# Quantifying the Impact of Moisture Transport during Extreme Blocking events in the North Atlantic

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## Introduction

Atmospheric blocking is a disruption of mid-latitudinal circulation characterized by a slowing of synoptic-scale Rossby waves. Over the North Atlantic Arctic (NAA), blocking can result in the development of a quasi-stationary surface high pressure system that can reverse the orientation of expected geopotential height gradients (Pelly & Hoskins, 2003). This disruption is characterized by mid-latitudinal temperatures and moisture being advected over Arctic regions, particularly the Greenland Ice Sheet (GrIS) (Mattingly et al., 2016). It is suspected that blocking has been a driving force in observed increased ice melt, including thinning at the margins and increased discharge from many outlet glaciers of the GrIS in recent years. Moisture transport is particularly important due to its ability to alter radiative and turbulent fluxes, winds, precipitation, surface melting, and snow accumulation. This study will identify and categorize blocking events using a predicted Greenland Blocking Index (GBI) and take a quantity-based look at the connection of these events to moisture transport, quantified by integrated vapor transport (IVT).

## Motivation

- Gain understanding of what factors are playing the most significant role is Greenland Ice Sheet melt.
- Produce forecasts and predictions of the future of the extreme Greenland blocking, opening avenues for impact mitigation efforts.
- Assess CMIP6's ability to create a climatology of extreme Greenland Blocking by comparing to observed historical datasets.
- Studying specific locations on the Greenland Ice Sheet to understand the impact that extreme Greenland Blocking has on DoD operations and installations in high-altitudes.

## Data and Methods

- This study uses outputs from four CMIP6 historical models. The iterations used are provided in **Table 1** below. Each model ran using the r1i1p1f1 variant label and variables of specific humidity (hus), u-direction wind (ua), v-direction wind (va), and geopotential height (zg). The spatial resolution (lon,lat) shown is in degrees.

| Institution ID | Institution Name | Years Covered | File Time Length | Spatial Resolution | Nominal Resolution |
|---|---|---|---|---|---|
| **NCAR** | National Center for Atmospheric Research | 1850-2015 | Decade | 1.3,0.9 | 100 km |
| **CCCma** | Canadian Centre for Climate Modelling and Analysis | 1850-2014 | Decade | 2.8,2.8 | 500 km |
| **MPI-M** | Max-Planck Institute of Meteorology | 1850-2014 | 20 years | 1.9,1.9 | 250 km |
| **NASA-GISS** | National Air and Space - Goddard Institute for Space Studies | 1850-2014 | Decade | 2.5,2.0 | 250 km |

***Table 1:*** *Information regarding the origin and contents of historical models that were used to calculate GBI and IVT.*

- The datasets from each of these institutions were used to create a climate model of Greenland.
  - Greenland Blocking Index (GBI) was calculated primarily as a function of the variations in geopotential height.
  - Integrated Vapor Transport (IVT) is calculated with **Eqn. 1**, which provides a value for the amount of water vapor present in the atmosphere between 1000hPa and 200hPa.

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

## 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, NASA, CCCma, and MPI 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 Atlantic Sector of the Arctic***

## Results: blocking and moisture transport from NCAR, NASA, CCCma, and MPI historical run in summer months

### *Greenland Blocking (GBI) Trends from 1850-2015*

**GBI historical model trends graph:**

- Four different historical model were used to calculate GBI over Greenland for the last 170 years. This calculation was then used to create a time-series with percentile distinctions made for how extreme events were (**Fig. 1**).
- The CCCma model shows very low GBI from 1850 to about 1960, with an insignificant number of 99th percentile events (**Fig. 1 C**). There is, however, a spike in all percentiles starting in about 1970. This increase plateaus until the end of the time series.
- NASA and CCCma models show a slight increase in the amount of 99th percentile events in the final 1/3rd of the time series (**Fig. 1 B,C**).
- NCAR, NASA, and MPI models all show a relative maximum in the 2000-2009 time period (**Fig. 1 A,B,D**).
  - It is also worth nothing that the final time period, (2010-2014/2015) is shorter time period than all other periods in the time series.

