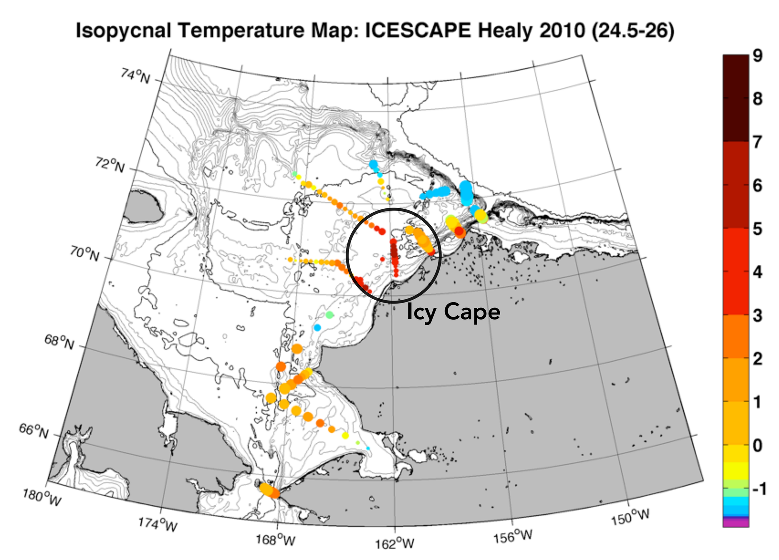
T-S early summer (2010):



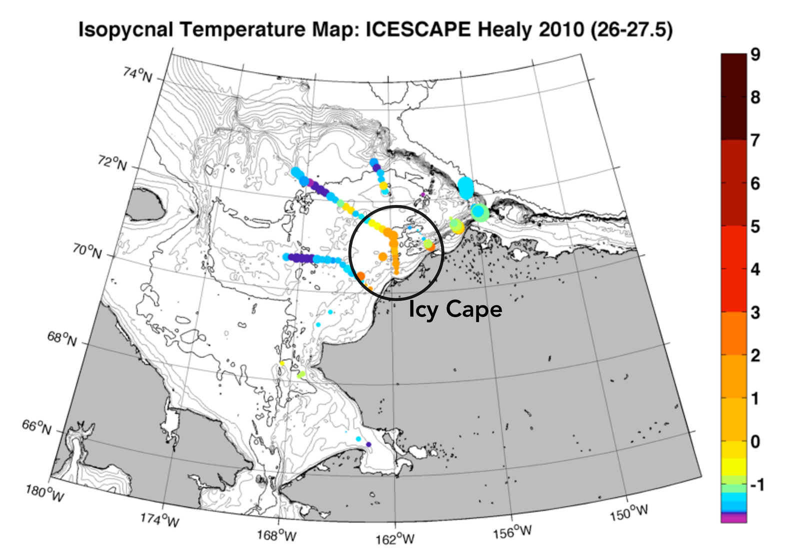
- ✧ Temperature-Salinity (T-S) plot from several mid- to late-summer surveys in the Chukchi and Beaufort Sea spanning multiple years is shown in the top left panel above. The water masses present are ACW, Bering Summer Water (BSW), Winter Water (WW), Atlantic Water (AW), and ice melt water.
- ✧ In comparison, the T-S plot for the ICESCAPE early-summer survey is shown in the top right panel. Note the presence of the previously unobserved water mass, which we call Chukchi Summer Water. The CSW is significantly saltier and denser than the typical summer water that came through Bering Strait.

Location & Origin of the Chukchi Summer Water:

Distribution of light summer water masses (2010):

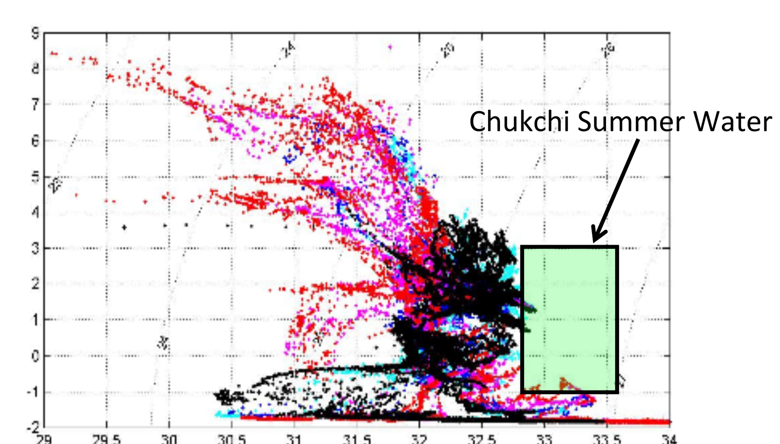


Distribution of dense winter water masses (2010):



The CSW was only observed in the region between Icy Cape and Barrow Canyon Head (right panel above). It is surrounded by cold winter water on all sides. The water immediately above it is also warmer than the surrounding surface water (left panel above).

