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SEA ICE CONDITIONS

IN THE

CHUKCHI AND BEAUFORT SEAS

Prepared by Andrew R. Mahoney
for The Pew Charitable Trusts

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OVERVIEW

The Chukchi and Beaufort seas lie north of Alaska and together contain the entire U.S. Arctic domain. Nominally, the two seas are separated by Point Barrow, the northernmost point of the North American mainland. Away from the coast, the boundary between the Chukchi and Beaufort seas is typically defined by the regional bathymetry (Figure 1). The Chukchi Sea is dominated by a broad, shallow shelf (the Chukchi Shelf) mostly less than 50 meters (160 feet) deep with shoals such as Hanna Shoal and Herald Shoal rising to around 20 m. Conversely, water shallower than 50 m in the Beaufort Sea occupies only a narrow strip less than 100 km from the coast. Most of the Beaufort Sea is greater than 1,000 m deep and is part of the Canada Basin. Figure 1 illustrates other geographic differences between the Chukchi and Beaufort seas, such as latitude and coastal confinement. These factors, along with the Chukchi's connection to the Pacific Ocean, play a large role in defining the sea ice conditions in the two seas and how they might respond to ongoing changes in the Arctic climate.

SEA ICE EXTENT AND AGE

One of the more obvious differences between the Chukchi and Beaufort seas is that the Chukchi Sea lies farther south overall. Also, the Chukchi Sea is connected to the Pacific Ocean via the Bering Strait, through which there is a net northward transport of heat that enhances the early loss of ice (Woodgate et al., 2010). As a result, the Chukchi Sea experiences a later onset of freezeup in winter and an earlier retreat of sea ice in spring. In contrast, circulation in the Beaufort Sea is dominated by the clockwise motion of the Beaufort Gyre (Figure 1), which transports into the Beaufort Sea some of the oldest and thickest ice in the Arctic from the region north of the Canadian Archipelago. One consequence of these differences is that the Beaufort Sea retains a significant perennial ice cover, whereas sea ice in the Chukchi Sea is, in general, newly grown each year. Figure 2 shows the mean sea ice extent in the Pacific sector of the Arctic by month as it advances and retreats each year. In this figure, ice extent is defined as the region covered sea ice with a concentration ≥ 15 percent. It is therefore important to note that sea ice can be encountered outside this region, though in low concentrations.[1]

This region of the Arctic has seen some of the most dramatic changes in sea ice extent, thickness and age in recent years.

Figure 3a shows the mean distribution and age of sea ice in the Chukchi and Beaufort seas. These data derived using passive microwave satellite imagery to track regions of sea ice every day during the period 1985-2011 (Maslanik et al., 2007). These data clearly show the differences in the age of sea ice in the two seas. The Chukchi Sea is dominated by ice less than 1 year old (first year or FY ice), whereas the Beaufort Sea contains significant concentrations of multiyear (MY) ice. As a result of its greater age, MY sea ice is generally thicker and stronger than FY ice. It therefore represents a greater obstacle and hazard to offshore operations.

In comparing the two seas, it is important to note that this region of the Arctic has seen some of the most dramatic changes in sea ice extent, thickness and age in recent years (Maslanik et al., 2007; Kwok and Cunningham, 2010). Figure 3b shows the mean ice age calculated using only the period 2005-2010. Comparing Figures 3a and 3b demonstrates that the Beaufort Sea has lost a significant portion of its MY sea ice in recent years and is likely to become dominated by FY ice, like the Chukchi Sea. Due to its greater thickness, MY sea ice is generally more resilient against summer melt and therefore acts as a buffer against rapid change. The loss of MY sea ice may therefore tend to accelerate further ice loss (Kwok, 2007; Comiso et al., 2008). Recent climate modeling studies predict that the Arctic could be free or nearly free of sea ice in summer within the next few decades (Holland et al., 2006; Eisenman and Wettlaufer, 2009; Wang and Overland, 2009; Overland and Wang, 2010).

ICE MOBILITY AND LEAD PATTERNS

As stated above, sea ice motion in the Beaufort Sea is dominated by the clockwise rotation of the Beaufort Gyre. This motion is driven by atmospheric circulation around a persistent region of high pressure (the Beaufort High). The strength of the Beaufort Gyre can vary from year to year and the ice motion can sometimes reverse for periods of a few days. However, in winter the average drift is approximately parallel to the coastline.[2] Surface winds in the Chukchi Sea are more variable and, due to the configuration of the coastline, whichever direction the sea ice drifts, it moves toward or away from some section of coast. This means that open water is almost always being created in the Chukchi Sea, even in winter. This open water is created in leads, which are linear openings in the ice formed either between floes or at the coast. Figure 4 shows some examples of "flaw leads," which commonly form along the northern Alaska Chukchi coast under the prevailing northeasterly winds.

