Atmospheric Bottlenecks over the Arctic: A Climatological Investigation of Extreme Greenland Blocking Episodes and Their Impact on Melting across the Greenland Ice Sheet

Jordan T. McLeod and Thomas L. Mote

University of Georgia, Department of Geography

Background

- Greenland blocks are synoptic-scale ridges of high pressure extending poleward from the North Atlantic to the Arctic region that advect warm subtropical air northward over the ice sheet.
- The Arctic region has been warming at a much faster rate than both the mid-latitudes and the tropics, a phenomenon known as Arctic Amplification.
- Some recent studies (Francis and Vavrus 2012, Petoukhov et al. 2013) have suggested that Greenland blocking may become more frequent in the future due to a weakened polar jet stream, although other studies (Screen and Simmonds 2013, Barnes 2013) have challenged this linkage between Arctic Amplification and high-latitude atmospheric circulation variability.
- Greenland blocks have played a significant role in recent extreme events from the mid-to-high latitudes, including the exceptional surface melting across the Greenland ice sheet (GrIS) during July 2012 and the unusual track of Hurricane Sandy in October 2012.

Research Questions

1) Has there been a significant increase in the frequency, strength, or duration of extreme Greenland blocks during the period of record from 1958-2013?
2) Is there a significant difference in the frequency, strength, or duration of extreme Greenland blocks by season? If so, are there any discernible trends by season from 1958-2013?
3) Are there any statistically significant predictors of summer melting conditions across the Greenland ice sheet from 1979-2008?

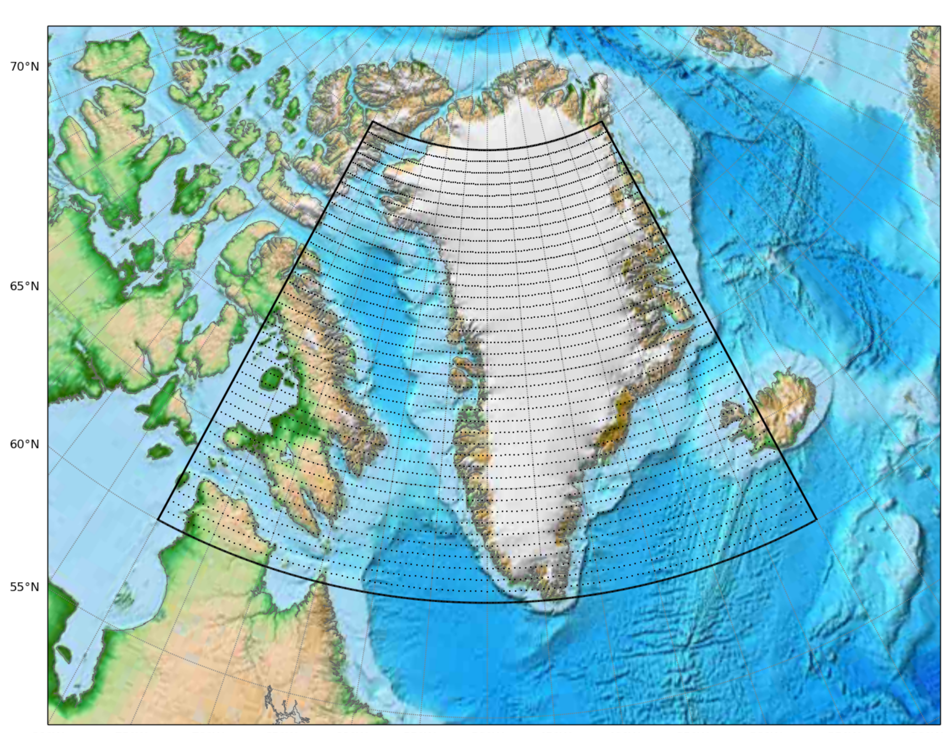

Fig. 1. Regional map indicating the spatial domain for the Greenland Blocking Index, based on Hanna et al. (2012).

