A possible link between winter Arctic sea ice decline and a collapse of the Beaufort High?

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Key Points:

- A new study by Moore et al., (2018) presents a possible link between the recent sea ice decline in the Barents Sea and 'collapse' of the wintertime Beaufort High circulation.
- This commentary discusses the importance of this idea and the challenges associated with understanding these possible linkages.

Abstract

A new study by Moore et al., (2018, this issue) highlights a collapse of the anticyclonic 'Beaufort High' atmospheric circulation over the western Arctic Ocean in the winter of 2017 and an associated reversal of the sea ice drift through the southern Beaufort Sea (eastward instead of the predominantly westward circulation). The authors linked this to the loss of sea ice in the Barents Sea, anomalous warming over the region, and the intrusion of low-pressure cyclones along the eastern Arctic. In this commentary we discuss the significance of this observation, the challenges associated with understanding these possible linkages, and some of the alternative hypotheses surrounding the impacts of winter Arctic sea ice loss.

1 Background

The Arctic has experienced unprecedented winters in recent years, including record warm air and surface temperatures and record low sea ice conditions, over and above what was expected from long-term trends (e.g., Cullather et al., 2016; Petty et al., 2018). Recent winter weather events in the Arctic have also been remarkable (e.g. Graham et al., 2018), including the extreme Arctic storm in the winter of 2015/2016 which raised temperatures around the north pole to above freezing and caused significant sea ice retreat in the Barents Sea region (Boisvert 2016; Moore 2016). The autumn (October-December) 2016 sea ice edge (15% ice concentration contour) and sea surface temperature (SST) anomalies are shown in Figure 1, highlighting the record low sea ice state and high SSTs observed in the Bering Sea and across much of the North Atlantic sector of the Arctic.

These rapid changes in wintertime Arctic conditions have raised important questions regarding the potential impacts of winter Arctic sea ice loss. Recent research efforts have demonstrated several possible impacts, including reduced ocean stratification and enhanced ocean convection, especially in the North Atlantic sector of the Arctic (e.g. Moore et al., 2015; Polyakov et al., 2017), with obvious connections to the biogeochemical balance of the Arctic and sub-Arctic system (e.g. Carmack et al., 2016). A new study by Moore et al.,

(2018) provides evidence of a more contentious impact of winter Arctic sea ice decline: the intrusion of low-pressure cyclones into the Arctic and a collapse of the anticyclonic atmospheric circulation that forces one of the key features of the Arctic Ocean - the Beaufort Gyre.

2 The Beaufort Gyre

The Beaufort Gyre (BG) is the principal anticyclonic ice-ocean circulation feature of the western Arctic Ocean, forced by the presence and strength of a semi-permanent high pressure system located over the Beaufort Sea north of Alaska, commonly referred to as the Beaufort High (e.g. Proshutinsky et al., 2002; Serreze and Barrett, 2010). The anticyclonic circulation driven by the Beaufort High results in the accumulation of fresh surface waters in the region through Ekman convergence, and a characteristic doming of the ocean surface. The mean (2011-2014) dynamic ocean topography of the Arctic Ocean derived from CryoSat-2 altimetry data (Armitage et al., 2016) is shown in Figure 1.

The BG has been accumulating freshwater since the 1990s (McPhee et al., 2009; Rabe et al., 2011; Giles et al., 2012), although this increase appears to have plateaued in recent years (e.g. Armitage et al., 2016). The combined influence of sustained anticyclonic wind forcing and sea ice declines helped drive this freshwater accumulation, modulated by a negative feedback associated with a concurrent strengthening of the ocean geostrophic currents (Petty et al., 2016, Armitage et al, 2017; Zhong et al., 2017; Dewey et al., 2018; Menghello et al., 2018). A freshening of the source waters (e.g. Krishfield et al., 2014) and increased Eurasian river runoff drawn into the region (Morison et al., 2012), have also likely contributed. This ~20 year period of freshwater accumulation is in stark contrast to the suggestion prior to this recent spin-up time period of a 7-8 year oscillation between cyclonic (freshwater release) and anti-cyclonic (freshwater accumulation) regimes (Proshutinsky and Johnson, 1997; Proshutinsky et al., 2015). A spin-down of the BG and a release of its stored freshwater could result in significant disruption to the North Atlantic (e.g. Aagaard & Carmack, 1989).

