GEOPHYSICAL RESEARCH LETTERS, VOL. 39, L05503, doi:10.1029/2011GL050691, 2012

The Wrangel Island Polynya in early summer: Trends and relationships to other polynyas and the Beaufort Sea High

G. W. K. Moore[1] and R. S. Pickart[2]

Received 19 December 2011; revised 11 February 2012; accepted 19 February 2012; published 15 March 2012.

[1] Polynyas, regions of reduced sea ice concentration relative to their surroundings, are important features of the polar climate system in which enhanced fluxes of heat, moisture, and momentum can occur between the atmosphere and ocean. As such, they play a significant role in many atmospheric, oceanographic and biological processes. There are concerns that in a warming climate, in which there is a trend towards a reduction in sea ice cover, that the location, size and duration of many polynyas may change resulting in climatological and ecological impacts. In this paper, we identify an early summer manifestation of the Wrangel Island polynya that forms in the western Chuckchi Sea. We show that over the past 30 years there has been an increased frequency of occurrence as well as a doubling in the size of the polynya. The polynya is shown to form when there is an enhanced easterly flow over the Chukchi Sea that is associated with an anomalously intense Beaufort Sea High (BSH), a closed anti-cyclonic atmospheric circulation that forms over the Beaufort Sea. We also show that there has been a concomitant trend towards a more intense BSH over the same time period and we propose that this trend is responsible for the observed changes in the Wrangel Island polynya. Given its large and increasing size, the early summer polynya may also play an important and unaccounted role in the physical and biological oceanography of the western Chukchi Sea. **Citation:** Moore, G. W. K., and R. S. Pickart (2012), The Wrangel Island Polynya in early summer: Trends and relationships to other polynyas and the Beaufort Sea High, *Geophys. Res. Lett.*, *39*, L05503, doi:10.1029/2011GL050691.

1. Introduction

[2] Polynyas are an important component of the polar climate system that have a profound impact on atmospheric, oceanographic and biological processes [*Smith and Barber*, 2007]. For example, they are regions of enhanced air-sea interaction that can lead to cloud formation as well as water mass transformation and abyssal water formation [*Minnett and Key*, 2007; *Williams et al.*, 2007]. Polynyas are also amongst the most biologically productive ecosystems on the planet with extensive phytoplankton blooms as well as enhanced concentrations of birds, fish and marine mammals [*Arrigo*, 2007].

[3] The Chukchi Sea, the marginal sea of the Arctic Ocean situated north of the Bering Strait between Siberia and Alaska, is a region that has seen a recent reduction in both sea ice cover and thickness as well as a commensurate increase in biological productivity [*Lindsay and Zhang*, 2005; *Arrigo and van Dijken*, 2011]. A number of polynyas form during the winter months along the its coasts as well as in the vicinity of Wrangel Island (Figure 1) that ventilate the cold halocline of the western Arctic Ocean [*Cavalieri and Martin*, 1994; *Winsor and Björk*, 2000]. *Pickart et al* [2010] showed that during the winter, the Wrangel Island polynya forms under conditions of enhanced northeasterly flow associated with an intense Beaufort Sea High (BSH).

[4] In this paper, we investigate an early summer manifestation of the Wrangel Island polynya and show that there exists considerable inter-annual variability as to its size and sea ice concentration. Despite this variability, its average size has more than doubled since the beginning of the space-based sea-ice observations in 1979. We furthermore show that its formation is strongly influenced by the intensity of the BSH and propose that the increasing size of the polynya is related to a recent trend towards a more intense BSH.

2. Results

[5] Figure 1 shows the monthly mean sea ice concentration in the Chukchi Sea region during June as derived from satellite-based passive microwave data using the NASA team (NT) algorithm [*Parkinson et al.*, 1999]. The mean for the entire period, i.e., 1979 to 2011, is shown as well as that for the 1st and 2nd halves of the record. This figure clearly reveals the retreat of the sea ice over the southern Chukchi Sea/northern Bering Strait region over the entire period of the record. It also shows the presence of two polynyas, defined as regions where the sea ice concentration is less than 80% that are surrounded by regions of higher sea ice concentration [*Comiso and Gordon*, 1996], situated to the north of Wrangel Island and along the Siberian coast west of 175°E. These have become more pronounced during the second half of the record.

