Extreme blocking in the North Atlantic Arctic in future climates

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Introduction

Recent changes in low-frequency atmospheric circulation in the North Atlantic sector of the Arctic (NAA) have increased sensible heat and moisture advection from the mid-latitudes into this region (Mattingly et. al, 2016). This, in turn, has altered the surface energy budget over the Greenland Ice Sheet and adjacent sea ice and contributed to unprecedented melt and freshwater runoff events, as was evident on July 8th 2012, where approximately 40% of the ice sheet's surface experienced melt (Nghiem et al. 2012). This and other intense melt events in subsequent years along with record or near-record warmth and lack of sea ice in the Arctic Ocean, provide an exceptional opportunity for timely investigation on the multiple ways in which large-scale atmospheric circulation drives land- and sea-ice changes across the NAA.

Greenland blocking

What is Greenland Blocking?

- Unusual waviness in the jet stream, centered over Greenland
- Occurs when there is a breaking of synoptic-scale Rossby waves resulting in a quasi-stationary high pressure system that blocks circulation.
- Typically results in a large-scale reversal of the meridional geopotential height gradient (Pelly & Hoskins, 2003).

Motivation

Impacts to DoD operations:

- Changes in sea ice concentration
- Snow and ice melt
- Impacts of freshwater input to the acoustic profile
- Unusual cloud cover and precipitation

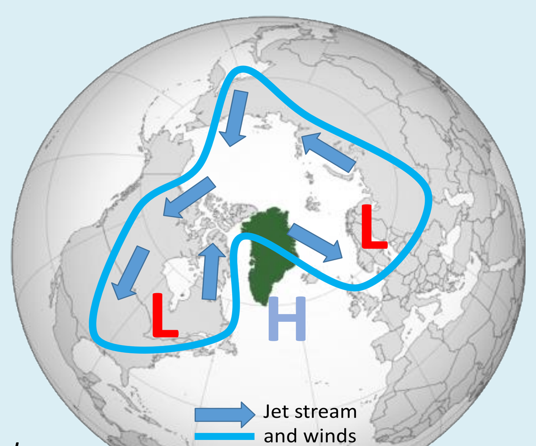

Figure 1: Schematic depicting an extreme block (ridge), and associated flow over Greenland and the North Atlantic sector of the Arctic (NAA).

Data and Methods

- This study uses output from the Climate Model Intercomparison Project 6 (CMIP6). The iteration used was the NCAR CESM historical 'day' variant r1i1p1f1 ranging from 1850-2015.
- Greenland Blocking Index (GBI) is defined as the mean 500hPa geopotential height over the Greenland region spanning between 60°–80°N latitude and 20°–80°W longitude (Hanna et. al, 2013).
- The data from CMIP6 was restricted over this range of latitude and longitude to represent a GBI value.
- An extreme instance of GBI is defined as above the 90th, 95th, 97th or 99th percentiles.
- Summer and winter seasons were represented by DJF and JJA.

Climate Model Intercomparison Project 6

The goal of the CMIP6 is to better understand past, present, and future climate scenarios with both forced and unforced modeling.

