Links Between Arctic Amplification and Extreme Weather in Mid-Latitudes

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What do we mean by "Extreme Weather?"

Extreme weather comes in many flavors. In this study we refer to events that result from persistent weather conditions, such as heat waves, cold spells, droughts, and prolonged precipitation that causes floods and snowy winters. These types of events are associated with high-amplitude patterns in 500 hPa heights that tend to move slowly and create persistent weather. Several examples of actual extreme weather events are illustrated in Figure 1.

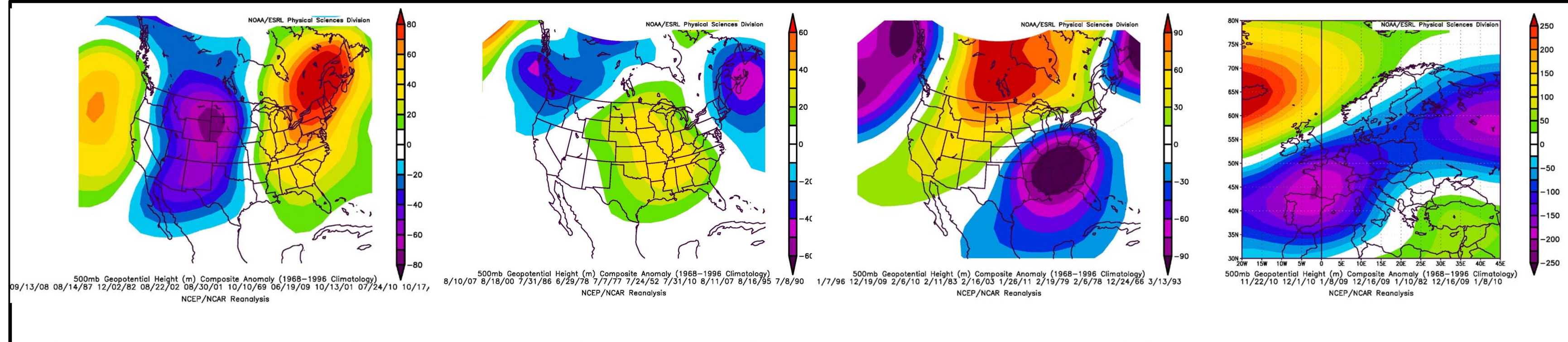


Figure 1: 500 hPa anomaly fields associated with 4 examples of extreme weather events. From left to right: Heaviest precipitation events in Chicago, hottest days in Atlanta, snowiest days in Philadelphia, and coldest days in W. Europe. Note that in each case the 500 hPa height field is characterized by a high-amplitude flow that tends to favor persistent weather conditions.