[6] Time series of the monthly mean sea ice concentration and areal extent of the Wrangel Island polynya during June are shown in Figure 2. The former metric is defined as the mean sea ice concentration in the region to the north of Wrangel Island bounded by 71°N to 73°N and 175°E to 175°W. The areal extent is defined as the area in which the sea ice concentration is less than a prescribed value. Results are shown for the NT algorithm and its enhanced version (NT2) that is available from 2003 to 2011 [*Markus and Cavalieri*, 2000]. There is a tendency for the NT to overestimate concentrations in the marginal ice zone by approximately 10% [*Meier*, 2005] and as a result, areal extents for this algorithm are shown for a cut off of 70%; while a cut off of 80% is used for the NT2 algorithm, which does not

[1]Department of Physics, University of Toronto, Toronto, Ontario, Canada.
[2]Department of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA.

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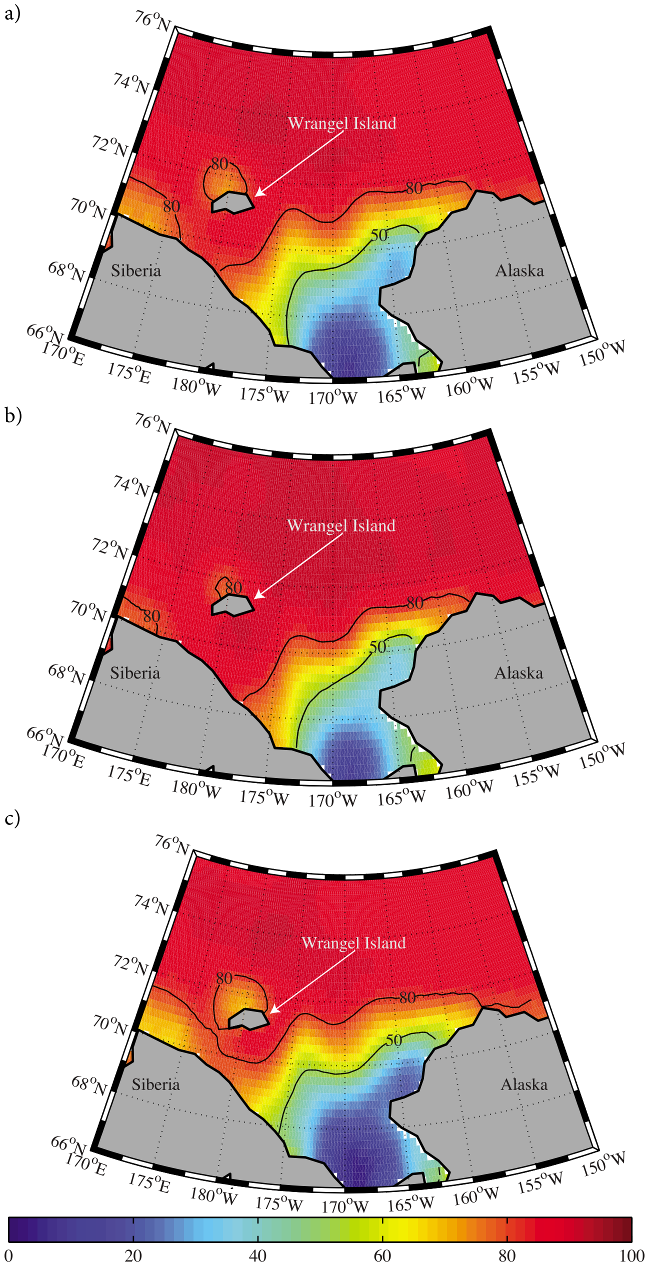