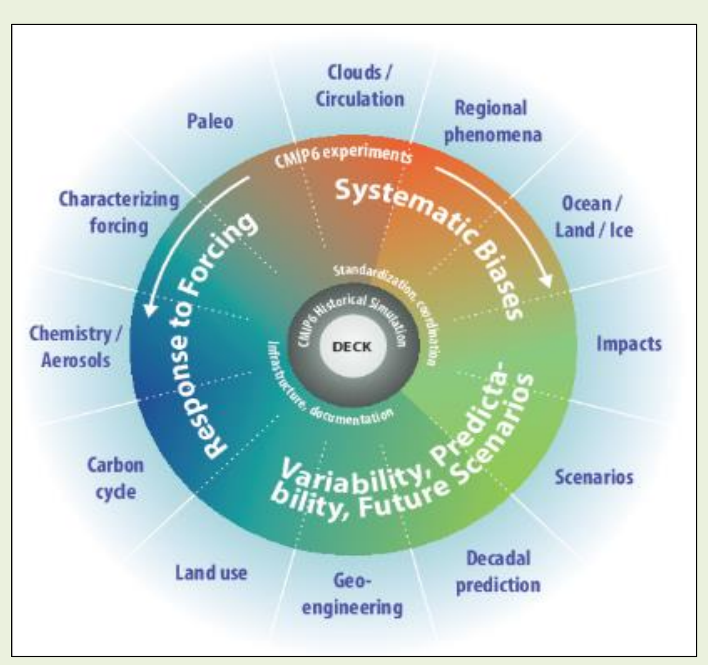

Image courtesy of CMIP6 website: https://www.wcrp-climate.org/

Research Goals

To anticipate and reduce the negative consequences of these extreme events, the objectives of this research are to:

1. ***Create a climatology of extreme Greenland Blocking as represented in the NCAR CESM CMIP6 historical model run.***
2. ***Compare modeled vs. observed extreme blocking climatologies.***
3. ***Assess the ability of CMIP6 models to replicate observed frequencies of extreme Greenland Blocking.***

➡ ***Assess impact on high-latitude DoD operations and installations in the North Atlantic Sector of the Arctic***

Results: Climatology of blocking over Greenland in both ERA-interim and CMIP6

Frequency of extreme blocking was analyzed from 1980-2015

ERA Interim blocking frequency:

- Blocking exhibits interannual variability with number of days with blocking increasing in frequency from 1980-2018 (Fig. 2).
- Shift to more frequent blocking in recent years is more pronounced in summer than winter.
- The most extreme blocking events (above the 97th and 99th percentiles) thus are more common in the 2nd half of the data record (1980-2018) in both seasons (DJF and JJA).
- ERA data has single years that account for large portions of the blocking occurrences.

Observations (ERA-interim)