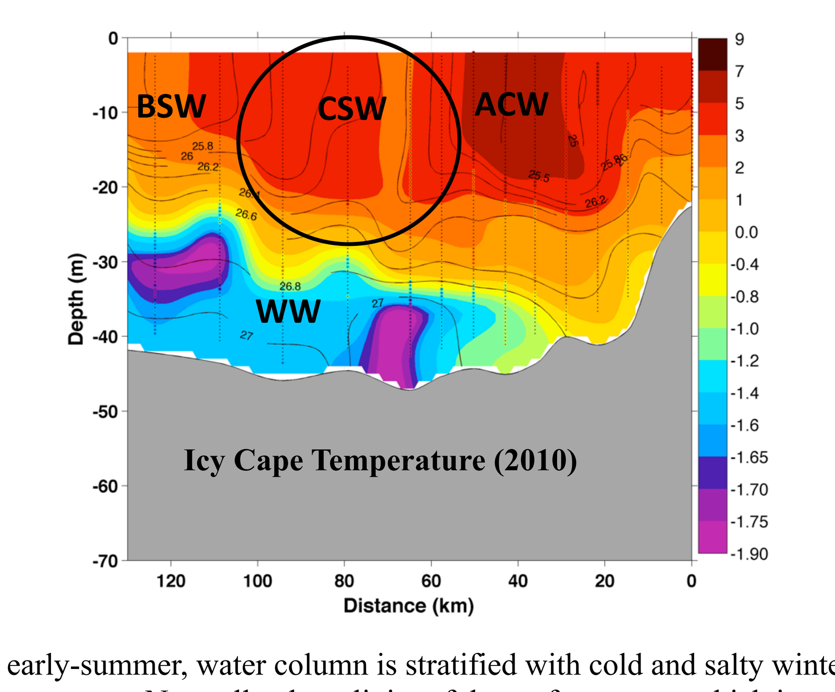
T-S at Bering Strait (2009-2010): Not a remote origin for CSW

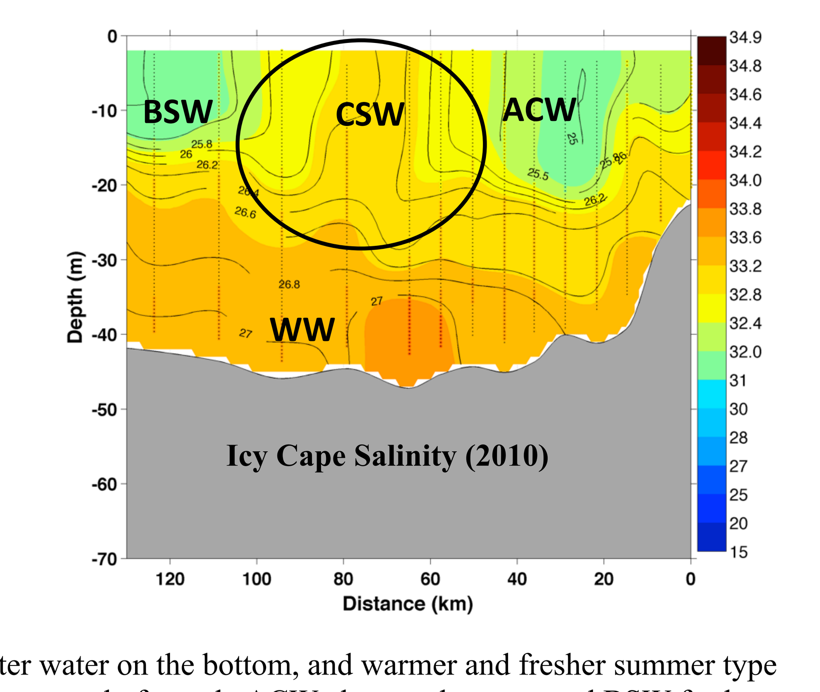


T-S measurements at the Bering Strait moorings (per. comm. Woodgate) indicate that no water with properties similar to CSW flowed through Bering Strait in 2010 (left panel). However downstream measurement at the AON mooring located on the Beaufort shelfbreak showed evidence of CSW. All of this suggest that the CSW formed locally in the eastern Chukchi Sea.