Arctic Amplification

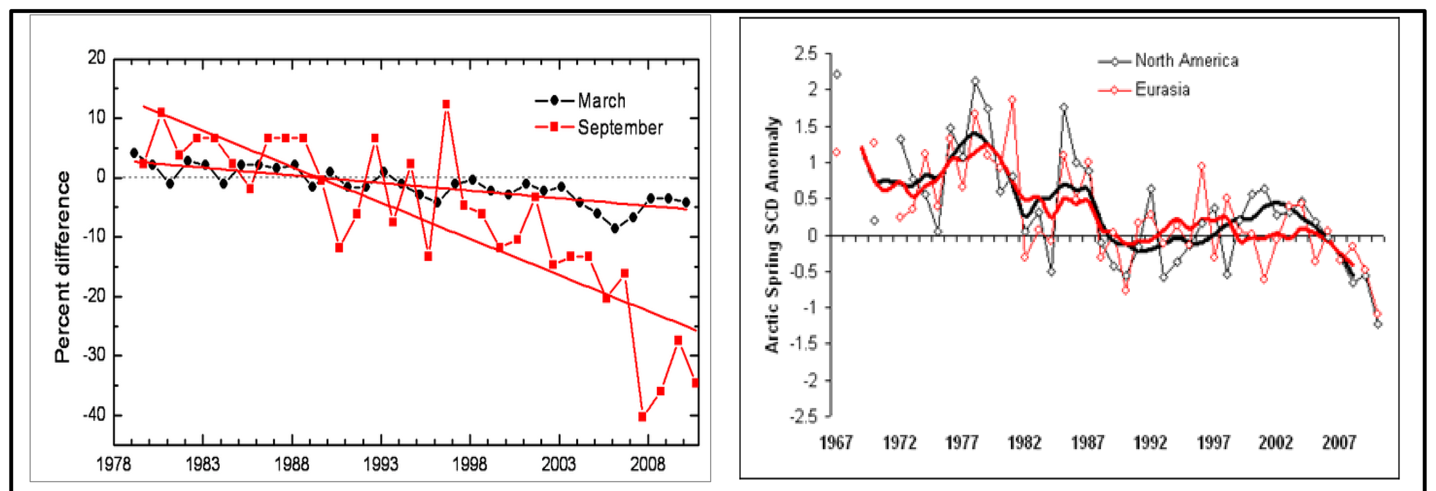
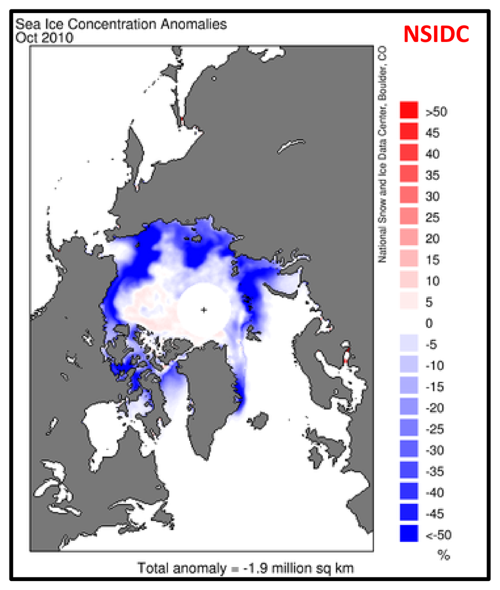


Figure 2: The loss of sea ice (left) has been dramatic in recent decades, particularly during summer (red). As the ice pack thins owing to increased export of thick ice and surface heating, remaining ice is more vulnerable to anomalies in wind patterns and surface energy fluxes. Snow cover (right) on high-latitude land areas has been melting earlier in spring, resulting in earlier warming and drying of soils that contribute to Arctic Amplification during summer. Sea ice data are from the National Snow and Ice Data Center, and snow anomalies are from Brown et al, (2010).



Increased ice loss during summer exposes additional open water to the cold autumn atmosphere, delaying freeze-up. A tremendous amount of heat and moisture is released into the air, resulting in temperature anomalies that persist into winter and extend to upper atmospheric levels.