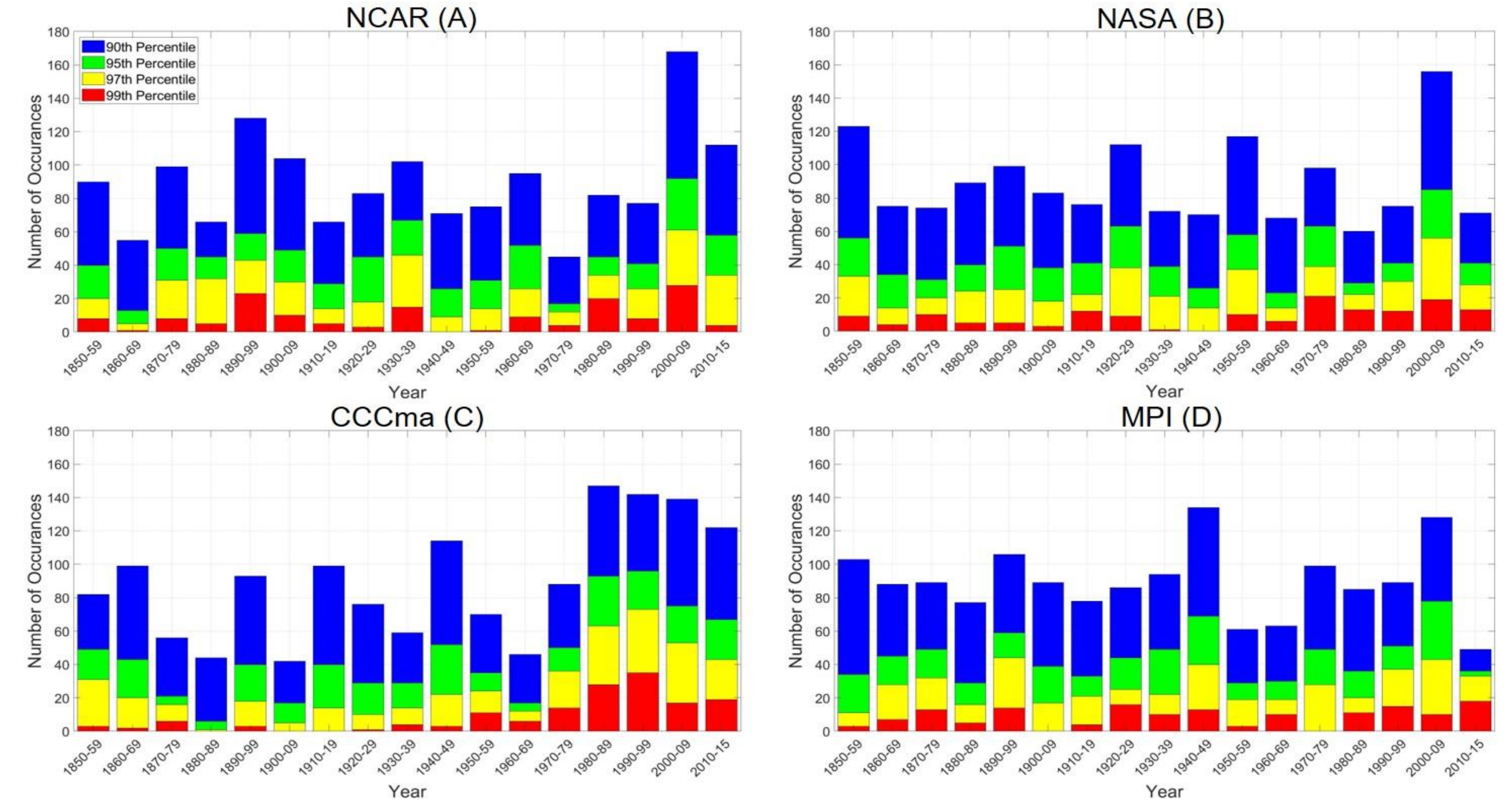


***Figure 1****: Time Series of GBI (m) values including 90th, 95th, 97th, and 99th percentiles for summer months. CMIP6 models cover the time period from 1850-2015.*