Figure 1. Monthly mean sea ice concentration (%) from the NASA team algorithm over the Chukchi Sea during June: (a) 1979 to 2011; (b) 1979 to 1995; and (c) 1995 to 2011.

experience this bias [*Meier*, 2005]. For both metrics, the time series exhibit considerable inter-annual variability as well as a recent tendency for lower sea ice concentration and larger polynya areal extent. Considering the NT algorithm results, Table 1 shows that the mean size of the polynya has doubled in areal extent over the period from 1979 to 2011 with evidence of a recent acceleration in its size over the period 2003 to 2011. Table 1 also confirms that the NT and NT2 algorithms differ by approximately 10% in mean sea ice concentration within the polynya.

[7] Figure 3 shows composites of the monthly mean sea ice concentration from the NT algorithm for June during years in which the Wrangel Island polynya was either large or small. Given the trend in the time series evident from Figure 2, they were detrended prior to the selection of years to be included in the composites. In this instance, large and small polynya years were selected as those in which the detrended sea ice concentration were in excess of $+/- 0.67\sigma$. This resulted in 9 years being included in each composite. Use of the areal extent yielded similar results as did spatial correlation analysis.

[8] The large polynya composite (Figure 3a) shows a well-defined region of reduced sea ice concentration north of Wrangel Island with evidence of a region of increased sea ice concentration to the south. Although the 80% sea ice concentration contour encloses both the Wrangel polynya and the polynya along the Siberian coast, there is evidence of a local maximum between the two indicating that they are still separate entities. The small polynya composite (Figure 3b) shows, as expected, no evidence of reduced sea ice concentration in the vicinity of Wrangel Island or along the Siberian coast. However, the difference from climatology shows a 10–15% increase in sea ice concentration north of Wrangel Island as well as along the Siberian coast in the small polynya composite (not shown). A comparison of the large and small polynya composites also indicates that an overall reduction in sea ice cover over the southern Chukchi Sea and northern Bering Strait is associated with the presence of the Wrangel Island polynya.

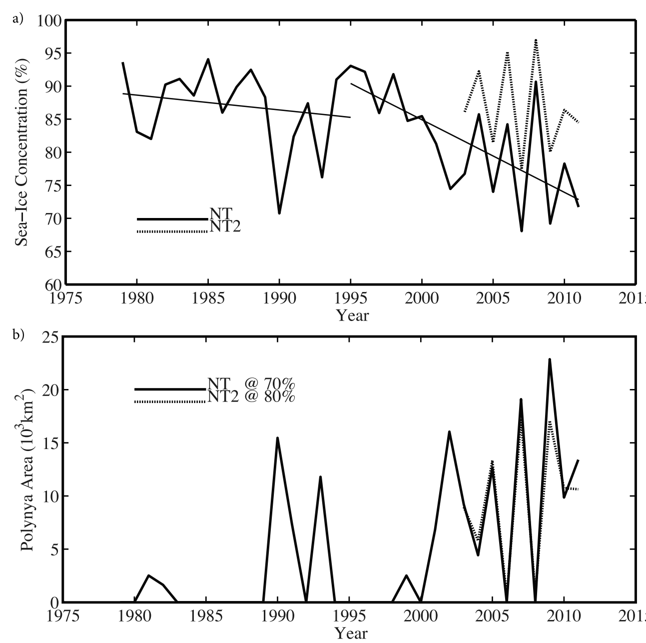

Figure 2. Monthly mean: (a) sea-ice concentration (%) and (b) polynya size (10^3 km^2) in the region north of Wrangel Island for June. Results from the NASA team algorithm (NT) are shown for the period 1979 to 2011; while those for enhanced NASA team algorithm (NT2) are shown for the period 2003 to 2011. Also shown in Figure 2a are the least squares trend lines from the NT algorithm for the periods from 1979 to 1995 and from 1995 to 2011. The polynya size results in Figure 2b from the NT algorithm are shown for a sea ice concentration cutoff of 70%; while those from the NT2 algorithm are shown for a sea ice concentration cutoff of 80%.