Data Sources and Methods

- A combination of the ERA-40 (1958–1978) and ERA-Interim (1979–2013) reanalysis datasets provided by ECMWF (Dee et al. 2011) at 0.5° spatial resolution was used to create a daily time series of the Greenland Blocking Index (GBI).
- According to Hanna et al. (2012), the GBI is defined as the mean 500 hPa geopotential height over the Greenland region spanning from 60°–80°N latitude and 20°–80°W longitude.
- The GBI time series was low-pass filtered and subsequently standardized in order to minimize spurious atmospheric disturbances and remove the seasonal cycle in 500 hPa heights.
- Based on composite maps of 500 hPa heights over the North Atlantic, extreme Greenland blocks are defined as sequences of at least 5 consecutive days in which the GBI equals or exceeds the 96th percentile (a Z-score of +1.75 standard deviations) of all daily GBI values from 1958-2013 within a 7-day window centered on the days in question.
- An OLS multivariate regression model is used to predict the average GrIS melt extent for each summer (JJA) season from 1979-2008. The following independent variables were selected as predictors: (1) mean GBI, (2) mean AO index (NOAA CPC), (3) frequency of all North Atlantic cyclones within the geographic domain from 50°-65°N latitude and 20°-70°W longitude (Serreze 2009, NSIDC), (4) the average intensity of these North Atlantic cyclones, and (5) the mean sea surface temperature (SST) over the North Atlantic region extending from 50°-65°N latitude and 20°-70°W longitude (Dee et al. 2011).