Sea ice in the Chukchi Sea is more mobile than that in the Beaufort Sea.

The combination of prevalent open water and an almost exclusively FY ice pack makes the sea ice in the Chukchi Sea more mobile than that in the Beaufort Sea. As a result, winter lead patterns in the Chukchi Sea are characterized by numerous intersecting openings that change rapidly, whereas the Beaufort Sea generally has fewer, more isolated leads (see Figure 4).

Islands and grounded ice also affect lead distributions which further differentiate the two seas. At some point during the winter, deep-keeled ice ridges commonly become grounded on Hannah and Herald shoals (see Figure 1). These create polynyas or openings on the leeward side of the shoals with respect to the ice drift. These polynyas are shown Figure 4, where their effect on lead patterns is also evident.

LANDFAST SEA ICE

Landfast ice is the stationary apron of sea ice that remains attached to the coast. Its seaward edge is sometimes marked by open water, such as the coastal flaw leads shown in Figure 4. However, there is often no water between landfast ice and drifting pack ice, as is the case in much of the Beaufort Sea in Figure 4. As a stable extension of the land, landfast sea ice is a critical habitat for ringed seals and polar bears for denning and access to prey (Laidre et al., 2008). In addition, landfast ice is used as a hunting and traveling platform by Arctic coastal communities (George et al., 2004; Gearheard et al., 2006; Krupnik, 2010) for whom it also mitigates coastal erosion by protecting the shore from waves (Lantuit and Pollard, 2008). In the Beaufort Sea, landfast sea ice is used to construct ice roads for access to drilling platforms (Potter et al., 1981; Masterson, 2009).

In the Chukchi and Beaufort seas, landfast sea ice is a seasonal phenomenon, advancing from the coast incrementally over winter and retreating rapidly at the end of spring. The horizontal extent of landfast ice is closely related to bathymetry. Mahoney et al. (2007) found that the modal water depth at the seaward edge of landfast sea ice in the Beaufort and northern Chukchi seas was between 16 m and 22 m. The 20 m isobath (shown in red in Figure 1) is therefore a reasonable approximation of the average stable extent of landfast ice. However, when atmospheric and oceanic conditions permit, landfast sea ice can extend into much deeper waters for short periods. Figure 5 shows the spatial and temporal variability of landfast sea ice in Alaska, derived from a 10-month satellite imagery sequence.

The Beaufort Sea has more landfast ice cover than does the Chukchi Sea.

Landfast ice forms first in lagoons and sheltered embayments. To extend into deeper water and remain stable, the ice must be anchored by grounded ridges, which partly explains the relationship between extent and bathymetry. The availability of such ridges limits the timing of stabilization as ridges formed from thin, young ice tend to have shallower keels than ridges created from thicker ice later in the season. The loss of MY ice from the Arctic (Maslanik et al., 2007) may partly explain the later formation and earlier break-up of landfast ice in northern Alaska (Mahoney et al., 2007).

Figure 5 shows that the Beaufort Sea has a much more extensive landfast ice cover than the Chukchi Sea. This is partly because the 20 m isobath is further offshore (see Figure 1), but may also be related to the larger number of deep-keeled ridges formed in the zone of intense deformation between the Beaufort Gyre and the coast. In addition to anchoring landfast ice, grounded ridges can create gouges in the seafloor; these ridges represent a significant hazard to seafloor infrastructure in the Arctic. It is not clear how the seafloor gouging regime may change with the ongoing retreat and thinning of the Arctic sea ice cover.

SUMMARY

Differences in geographic setting and bathymetry between the Chukchi and Beaufort seas lead to marked differences in the character of sea ice in these two regions. Due to its more southerly location and connection to the Pacific Ocean, the Chukchi Sea experiences a longer open water season than the Beaufort. In addition, due to the combination of a thinner ice pack and a coastline that offers the opportunity for open water creation under almost any drift direction, sea ice in the Chukchi Sea is more mobile and changeable than sea ice in the Beaufort. This is also reflected in the greater extent of landfast sea ice in the Beaufort Sea.

The differences between the two seas are important considerations for offshore activities.