3 Winds of change?

A spin-down of the BG requires a significant change in the wind forcing over the region. The atmospheric circulation in the Arctic is often characterized by the Arctic Oscillation (AO) or its North Atlantic counterpart - the North Atlantic Oscillation (NAO) (Thompson and Wallace, 1998). However, the relationship between the circulation regime of the Arctic and

Beaufort Gyre to these climate indices is still unclear, due in part to their limited contribution to the large-scale wind circulation and their changing nature in response to a rapidly warming Arctic (e.g. Overland and Wang, 2010, Vihma, 2014). An alternative approach thus involves more explicitly examining the atmospheric circulation and the processes contributing to its variability, e.g. cyclonic activity around and into the Arctic (e.g. Zhang et al., 2004; Simmonds et al., 2008).

Winter Arctic cyclones originate primarily from the North Atlantic and, to a lesser extent, the North Pacific, and are thought to be more intense than summer Arctic cyclones (e.g. Serezze et al., 1993; Zhang et al., 2004; Simmonds et al., 2008; Rinke et al., 2017). The climatological North Atlantic storm track results in cyclones extending into the Barents Sea region, with only limited intrusions into the central Arctic. Moore et al., (2018), however, show evidence of high storm track activity extended from the Barents Sea along the Siberian coast in the winter (January-March) of 2017, driving a cyclonic circulation over the Beaufort Sea (a Eulerian diagnostic was used, limiting knowledge of specific cyclone tracks). This was linked to a northward shift of the tropospheric polar vortex, combined with anomalous surface heating in the Barents Sea linked to the autumn 2016 sea ice declines (Figure 1), and reductions in the tropospheric static stability. This is in stark contrast to other studies that suggest possible reductions in cyclonic activity in response to Arctic sea ice loss (e.g. Day et al., 2017), with Inoue et al., (2012), for example, suggesting that increases in Barents Sea SSTs can drive reductions in baroclinicity and thus cyclogenesis.

4 Questions remaining

The new Moore et al., (2018) study provides evidence only of a reversal in the sea ice circulation over the Beaufort Sea (in January-March, 2017), with no evidence yet available of the ocean's response, e.g. a concurrent reversal of the underlying ocean geostrophic circulation. Note that the winter (January-March) 2017 ice drifts calculated from the daily, near real-time, OSI-SAF ice drift product (Lavergne et al., 2010) are shown in Figure 1, corroborating the westward sea ice drift through the Beaufort Sea demonstrated by the PIOMAS model used in Moore et al., (2018). The ocean response to this wind/ice drift reversal, however, depends on the relative strength and direction of the ice drifts and underlying ocean currents (to calculate an ice-ocean stress), and the duration of this reversal. The importance of low-pressure cyclone intrusions into the Arctic has already been demonstrated in summer, however, where the Great Arctic Cyclone in the summer of 2012

(Simmonds et al., 2012) drove a reversal of the summer Beaufort High, resulting in an anomalous year of Ekman divergence, instead of Ekman convergence, in the Beaufort Sea (e.g. Menghello et al,. 2018).

The contribution from declines in sea ice thickness over shifts in the location of the ice edge/changes in open water in the North Atlantic sector is also uncertain. In other words, it is still unclear if the reduction in sea ice thickness within the winter pack ice (from a ~2 m mean to ~ 1-1.5 m in 2016, as shown in the PIOMAS model) played a significant role in generating and maintaining the high cyclone activity observed in the region.

Finally, many of the studies exploring winter Arctic sea ice loss have focused on the Barents Sea region, due to the rapid sea ice declines observed there and the relatively frequent intrusions of cyclones into the region. However, the winter of 2017 also featured record low sea ice and high SSTs in the Bering Sea. The intrusion of cyclones into the Arctic from the North Pacific sector is generally less significant than the North Atlantic (Simmonds et al., 2008), however cyclone intrusions from this region could become more significant considering the rapid changes being observed there.