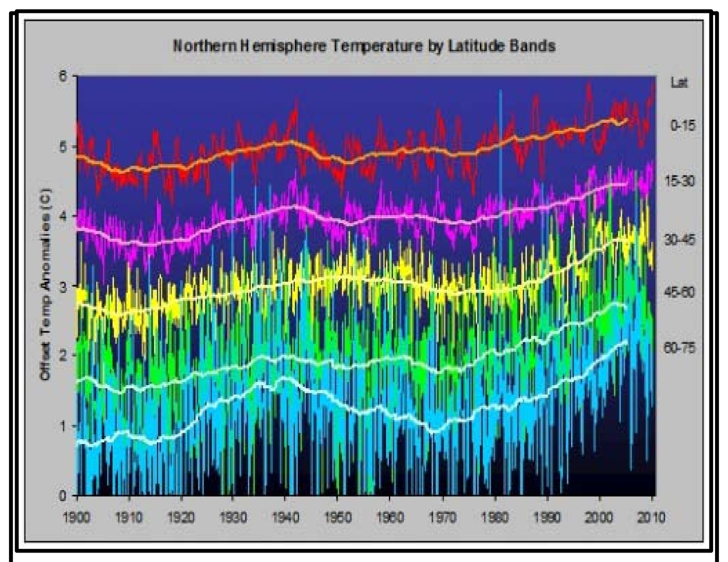


Figure 3: Surface air temperature anomalies by latitude band, offset by 1°C (figure by P. Hogarth based on CRUTEM3 and HadSST2 data). The existence of ice and snow in the Arctic enhances its sensitivity to forcing anomalies. Note that Arctic temperatures (bottom curve) exhibit larger fluctuations, as well as larger positive trends since mid-century .

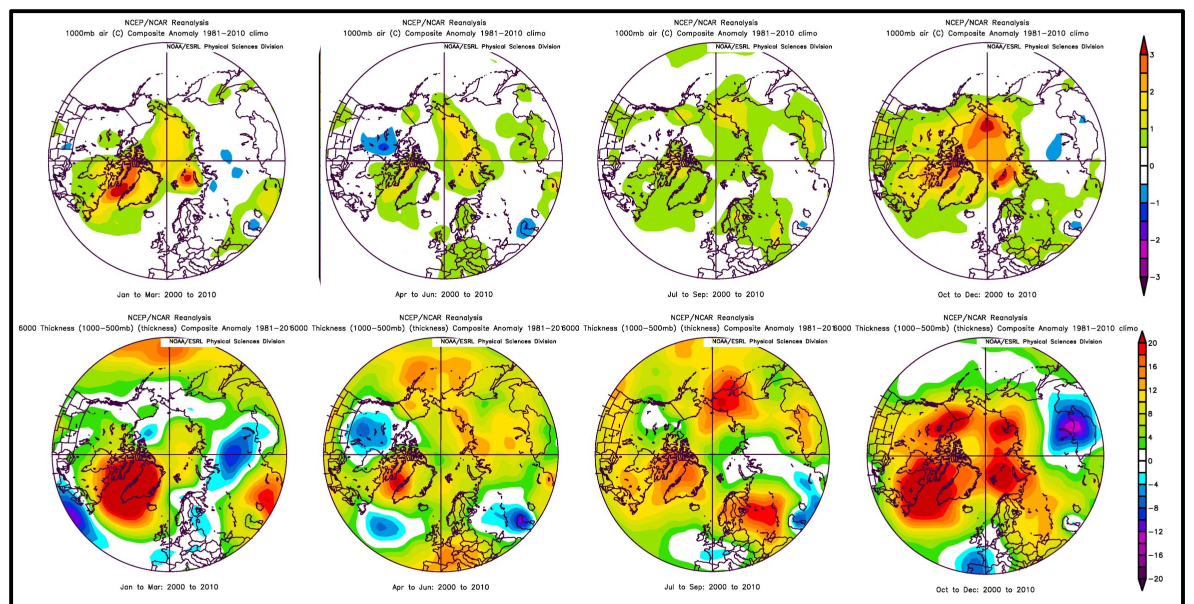


Figure 4: Anomalies in air temperature (C) at 1000 hPa (top row) and 1000-500 hPa thicknesses (m) (bottom row) in each season (columns): JFM, AMJ, JAS, and OND during 2000-2010. Data are from the NCEP/NCAR Reanalysis, http://www.esrl.noaa.gov/psd/. Note large positive anomalies in surface temperatures, especially during fall and winter in close proximity to the ice pack, with evidence of effects of earlier snow melt during summer. Corresponding positive anomalies in 1000-500 hPa thickness are more widespread but largest in high latitudes.

How are these phenomena linked?