These differences represent important considerations for offshore activities in the U.S. Arctic domain. In particular, operational experience gained in one sea may not be directly applicable to the other. It is also important to recognize that the extent of our understanding of the sea ice environment for the Chukchi is different from the Beaufort. This is partly because there is a shorter history of commercial interest in the Chukchi Sea than the Beaufort Sea and therefore fewer baseline sea ice data are available. This is demonstrated in Figure 5, which only covers the northern portion of the Alaskan Chukchi coast.3 In addition, the Pacific sector of the Arctic is undergoing some of the most rapid environmental changes on Earth, which reduce the value of data from previous decades for planning and design purposes. However, Arctic stakeholders, including academics, industry executives, state and federal regulators, and local communities are rising to the challenge, and there is currently an unprecedented number of active observing programs in the region (e.g.: www.ims.uaf.edu/hfradar/locations/ and www.sizonet.org).

ENDNOTES

[1] Although navigable, low concentration sea ice can still be hazardous, in part because it can be difficult to detect.

[2] In recent years, there has been a strong poleward component to summertime ice drift in the Beaufort Sea, moving ice away from the coast (Hutchings and Rigor, submitted 2011).

[3] The author is currently involved in an ongoing effort to characterize landfast sea ice and lead patterns throughout the Chukchi Sea (http://boemre-new.gina.alaska.edu), but the results are not yet published.

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FIGURES

Figure 1: Chukchi and Beaufort Seas Bathymetry

The bathymetry of the Chukchi and Beaufort seas, showing the location of lease areas (in yellow) for oil and gas development (bathymetry data from Danielson, 2008). The red contour indicates the location of the 20 m isobath. Colored arrows indicate predominant current directions (from Weingartner, 2005).

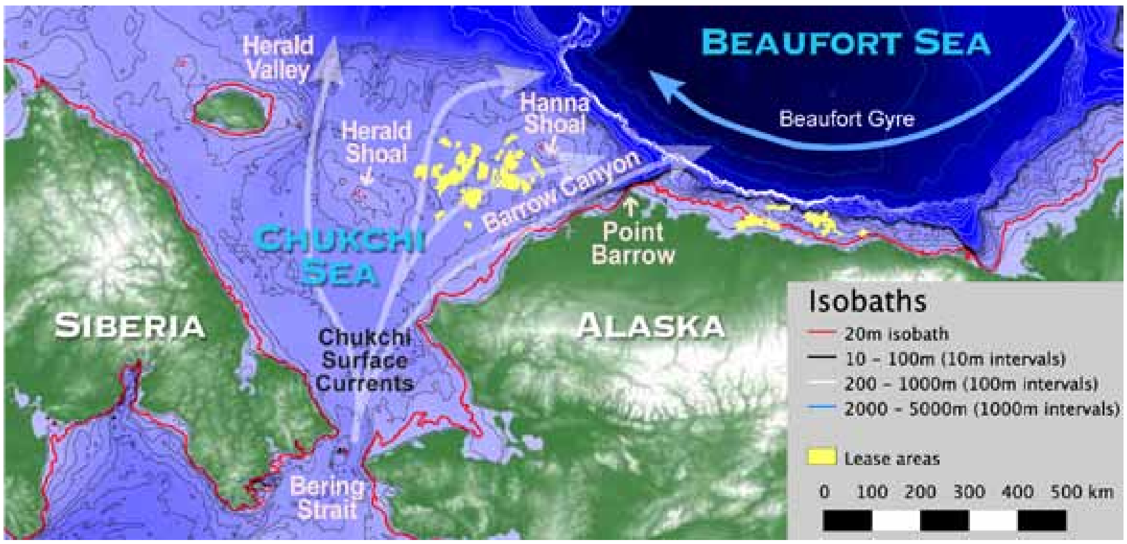


Figure 2: Ice Extent in the Pacific Sector of the Arctic

Mean monthly sea ice extents for the period 2000-2010 derived from passive microwave satellite data (Cavalieri et al., 1996), showing (a) the seasonal advance and (b) the seasonal retreat of sea ice in the Pacific sector of the Arctic.