At the time of writing (February, 2018), the Arctic is experiencing further record breaking temperatures and low sea ice conditions in both the Barents Sea and, in particular, the Bering Sea (http://nsidc.org/arcticseaicenews/2018/02/sea-ice-tracking-low-in-both-hemispheres/). The fall 2017 sea ice edge and SST anomalies, along with the winter (January) 2018 ice drifts are shown in Figure 2, to compare with the conditions observed in the previous fall/winter (Figure 1b). The spatial patterns of high SST anomalies and low sea ice is similar to 2016, but with stronger (weaker) sea ice declines in the Bering (Barents) Sea. However, the ice drifts, albeit only for the month of January, indicate a more characteristic Beaufort High sea ice circulation, compared to the reversal observed in the winter of 2017. This opposite circulation response highlights the challenges associated with understanding the linkages between Arctic sea ice decline and atmosphere/ice circulation patterns. Further research is clearly needed to understand if the winter 2017 cyclone intrusion into the Arctic was an anomaly, or if such intrusions could become more frequent with continued loss of Arctic sea ice.

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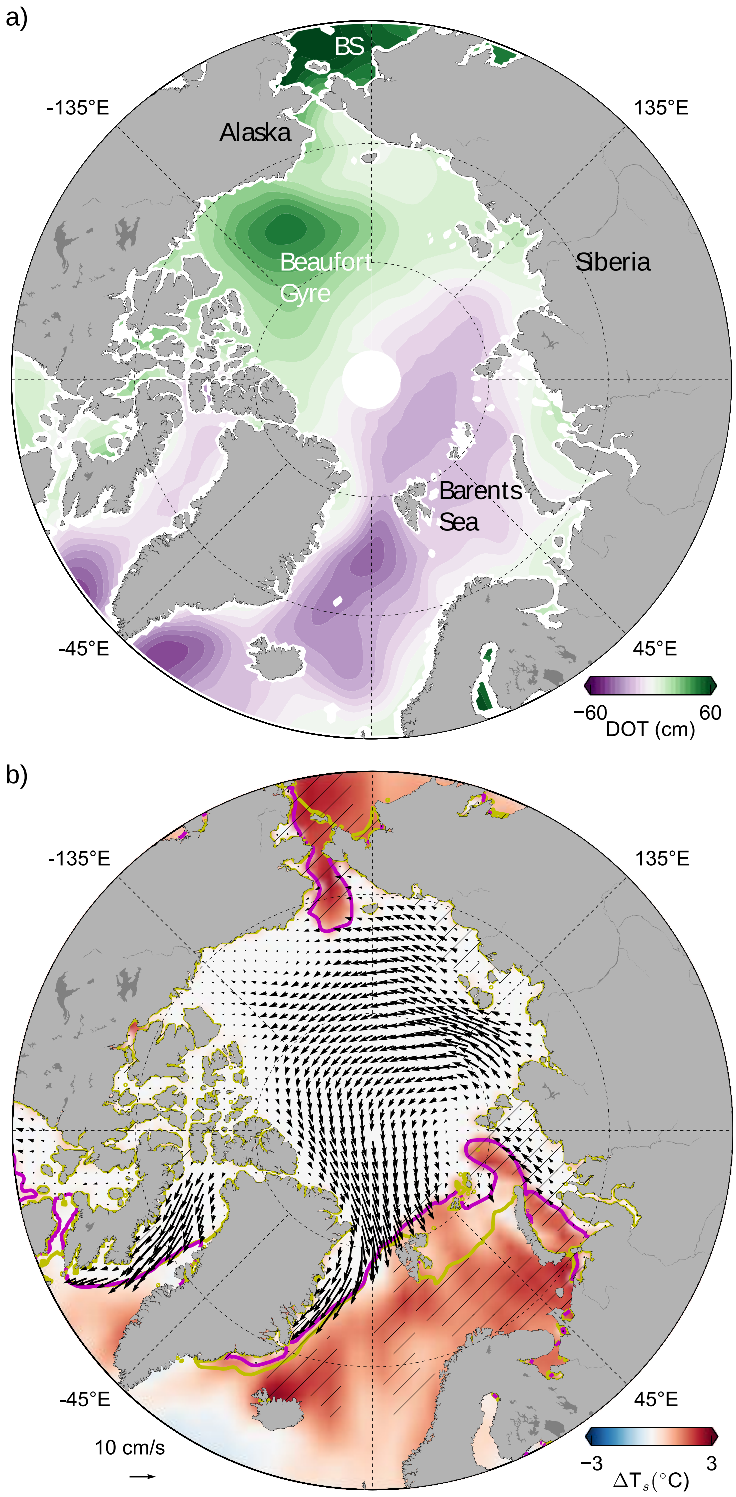