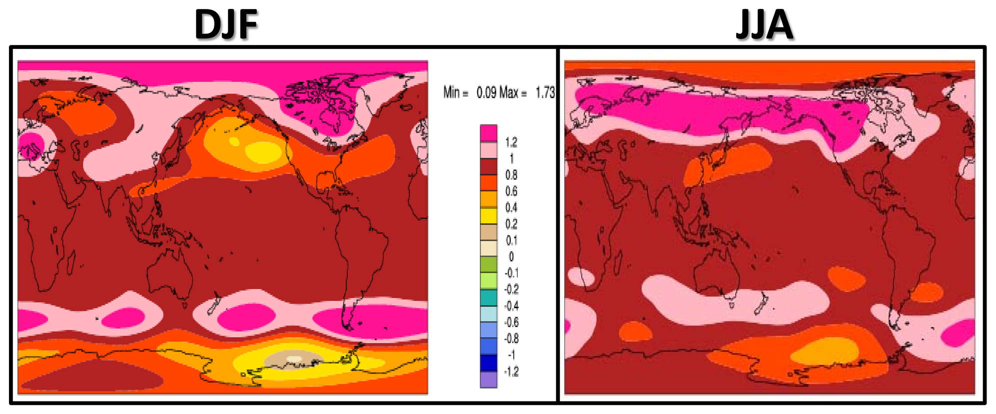


Figure 5: Arctic Amplification causes the thickness over the Arctic to increase more than at mid-latitudes (see Fig. 4). NCAR's CCSM4 model forced by 4xCO_2 conditions (left) projects elevated 500 hPa heights over the Arctic in winter owing to sea-ice loss and over the sub-Arctic during summer caused by earlier snow melt. Both effects reduce the poleward height gradient and weaken the zonal flow. Observations (NCEP reanalysis) suggest that this change is already occurring – see Figure 6.

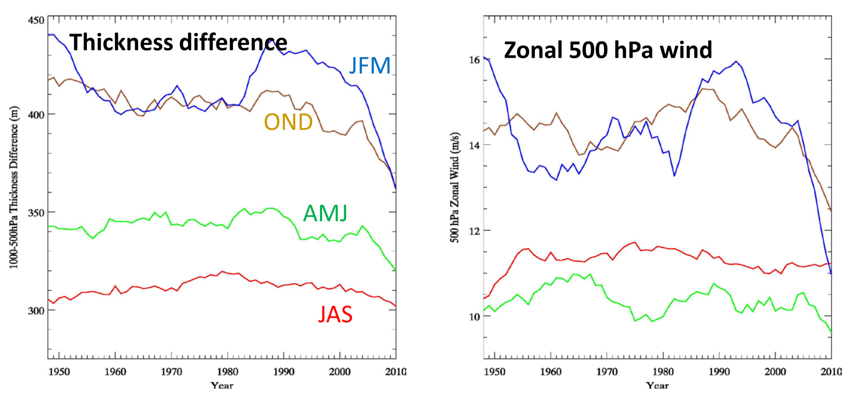


Figure 6: Time series of 1000-500 hPa thickness differences (left) between 80-60°N and 50-30°N over N. America and zonal mean winds at 500 hPa between 40-60N for winter (blue), spring (green), summer (red), and fall (brown). Data were obtained from the NCEP/NCAR reanalysis. Since the mid-1980s, the **poleward thickness gradient has decreased markedly,** particularly in fall and winter. The **zonal wind speed at 500 hPa has followed suit, with a decrease of about 20%.**