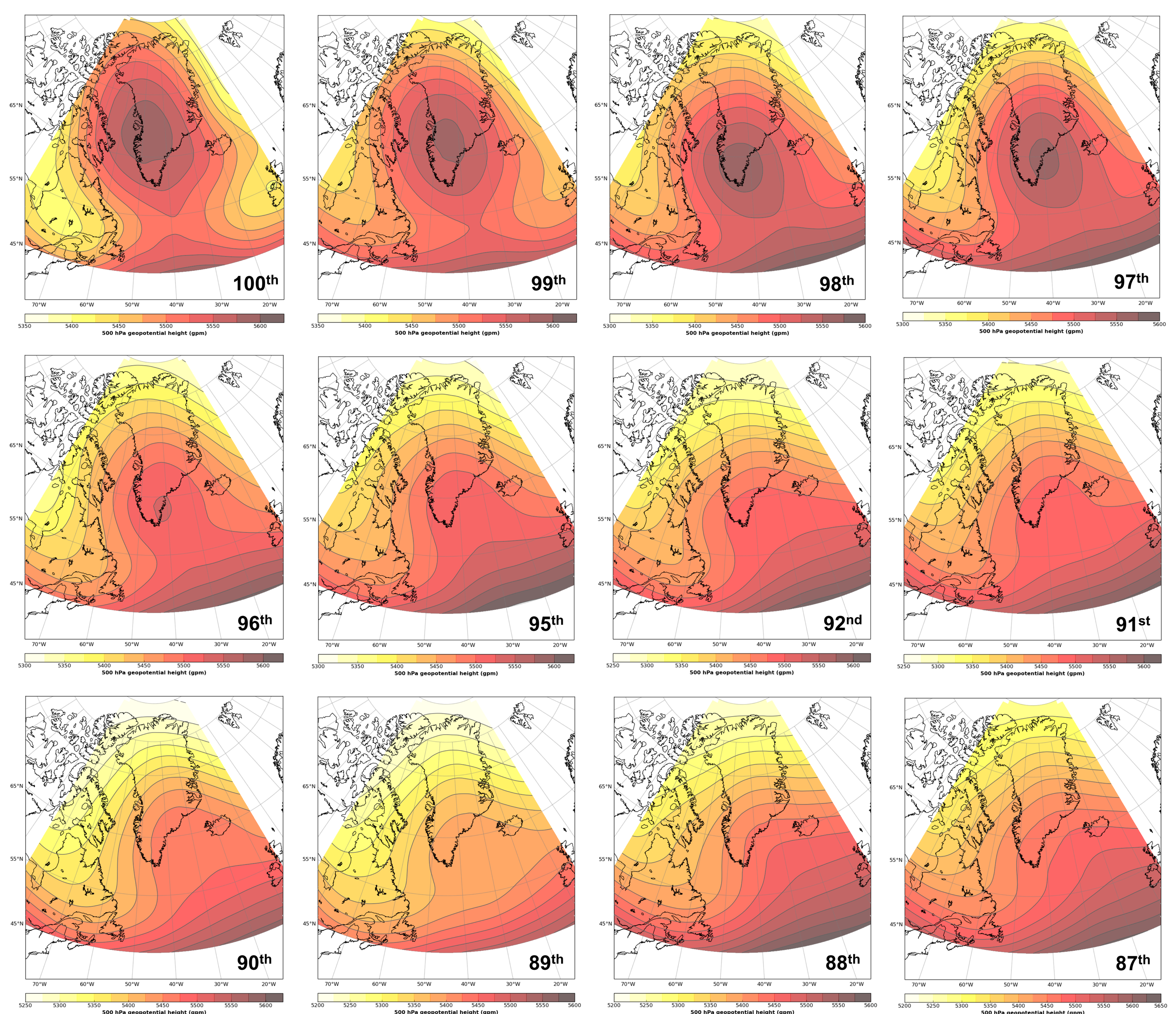

Fig. 2. Composite maps of 500 hPa geopotential heights over the North Atlantic for all days in which the GBI ranked within a unit percentile range based on the entire 55-year climatological distribution. Maps for the 87th – 100th percentiles (excluding the 93rd and 94th percentiles due to a strong similarity with the 95th percentile) are shown in a row-wise descending order.