### *Greenland Blocking Index (GBI) Distributions from 1850-2015*

| GBI Percentile | JJA NCAR | NASA | CCCma | MPI |
|---|---|---|---|---|
| 90th | **5637** | *5591* | 5618 | 5604 |
| 95th | **5664** | *5619* | 5641 | 5628 |
| 97th | **5681** | *5636* | 5657 | 5643 |
| 99th | **5711** | *5665* | 5682 | 5671 |

***Table 2****: Table of GBI values (in m) including 90th, 95th, 97th, and 99th percentiles for summer months. CMIP6 models cover the time period from 1850-2015.*

**GBI and IVT Distributions by Percentile**

- GBI and IVT distributions were derived from histograms of each model's outputs.
  - GBI histograms produced similar gaussian shapes throughout models.
  - IVT histograms were varied among models, with NCAR and NASA showing a more significant right tail than CCCma and MPI.
- The NCAR model has the highest GBI and IVT values for every percentile in summer months.
  - NCAR's 97th percentile GBI events were higher than NASA and MPI's 99th percentile GBI events (**Table 2**).
  - NCAR's 90th percentile IVT events were higher than CCCma and MPI's 99th percentile events (**Table 1**).
- The NASA model has the lowest GBI and MPI has the lowest IVT values for every percentile in summer months.
  - NASA's 97th percentile GBI events were lower than NCAR's 90th percentile GBI events (**Table 2**).
- MPI and CCCma show a much smaller difference from 90th to 99th IVT percentiles than NCAR and NASA (**Table 1**).
  - CCCma has a difference of 37 $\mathrm{kg\ m^{-1}s^{-1}}$ and NCAR has a difference of 144 $\mathrm{kg\ m^{-1}s^{-1}}$ .

### *Integrated Vapor Transport (IVT) Distributions from 1850-2015*

| IVT Percentile | JJA NCAR | NASA | CCCma | MPI |
|---|---|---|---|---|
| 90th | **290** | 196 | 165 | *157* |
| 95th | **339** | 235 | 178 | *172* |
| 97th | **372** | 266 | 186 | *181* |
| 99th | **434** | 337 | 202 | *201* |

***Table 3****: Table of IVT values (in kg $m^{-1}$ $s^{-1}$) including 90th, 95th, 97th, and 99th percentiles for summer months. CMIP6 models cover the time period from 1850-2015.*