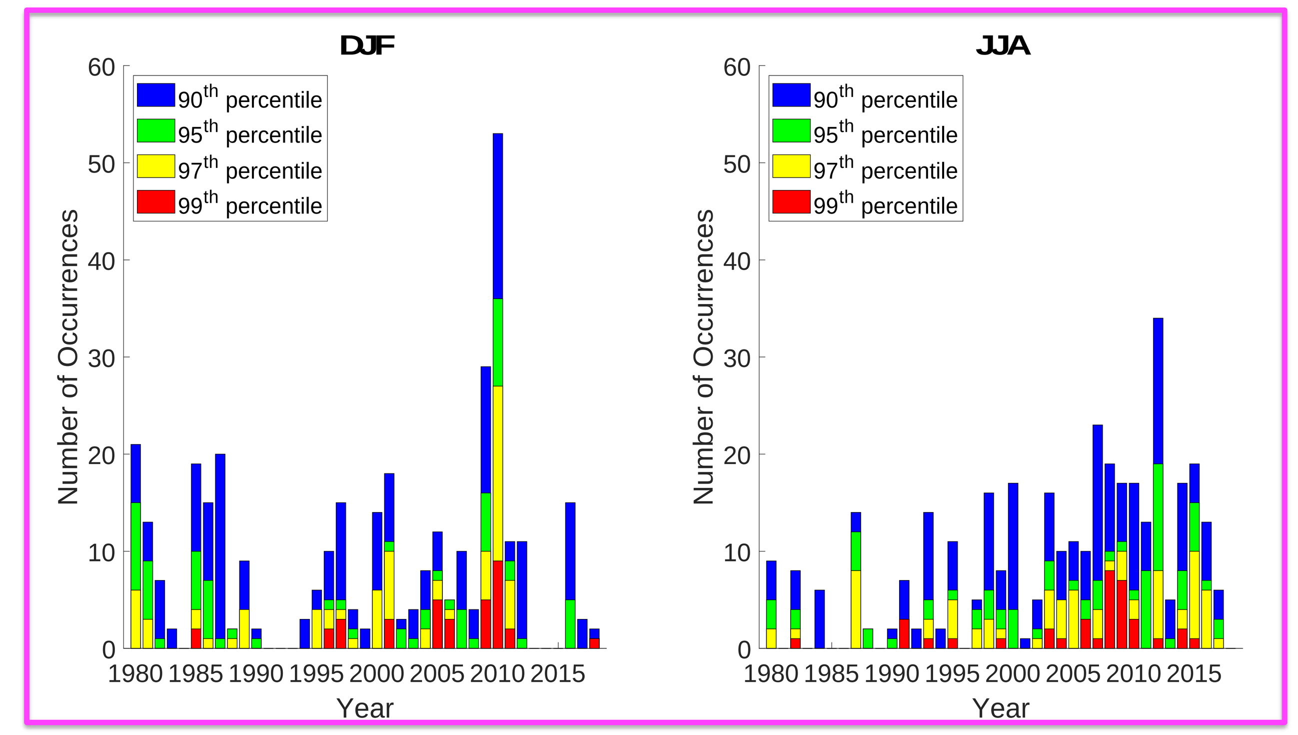

***Figure 2**: Frequency of extreme daily Greenland Blocking events per year from 1980-2018 (Henry et al, 2018)*

***Table 1**: Winter & summer seasonal analysis of top 90th, 95th, 97th & 99th percentiles of daily Greenland Blocking Index (GBI) statistics from ERA interim & CMIP6 model output.*

Percentile of GBI Values	Season	Total Occurrences	ERA Interim % Occurrences		Total Occurrences	CMIP6 % Occurrences	
			1980-1999	2000-2018		1980-1997	1998-2014
90th	DJF	352	42.6%	57.4%	332	56.0%	44.0%
	JJA	359	29.5%	70.5%	379	43.5%	56.5%
95th	DJF	176	37.5%	62.5%	154	55.8%	44.2%
	JJA	179	29.1%	70.9%	193	47.1%	52.9%
97th	DJF	106	30.2%	69.8%	87	52.9%	47.1%
	JJA	108	27.8%	72.2%	130	50.8%	49.2%
99th	DJF	35	20.0%	80.0%	25	56.0%	44.0%
	JJA	36	19.4%	80.6%	42	54.8%	45.2%

CMIP6 model output

CMIP6 blocking frequency:

- When considering blocking frequency as represented by the NCAR CESM historical CMIP6 model run, differences between this and the ERA Interim reanalysis product are evident (Fig. 3).
- Specifically, no increase in extreme blocking is evident when considering the overlapping period of 1980-2014 (Fig. 3, Table 1).