Results

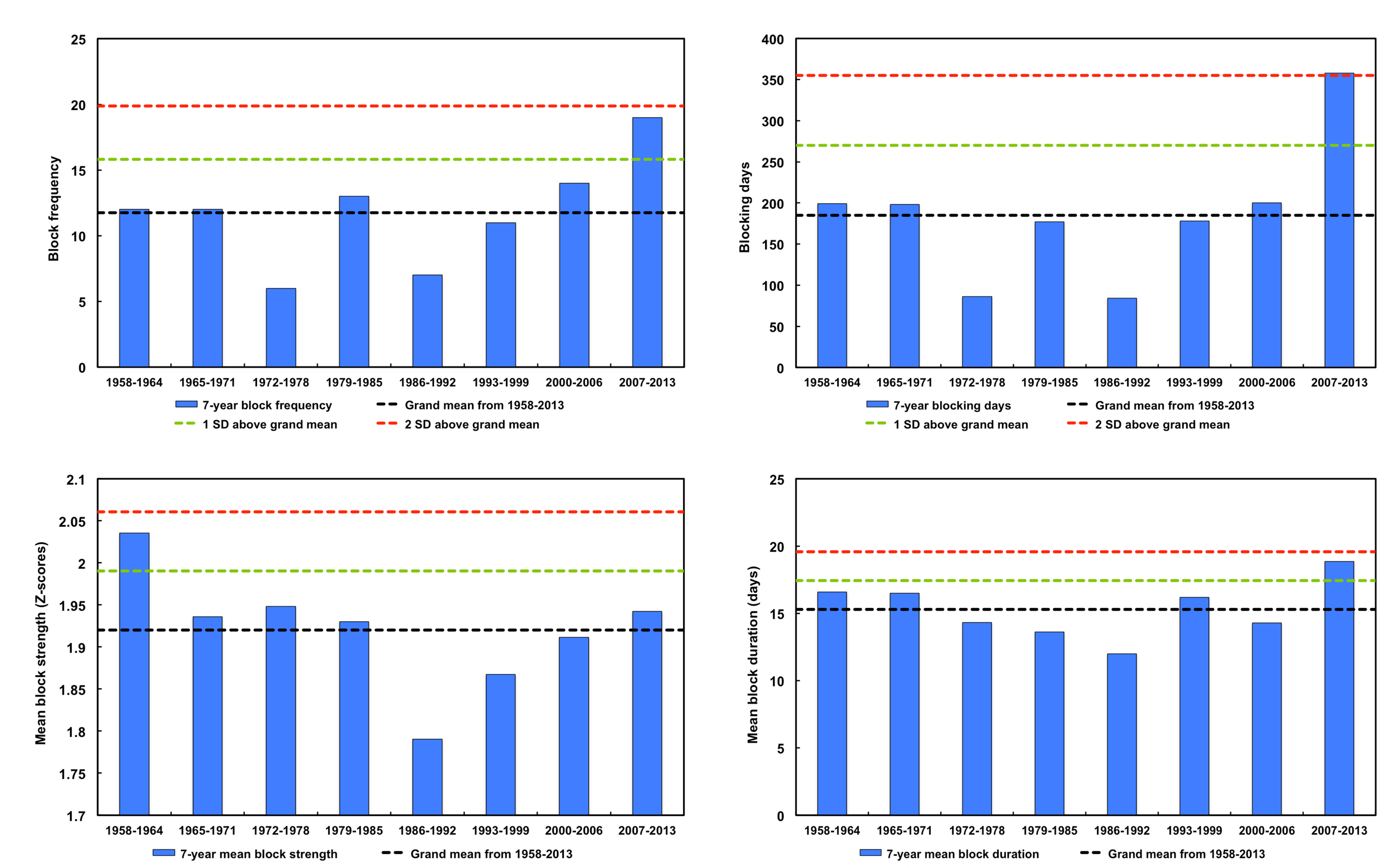

Fig. 3. 7-year frequency (top left), blocking days (top right), mean strength (bottom left), and mean duration (bottom right) of extreme Greenland blocks from 1958–2013. The mean block duration from 2007–2013 (~18.8 days) is statistically greater than the mean block duration from 1958–2006 (~15.0 days) at the 99% confidence level.