Figure 1: a) Mean 2011-2014 Dynamic Ocean Topography (DOT) of the Arctic Ocean (Armitage et al., 2016), BS: Bering Strait. b) Autumn (October-December) 2016 Sea Surface Temperature (SST) anomalies from the autumn 1982-2015 mean, calculated from NOAA's OISSTv2 dataset (Reynolds et al., 2007). Only data over the open ocean (October-December, 2016) are shown. The hatchings indicate regions that are experiencing record high SSTs in 2016 (since 1982). The magenta (yellow) lines indicate the autumn 2016 (median, 1982-2015) sea ice edge, calculated using a 15% concentration contour from NASA Team ice

concentration data (Maslanik and Stroeve, 1999; Cavalieri et al., 1996, updated 2017). Black vectors show the winter (January-March) 2017 mean OSI-SAF ice drift.

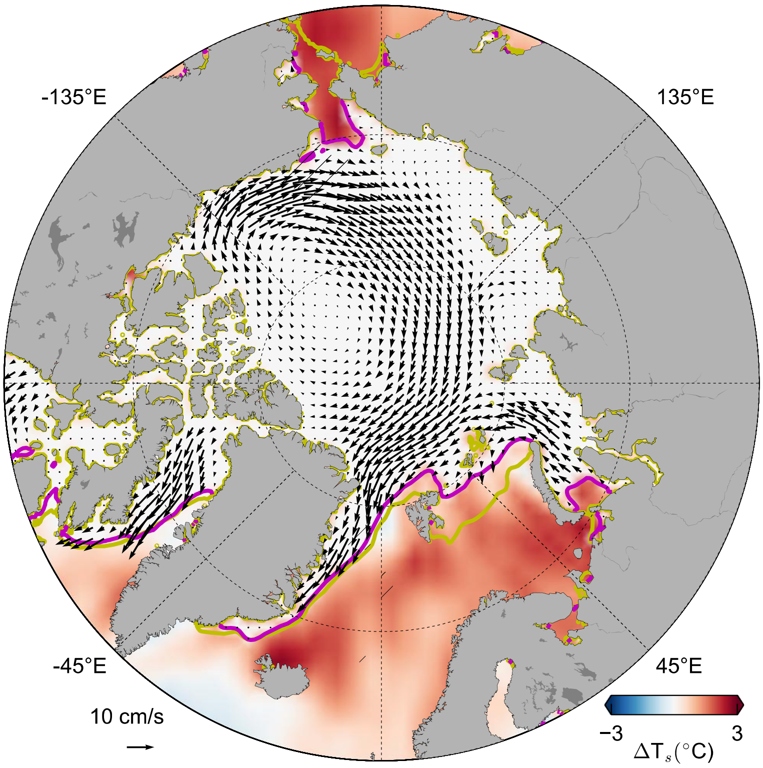

Figure 2: a) As in Figure 1b but for the autumn (October-December) 2017 Sea Surface Temperature (SST) anomalies (also calculated relative to the fall 1982-2015 mean) and sea ice edge (magenta line). Black vectors show the January 2018 mean OSI-SAF ice drift.