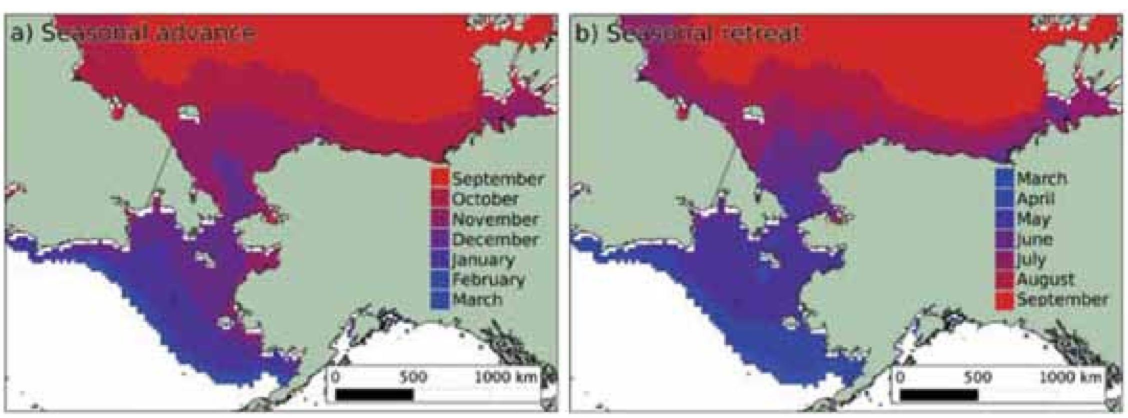


Figure 3: Ice Age in Chukchi and Beaufort Seas

Mean sea ice age in the Chukchi and Beaufort seas calculated for the periods (a) 1985-2010 and (b) 2005-2010 (data courtesy of J. Maslanik).

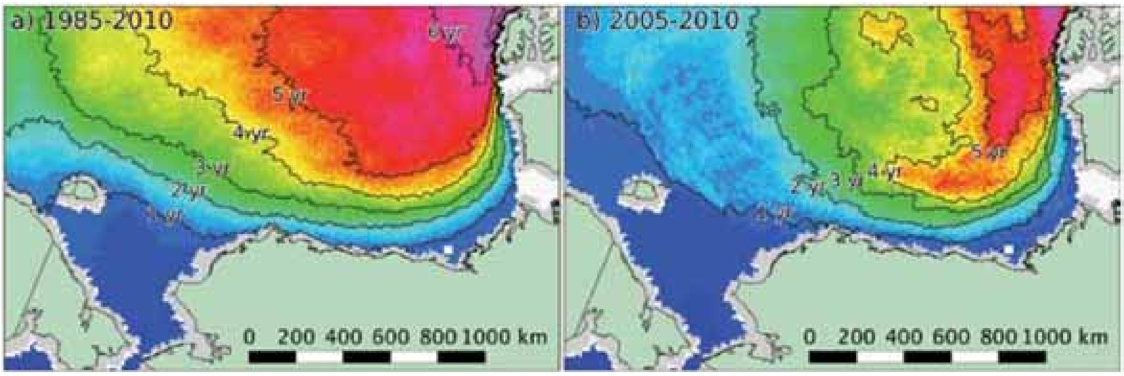


Figure 4: Temperatures in Chukchi and Beaufort Seas

Advanced Very High Resolution Radiometer (AVHRR) thermal (channel 4) image of the Chukchi and Beaufort seas on March 20, 1997. Bright pixels indicate cold temperatures associated with ice-covered ocean. Dark pixels indicate warm temperatures and therefore identify leads and openings in the ice, except those pixels associated with clouds as shown.