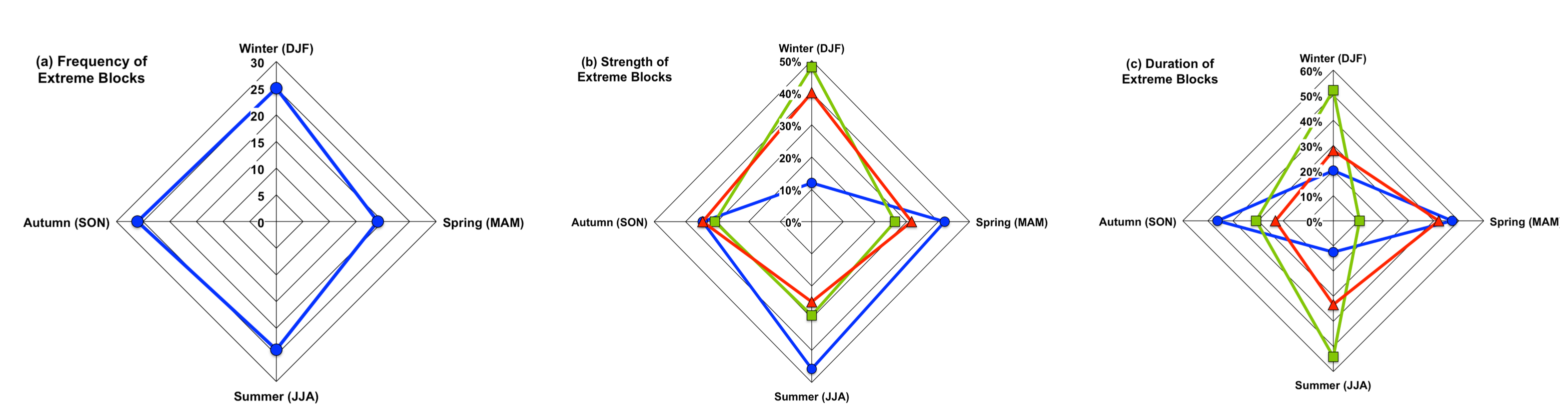

Fig. 4. Frequency, strength, and duration of extreme Greenland blocks by season from 1958–2013 (n = 94). For plot (b), blocks are grouped into nearly equally-sized terciles based on the standardized magnitude of the GBI as follows: 1st tercile (n = 31), 2nd tercile (n = 32), and 3rd tercile (n = 31). For plot (c), the quasi-normal distribution of block durations necessitated the less optimal use of unequally-sized terciles as follows: 1st tercile (n = 29), 2nd tercile (n = 36), and 3rd tercile (n = 29).