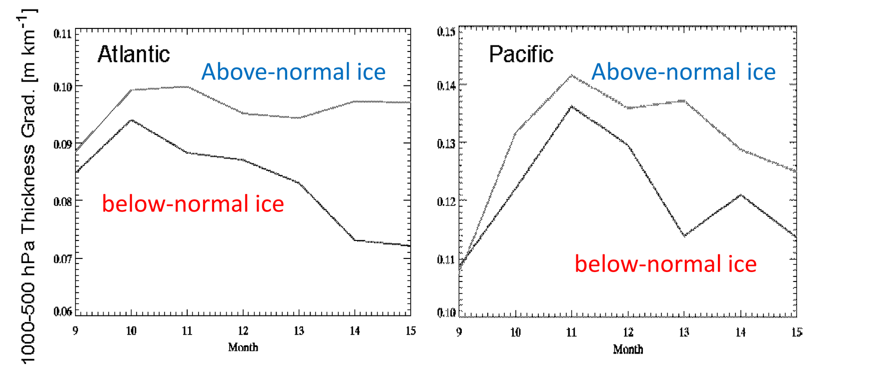


Figure 7: It's also apparent that the changes in poleward gradient are related to the loss of sea ice. This pair of plots shows time series of 1000-500 hPa thickness gradients in the N. Atlantic and N. Pacific during years with above- and below-normal sea ice extent. Data extend from September of the extreme ice year to the following March. **Thickness gradients are weaker after summers with less ice than normal, and the weakening extends to the following spring.** (from Francis et al, 2009)

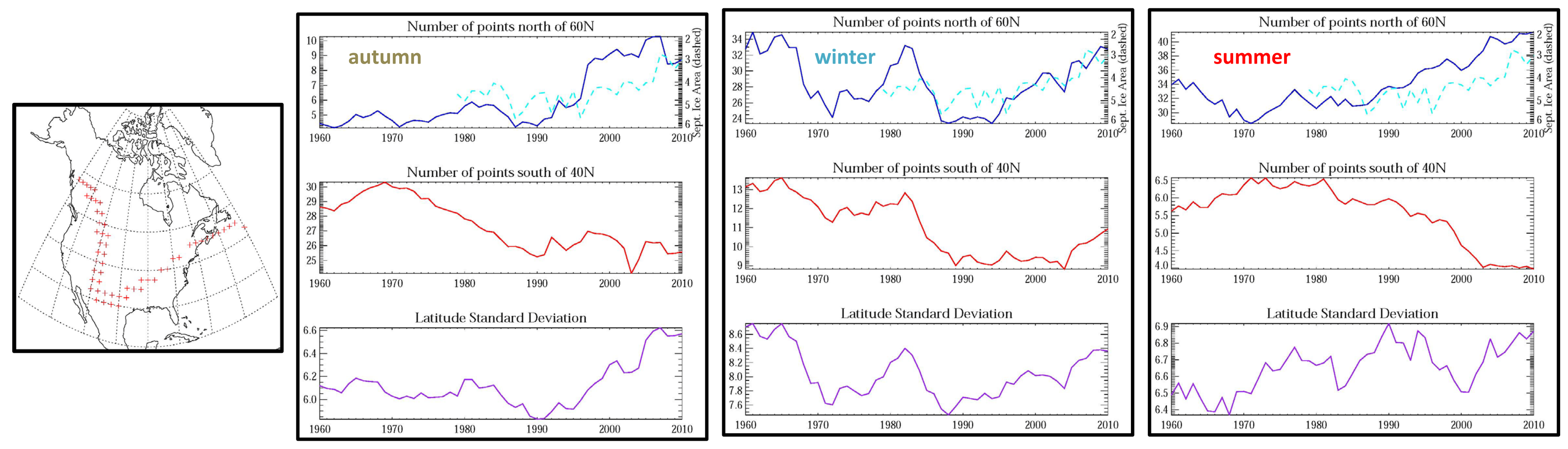


Figure 8: We analyze selected isopleths of the 500 hPa height field over several decades to characterize changes in the 500 hPa pattern over N. America. Left is an example of a typical isopleth. The plot for autumn shows the annual-mean number of gridpoints with 500 hPa heights at 5600 m ±50m located north of 60°N (top) and south of 40°N (center). The bottom plot is the standard deviation of gridpoint latitudes, which indicates the amplitude of waves in flow. The winter plot is the same but for the 5400 m ±50m isopleth, and the summer is for 5700m. The dotted turquoise line shows the Sept-minimum sea-ice extent. Curves have been smoothed with a 10-year moving boxcar filter.