Table 1. Statistics on the Summer Wrangel Island Polynya as a Function of Time Period and Sea Ice Concentration Algorithm[a]

	NT 1979–2011	NT 1979–1995	NT 1995–2011	NT 2003–2011	NT2 2003–2011
Mean Sea Ice Concentration	84 (%)	87 (%)	82 (%)	78 (%)	87 (%)
Mean Areal Extent	4.7 (10^3 km^2)	2.3 (10^3 km^2)	6.8 (10^3 km^2)	10.1 (10^3 km^2)	9.5 (10^3 km^2)

[a]For the NT and NT2 algorithms, the mean areal extent is shown for a sea ice concentration cutoff of 70% and 80% respectively.

[9] To address the atmospheric conditions associated with the formation of the polynyas, we present the difference in the sea-level pressure and 10 m wind fields for June between those years in which there was either a large or small polynya north of the island (Figure 4a). The selection of years included in the composites was the same as that used for the sea-ice composites shown in Figure 3. The atmospheric fields are from the North American Regional Reanalysis (NARR), a reanalysis that was created to provide a long-term consistent climate data set for North America [*Mesinger et al.*, 2006]. Mean atmospheric conditions in June in the western Arctic are dominated by the BSH with easterly flow over the Chukchi Sea. Therefore the composite shown in Figure 4a indicates that the large Wrangel Island polynya is associated with the BSH being anomalously intense as well as sea-level pressures to west of the Aleutian Low being deeper than usual. This results in an enhanced divergent easterly flow across the Beaufort and Chukchi Seas. On the contrary, the small Wrangel Island polynya is associated with a weaker BSH and weaker easterly flow across the region.

[10] Figure 4b shows the trend in the monthly mean sea-level pressure during June from the NARR for the period 1995–2011. The statistical significance of the trend was assessed at each grid point with a resampling technique that preserves the parent time series' power spectra including any red noise characteristics that may bias other significance tests [*Rudnick and Davis*, 2003]. The trend shows a similar pattern to that associated with polyna formation (Figure 4a)

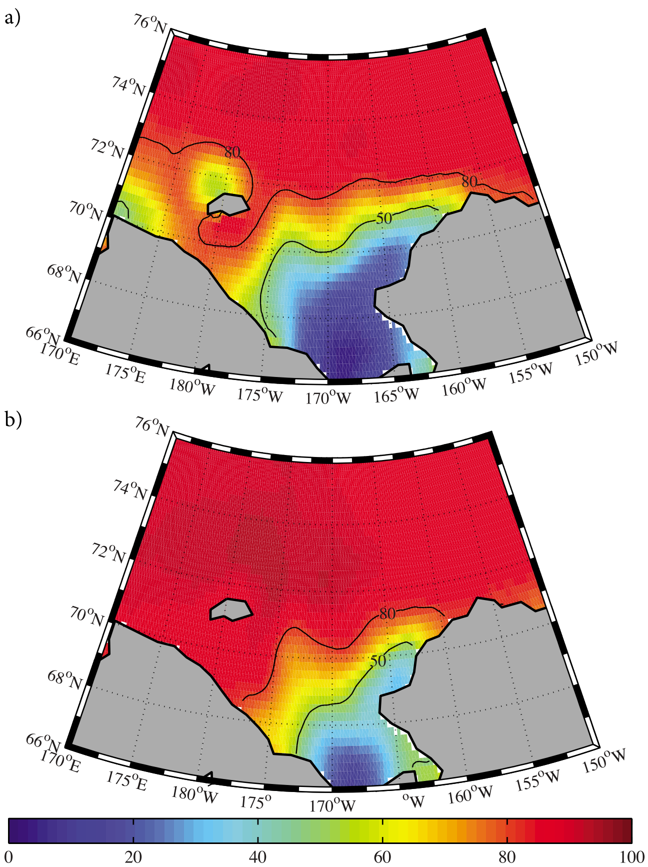

Figure 3. Monthly mean sea ice concentration over the Chukchi Sea from the NASA team algorithm for June during years in which the polynya north of Wrangel Island is either (a) large or (b) small.