## Results: lead-lag relationship between extreme GBI and high IVT

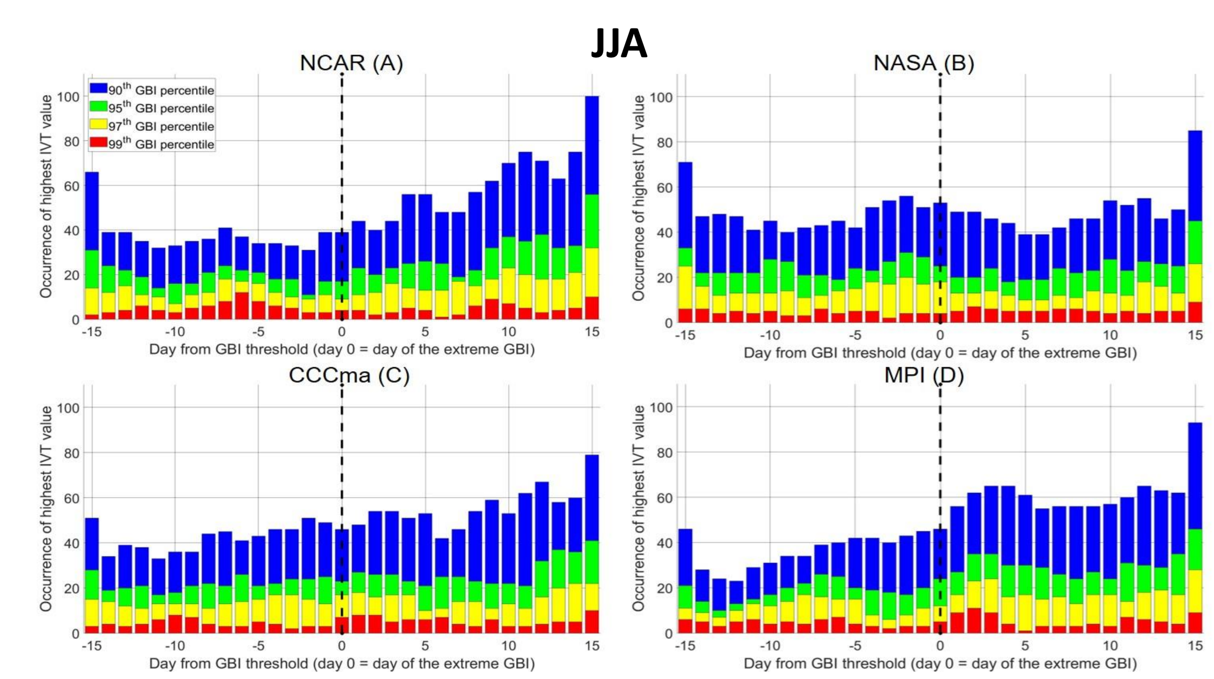


***Figure 2****: Lead-lag relationship between extreme GBI event and above average IVT events. Data from historical NCAR (A), NASA (B), CCCma (C), and MPI (D) CMIP6 model for 1850-2015.*

**Lead-Lag relationship in summer months:**

- The NCAR, CCCma, and MPI models all show a similar pattern of generally increasing for the entire 30 day period of the lead-lag while NASA remains relatively constant (**Fig. 2**).
  - For NCAR, CCCma, and MPI models, the overall increase is most prevalent in the 90th percentile GBI events (**Fig. 2 A,C,D**).
- The 99th percentile GBI values are constant over all 30 days (**Fig. 2**).
- There is a relative maximum at -15 and +15 days of the extreme GBI events in all four models.

**Lead-Lag relationship in winter months:**

- The NASA, CCCma, and MPI models all show a significant decrease in IVT measurements from -15 days to the day of the extreme GBI event (**Fig. 3 B,C,D**).
- For these same three models, the pattern stays fairly constant after the extreme GBI event, only increasing slightly immediately after the event.
- The NCAR model shows fairly insignificant tri-model peaks for the overall level of highest IVT measurements (**Fig. 1 A**).
- The NASA, CCCma, and MPI models show the most variation among the 95th and 97th percentiles whereas the 90th and 99th percentile GBI events are fairly constant (**Fig. 1 B,C,D**).