What does this all mean?

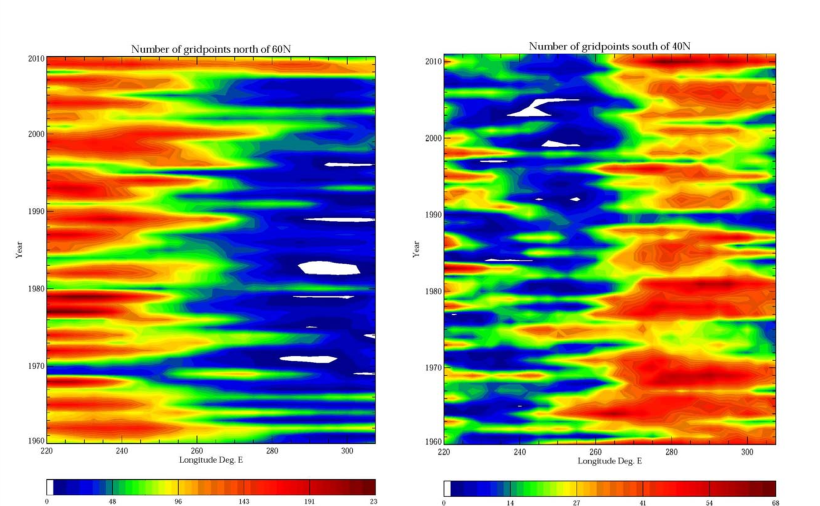
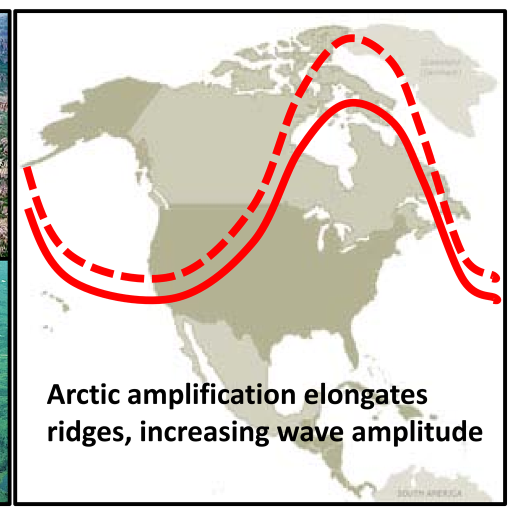


Figure 9: Hovemöller diagrams show longitudinal variations with time of the number of gridpoints with 500 hPa heights of 5700m north of 60°N during summer (left) and with heights of 5400m south of 40°N during winter over N. America.



Based on these results for N. America, as well as similar analyses for other regions not shown here, we conclude:

- **Arctic Amplification leads to weaker zonal flow in upper levels**, particularly in fall and winter and also to a **higher-amplitude pattern in all seasons.**
- **Figure 8** shows that the number of gridpoints with 500 hPa heights representative of the maximum flow has increased north of 60°N (top panels), suggesting that **the peaks of ridges have shifted northward, while the number of points south of 40°N has decreased,** suggesting the entire jet stream has shifted northward. This is consistent with other studies (e.g., Seidel et al, 2007) suggesting that the tropics are expanding as a result of global warming.
- **Ridges are shifting northward faster,** however, as indicated by increasing standard deviations (Fig. 8, lower panels) and as illustrated in schematic to left.
- **Waves in 500 hPa heights have elongated and the flow has amplified, favoring more persistent weather conditions**
- Weaker zonal flow further enhances wave amplitude, just as a river flowing down a steep slope tends to flow straighter than one on a flat coastal plain (photos left).
- Hovemöller diagrams suggest that **ridges have strengthened over western N. America during summer (Fig. 9, left), resulting in drier and hotter conditions**, while **troughs during winter (Fig. 9, right) have shifted eastward, weakened in the west, and strengthened in the east, contributing to colder, snowier East-Coast winters.**

References
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