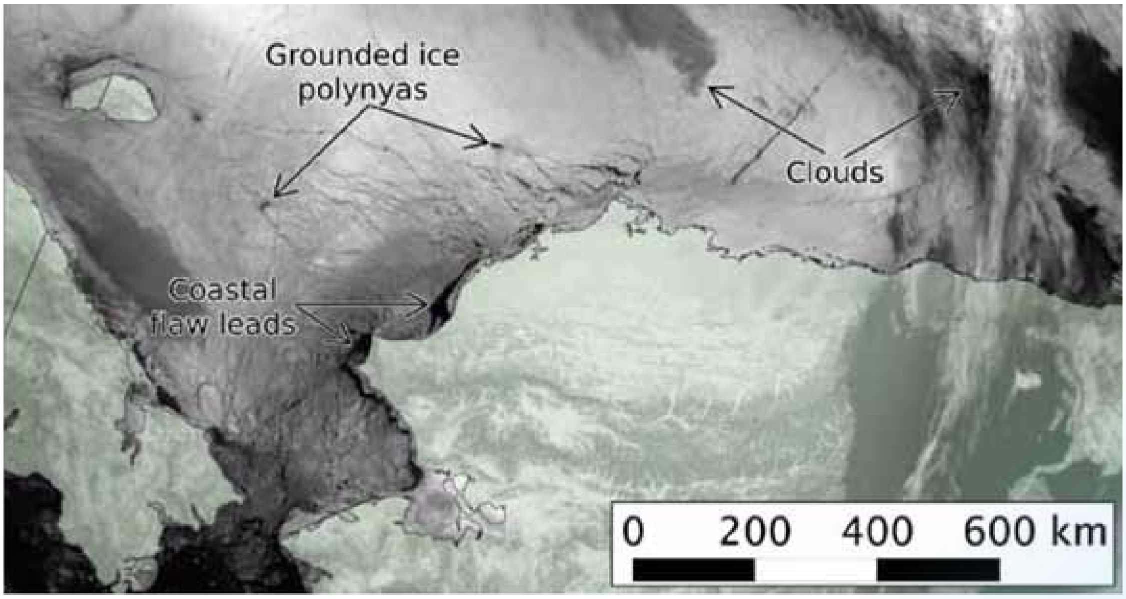
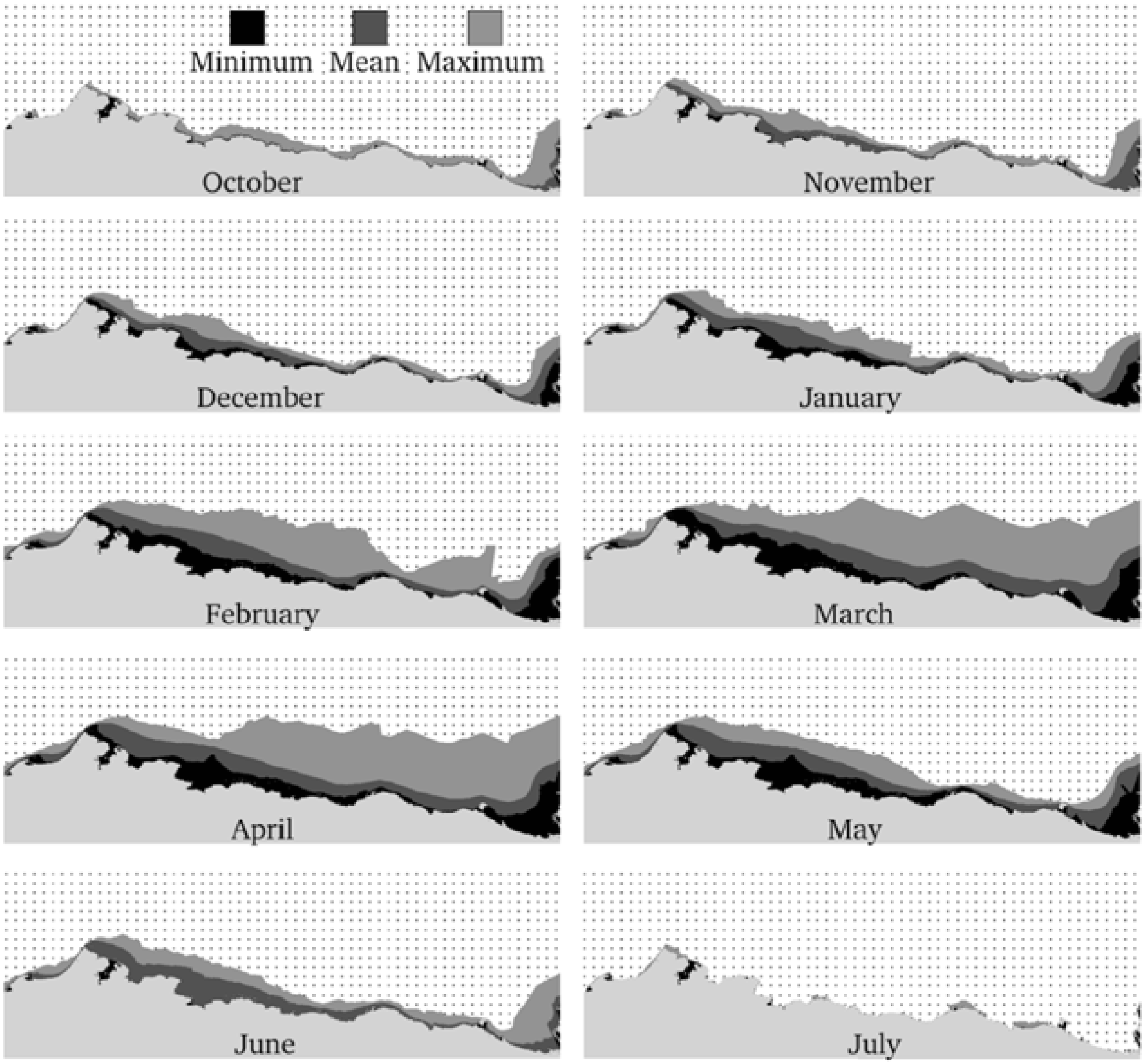


Figure 5: Landfast Sea Ice Extents in Chukchi and Beaufort Seas

Monthly minimum, mean, and maximum landfast sea ice extents in the eastern Chukchi and western Beaufort seas (from Mahoney et al. 2007).



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