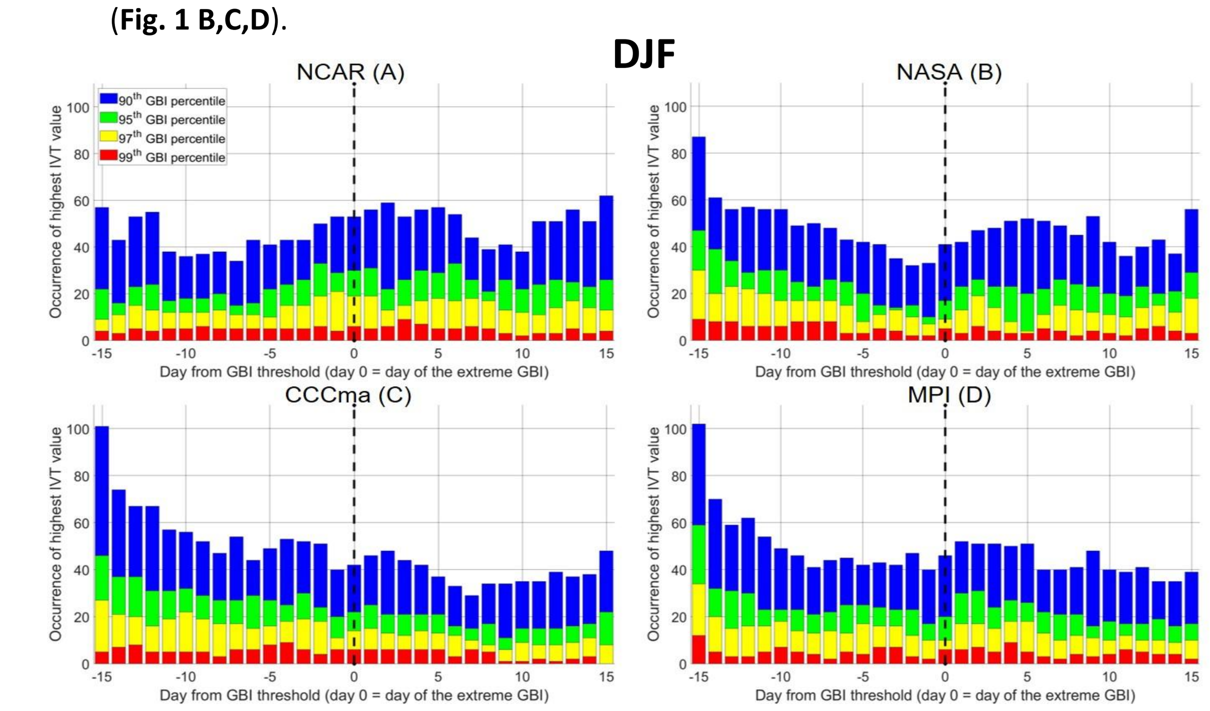


***Figure 3****: Lead-lag relationship between extreme GBI event and above average IVT event. Data from historical NCAR (A), NASA (B), CCCma (C), and MPI (D) CMIP6 model for 1850-2015.*

## Future Work

The next steps in this research are to:

- Understand blocking as defined by more complex methods. The metric to examine atmospheric blocking (GBI) is among the simplest methods available.
- Calculate IVT in the different coordinates of, 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. In this study, IVT was averaged between 60°–80°N and 20°–80°W.
- Consider different resolutions of the CMIP6 output to assess the sensitivity of IVT to both horizontal and vertical resolution of pressure levels.
- Assess further the impacts of these trends on DoD installations and suggest plans to mitigate the risks involved with NAA operations.
- Link blocking and moisture transport to changes in surface mass balance over Greenland, with particular emphasis on how extreme blocking may affect ice mass balance at US DoD installations in Northwest Greenland (Thule AFB, Camp Century, etc.).

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### References

Danabasoglu, G. (2019), NCAR CESM2 model output prepared for CMIP6 CMIP historical, Accessed 20201221, Earth System Grid Federation. doi:10.22033/ESGF/CMIP6.7627
Hanna, E., T. E. Cropper, R. J. Hall, J. Cappelen (2016), Greenland Blocking Index 1851-2015: a regional climate signal, Int. J. Climatol. vol: 36, 4847-4861.
Mattingly, K. S., C. A. Ramseyer, J. J. Rosen, T. L. Mote, R. Mythyala, (2016), Increasing water vapor transport to the Greenland Ice Sheet revealed using self-organizing maps, Geophys. Res. Lett., 43, 9250-9258, doi: 10.1002/2016GL070424.
Pelly, J., and B. Hoskins (2003), A new perspective on blocking, J. of Atmos. Sci., vol: 60(5), 743–755.