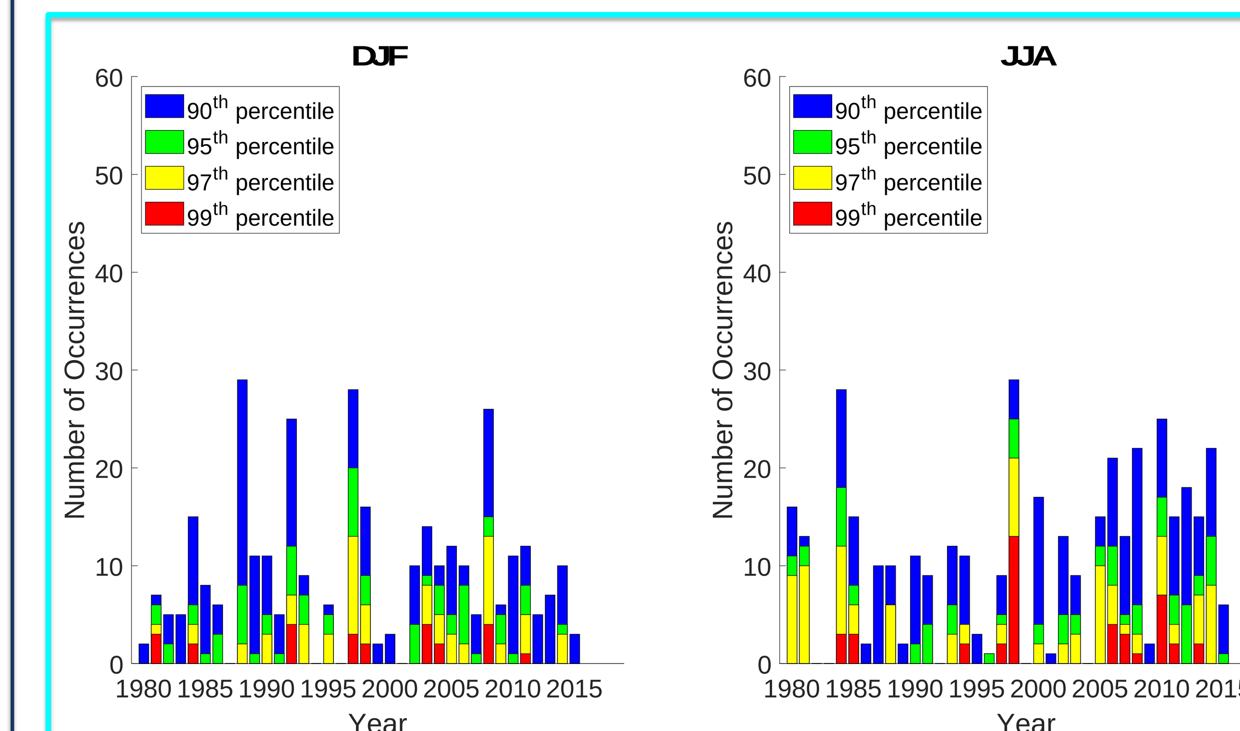

***Figure 3**: As in Fig. 2 for CMIP6 model output from 1980-2014.*

Source	Institution	Experiment	Variant	Table	Variable
CESM2	NCAR	historical	r1i1p1f1	day	zg, ua, va, hus