Left figure: Bering Strait 09-10 Preliminary Seacat r=A4,m=A4w,b=A2,c=A2W,r=A3

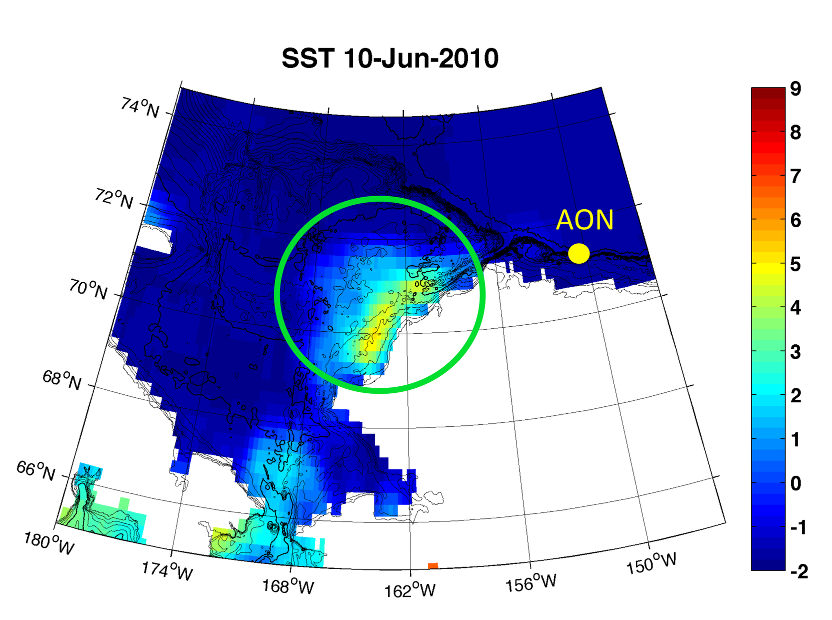
Local formation of Chukchi Summer Water:

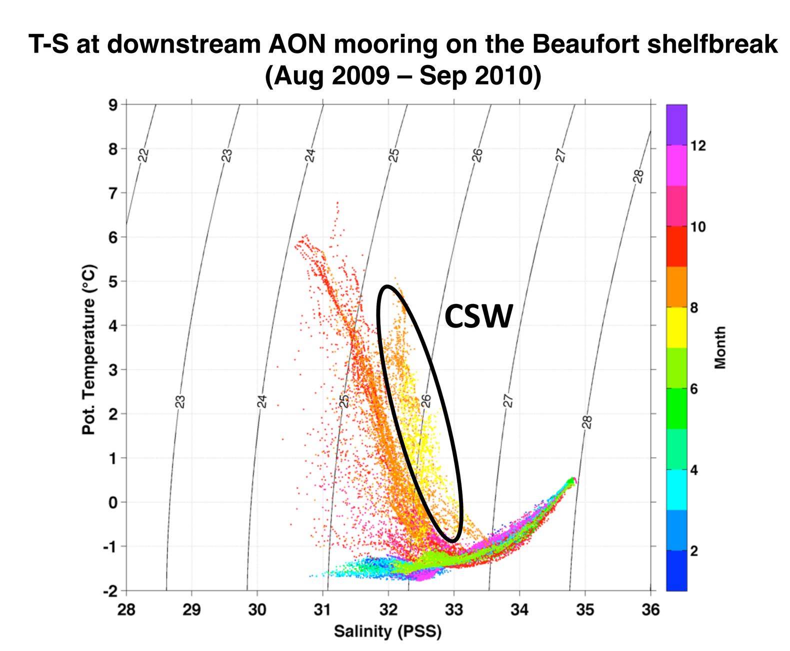




In early-summer, water column is stratified with cold and salty winter water on the bottom, and warmer and fresher summer type water on top. Normally, the salinity of the surface water, which is composed of mostly ACW close to the coast and BSW further offshore, is less than 32.5 PSU. However for early-summer 2010, saltier water with salinity of 33 PSU and density of 26.2 kg/m^3 was observed in the surface layer. Water this salty and dense is typical of winter water, not summer water. We hypothesize that the late ice melt back in 2010, combined with strong solar isolation in late June, resulted in rapid warming of the water column filled with salty winter led to the formation of the warm and salty CSW.

Formation Mechanism and fate of Chukchi Summer Water





SST observations (left panel) of the Chukchi Sea in June 2010 and T-S observation at the AON mooring (right panel, color coded by month) is shown. The SST and ice coverage map (not shown) clearly indicate the development of a late season polynya off the coast of Icy Cape. Note that while SST indicate that the polynya has warmed to temperature above 2 C, it is surrounded by cold water and the warm water off Icy Cape is not connected to the warmer water to the south. Concurrent mooring observations downstream shows CSW like water flowing through a month later in July (right panel).

Implication: The CSW has the proper density to ventilate the upper halocline in the western Arctic basin even though it is significantly warmer than the typical halocline water masses. Depending on how frequent the early summer 2010 condition occur, CSW may exert a long term influence on the upper ocean heat budget of the western Arctic.