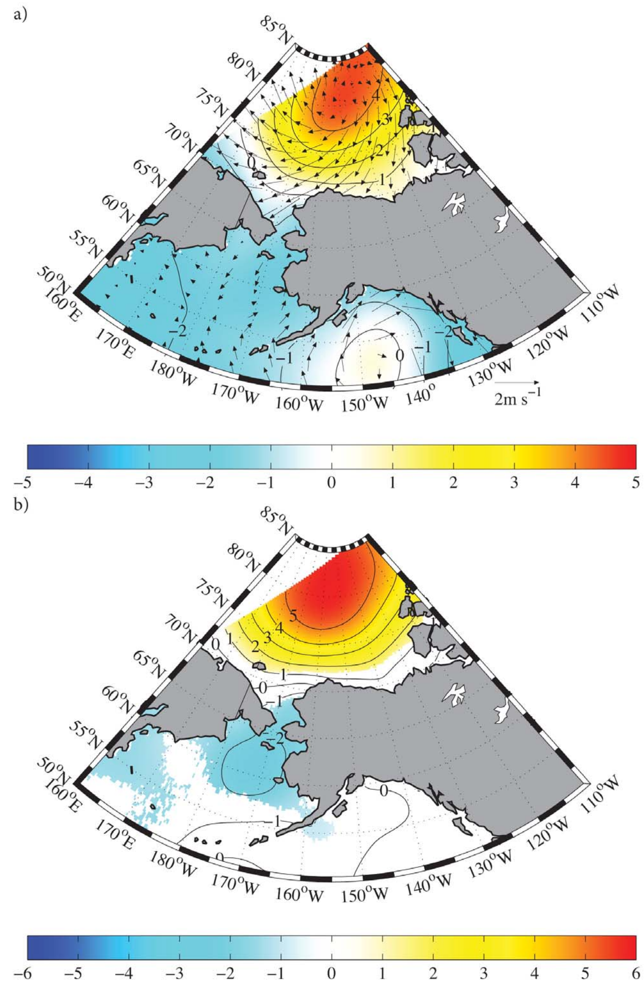

Figure 4. (a) The difference in the monthly mean sea-level pressure (contours and shading - mb) and 10 m wind field (vectors - m/s) for June between those years in which there is either a large or small polynya north of Wrangel Island. (b) The trend in monthly mean sea-level pressure (contours and shading - mb/decade) for June 1995 to 2001. The shading in Figure 4b represents those regions where the trend is statistically significant at the 5% level.

with a tendency for a deeper BSH and a tendency for lower sea-level pressure to the west of the Aleutian Low. The trends in the centers of both of these features are statistically significant at the 5% level. This tendency would lead to intensification in the meridional pressure gradient over the Beaufort and Chukchi Seas and thus enhance the easterly flow in the region. This is confirmed by the trend in the zonal component of the 10 m wind (not shown). In addition, the trend in the BSH during June over the period, 1979 to 2011, is approximately half that shown in Figure 4 indicating a recent acceleration in the intensity of the BSH that is consistent with the recent increase in the size of the polynya.

[11] A close-up view of the wind field in the region of interest (not shown) reveals the easterly flow in the vicinity of Wrangel Island as well as alongshore flow adjacent to the Siberian coast in the vicinity of the coastal polynya there.