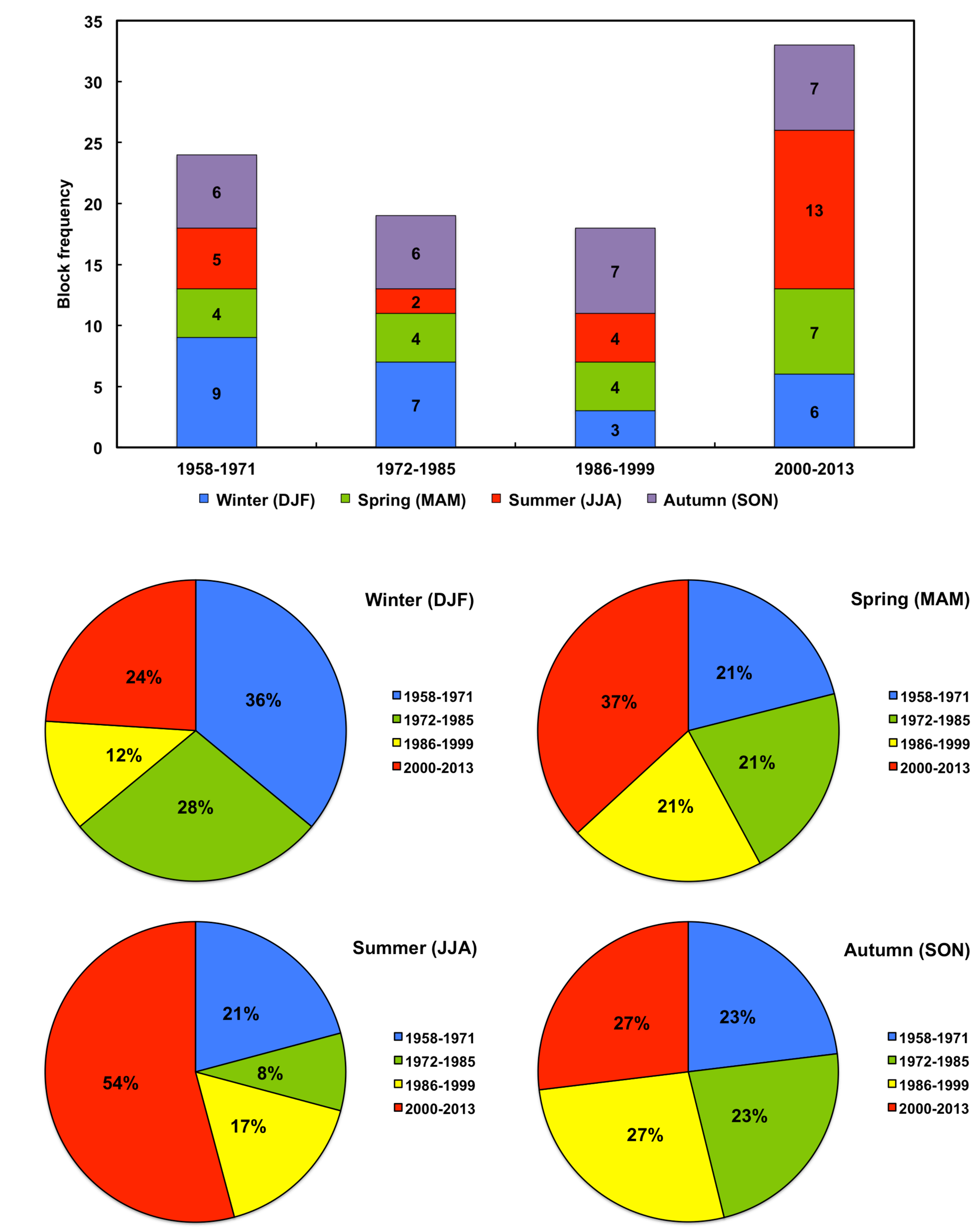

Fig. 5. Seasonal frequency (top) of extreme Greenland blocks across 14-year bins from 1958–2013. Percentage of extreme Greenland blocks by season within each of the four 14–year bins from 1958-2013 (bottom).

Table 1. Statistical results for the OLS multivariate regression model.

Predictors	Slope Coefficient	Standard Error	Standardized Slope Coefficient	t-value	p-value
GBI	0.166	0.041	0.801	4.01	0.001*
AO	2.532	3.105	0.153	0.82	0.423
NAC_freq	0.713	0.271	0.401	2.63	0.015*
NAC_strength	-2.103	0.638	-0.511	-3.29	0.003*
NA_SST	2.154	2.402	0.144	0.9	0.379

Number of obs	30
F-statistic	7.24
p-value for F	<0.001
R^2	0.602
Adjusted R^2	0.518
Mean Squared Error	3.679

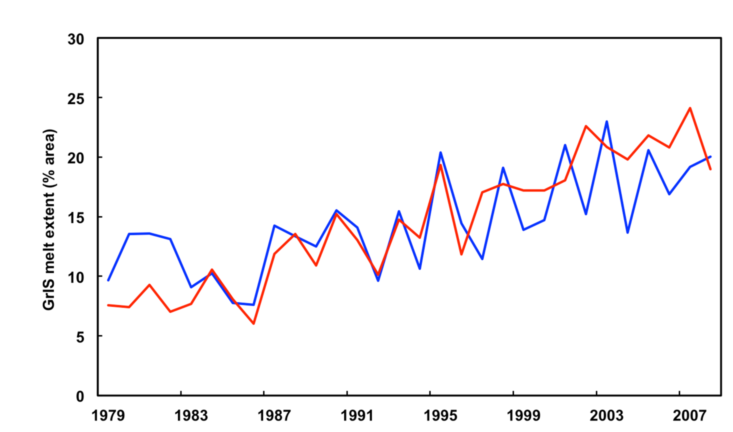

Fig. 6. Time series of observed versus predicted values of mean GrIS melt extent during the summer (JJA) from 1979-2008.

Discussion and Conclusions

- Extreme Greenland blocking frequency (event counts or daily sums) and duration were unprecedentedly high from 2007–2013 with respect to the 55-year period of record, approaching two standard deviations above their climatological mean values (***Fig. 3***).
- The strength and duration of extreme blocks varies considerably by season. Extreme blocks during summer (winter) tend to be relatively weak (strong). Winter and summer blocks tend to be the longest-lasting. Spring blocks have the greatest variability in duration (***Fig. 4***).
- While the frequency of autumn and winter blocks has remained fairly constant since 1958, the frequency of spring and, especially, summer blocks reached an exceptionally high level from 2000–2013. Approximately 54% of all extreme summer blocks occurred during this 14-year period (chi-square = 11.67, p < 0.01) (***Fig. 5***).
- Three independent variables had a statistically significant effect on GrIS summer melting at the 95% confidence level: the GBI, North Atlantic cyclone frequency, and North Atlantic cyclone intensity (***Fig. 6***).

Contact Information: Jordan T. McLeod, Department of Geography, UGA; Email – jtmcleod@uga.edu