Results: CMIP6 historical run

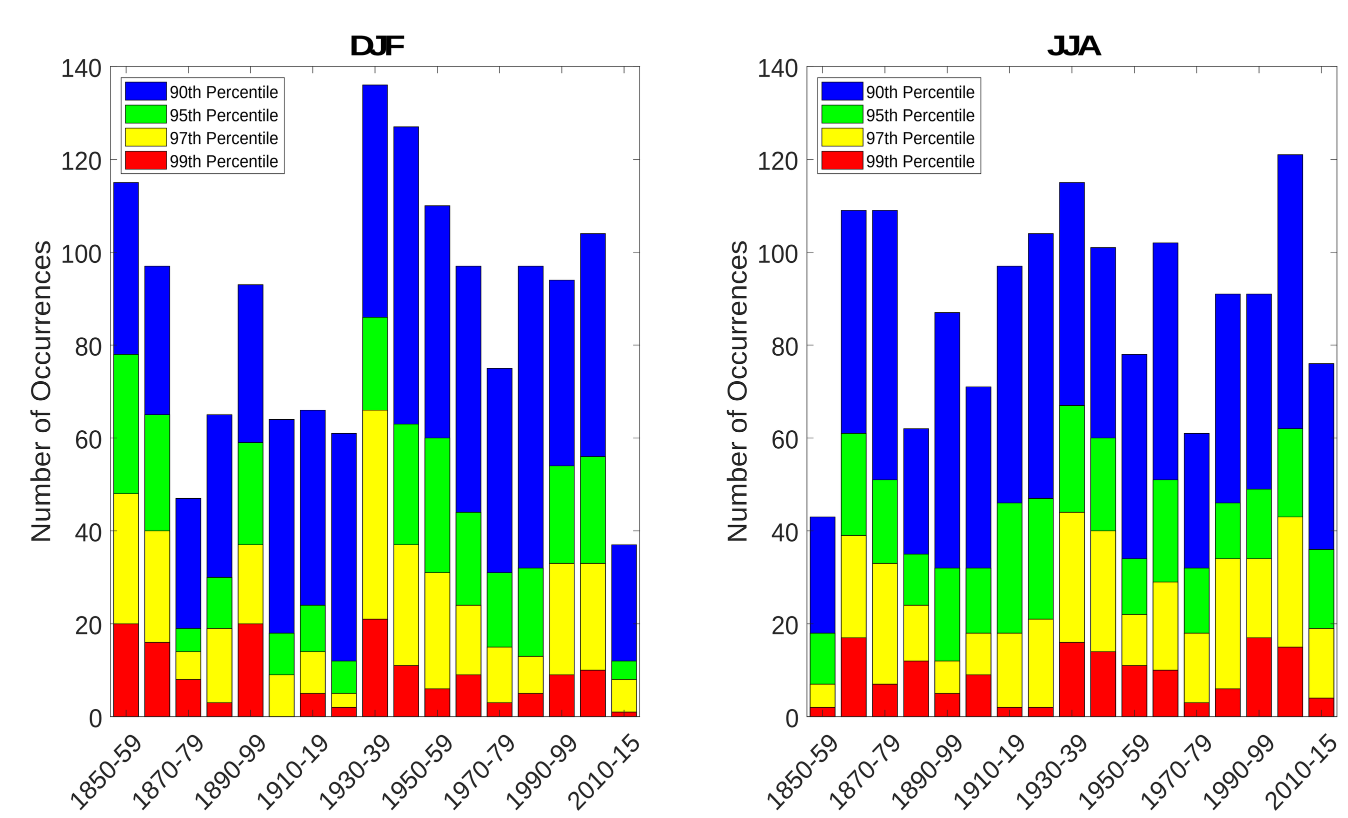

***Figure 4**: CMIP6 model output from 1850-2014. Note that each bar represents one decade.*

CMIP6 decadal analysis of blocking:

- When considering the entire period of historical model run (1850-2014), a long-term increase in blocking is most evident in DJF (Fig. 4, left).
- Summer months seem to display a long-term periodicity of blocking events (Fig. 4, right).
- In the 90th percentile of JJA there seems to be an increase in frequency of extreme blocking.
- The increase in extreme blocking seems to be more pronounced in the 99th percentile (Table 2, Fig. 4).

***Table 2:** Winter and summer months of CMIP6 data from 1850-2014*

Percentile of GBI Values (CMIP6)	Season	Total Occurrences	Percent of Occurrences	
			1850-1932	1932-2015
90th	DJF	1485	42.9%	57.1%
	JJA	1518	45.5%	54.5%
95th	DJF	743	44.2%	55.8%
	JJA	759	43.3%	56.7%
97th	DJF	446	46.0%	54.0%
	JJA	455	38.2%	61.8%
99th	DJF	149	55.0%	45.0%
	JJA	152	38.5%	61.5%

Ability of CMIP6 to represent blocking in past climates:

- Although trends in extreme blocking frequency differed between CMIP6 and ERA-Interim for the overlapping period (1980-2015), the CMIP6 output did show an increase in extreme blocking from the 1930s onward in winter for all percentiles apart from the 99th.
- In contrast, summer months displayed an increase in extreme blocking in both the 97th and 99th percentiles from 1932 onwards (Table 2).
- Additional runs of CMIP6 data may produce similar signals.

Future Work

The next steps in this research will include:

- Examining the integrated vapor transport under extreme blocking events within the CMIP6 realization for comparison with similar analysis conducted for the ERA-Interim product.
- IVT shall be calculated with the following equation (Eqn. 1), by integrating specific humidity (*q*) with vector winds (V) at the following pressure levels; 1000, 850, 700, 500, 250 hPa. Gravitational acceleration (g) is included also in the integration.

$$IVT = \frac{1}{g}\int_{1000\,hPa}^{200hPa} q\,V dp \quad \text{(Eqn. 1)}$$

- IVT calculations will be curtailed differently to 55°-80°N by 15°-85°W to account for IVT outside of the GBI box that could have still impacted the Greenland Ice Sheet.
- To compare the temporal relationship between GBI and IVT, above average IVT will be compared with the 4 thresholds of GBI and lagged to find when above average IVT occurred 15 days before and after a peak blocking event. The above average IVT across 31 days will create a temporal sense of how GBI and IVT coincide.
- Consider additional iterations of the CMIP6 output to determine if atmospheric patterns under extreme blocking events are robust across different model runs as well as assess the sensitivity of IVT to vertical resolution of pressure levels.
- Further assess the impacts of these trends on DoD installations and suggest plans to mitigate the risks involved with NAA operations.

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SERDP DOD • EPA • DOE
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