3. Discussion

[12] Based on the above results linking the intensity of the BSH and the associated enhanced easterly winds over the Chukchi Sea with the presence of the early summer Wrangel Island polynya, the polynya would thus appear to be a wind-driven. This finding is consistent with the results of *Pickart et al.* [2010] who found that during the winter of 2002/2003 an intense BSH and easterly flow across the Chukchi Sea was associated with the formation of the winter Wrangel Island polynya. In that case the winds were northeasterly in the vicinity of the island and consequently, the polynya formed on the west/northwest side of the island due to the northwestward-directed Ekman transport. In contrast, the early summer manifestation of the polynya forms on the north side of Wrangel Island. This is due to the fact that the winds near the island are directly out of the east during this time of year, so the northward-directed Ekman flow advects ice away from the northern coast. The polynya that forms along the Siberian coast of the Chukchi Sea also occurs in a region where the wind is parallel to the coast and so northward Ekman transport is also most likely responsible for its formation. This mechanism has also been proposed to be responsible for the formation of the northern polynya in the Sea of Okhotsk [*Kawaguchi and Mitsudera*, 2009]. In addition, a correlation with the intensity of the BSH was also found for the winter polynya that forms along the northeast coast of the Chukchi Sea south of Point Barrow Alaska [*Kawaguchi et al.*, 2011].

[13] This common association with the intensity of the BSH suggests that this atmospheric circulation pattern plays a fundamental role in polynya formation across the Chukchi Sea that is in addition to its documented role in modulating sea ice concentration in the region [*Screen et al.*, 2011]. We have also shown that there has been an amplification of the BSH and a concomitant increase in the strength of easterly flow across the Chukchi Sea in the month of June since the late 1990s. Based on the frequency of anticyclonic events, *Serreze and Barrett* [2011] did not find any statistically significant trend in the strength of the BSH during any season. However they did note a recent tendency for a stronger BSH during the summer. The reasons behind this trend in the BSH are under investigation.

[14] Given the association of the Wrangel Island polynya with the intensity of the BSH, it is likely that the BSH amplification is the cause behind the observed recent increase in polynya size during the early summer. The documented reduction in sea ice extent and thickness in the region, which may also be related to the BSH, undoubtedly plays a role as well [*Lindsay and Zhang*, 2005]. The retreat of sea-ice in the region may change the timing of the polynya's occurrence or may lead to its elimination.

[15] It is now commonly accepted that the cold halocline of the Arctic Ocean is predominantly maintained by lateral processes [*Aagaard et al.*, 1981]. In particular, dense water formed on the shelves is transported by a variety of processes into the interior basins [e.g., *Garrison and Becker*, 1976; *Spall et al.*, 2008]. In the western Arctic much of this dense water emanates from the polynyas in the Chukchi Sea [*Cavalieri and Martin*, 1994; *Winsor and Björk*, 2000]. With such increases in the size and duration of the Wrangel Island polynya as documented in our study, the corresponding reservoir of dense water - already known to be important [*Pickart et al.*, 2010]-should expand and hence ventilate the interior halocline over a greater portion of the year. Since the halocline is crucial for shielding the deep (warm) Atlantic water from the ice cover, is imperative that we understand how the halocline will evolve in a changing climate. In addition, the reduced sea ice concentration associated with the polynya may also play an unaccounted role in regional primary production [*Arrigo*, 2007; *Arrigo and van Dijken*, 2011]. The presence of open water near Wrangel Island in the early summer has been identified as a region where bowhead whales congregate [*Moore and Laidre*, 2006] and so the presence of the polynya may have an impact on this species as well.

[16] **Acknowledgments.** The authors would like to thank the reviewers for their comments well as the National Snow and Ice Data Center and the Physical Sciences Division of NOAA/ESRL for providing access to data. GWKM was supported by the Natural Science and Engineering Research Council of Canada. RSP was supported by the NOAA project NA08-OAR4320895.

[17] The Editor thanks Kevin R. Arrigo and an anonymous reviewer for their assistance in evaluating this paper.

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G. W. K. Moore, Department of Physics, University of Toronto, 60 St. George St., Toronto, ON M5S 1A7, Canada. (gwk.moore@utoronto.ca)

R. S. Pickart, Department of Physical Oceanography, Woods Hole Oceanographic Institution, Mail Stop 21, Woods Hole, MA 02543, USA. (rpickart@whoi.edu)