Simulation of Extreme Arctic Cyclones in IPCC AR5 Experiments

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Overview

A wild card in impending Arctic climate change is how extreme weather events will respond. Intense polar cyclones are one such high-latitude phenomenon, including strong synoptic-scale cyclones and mesoscale polar lows. These systems inflict damage through high winds, heavy precipitation, and coastal erosion, and their future impact should increase, as waning sea ice cover allows enhanced wave energy.

Hypothesis

Extreme Arctic cyclones will become more frequent and intense in a warming climate, as retreating ice cover causes more open water to fuel storms and a poleward shift of baroclinicity. Climate models typically simulate lower mean Arctic sea level pressure (SLP) under greenhouse forcing, suggesting that extreme cyclones may follow suit.

Methods

To explore this hypothesis, I use one of the climate models in the CMIP5 archive---the Community Climate System Model (CCSM4)---and the 20th Century Atmospheric Reanalysis. These two tools allow both a retrospective analysis of trends since the mid-1800s and a prospective analysis of 21st-century changes under the RCP8.5 greenhouse forcing scenario.

Distribution of Daily Arctic SLP (CCSM4, Reanalysis)

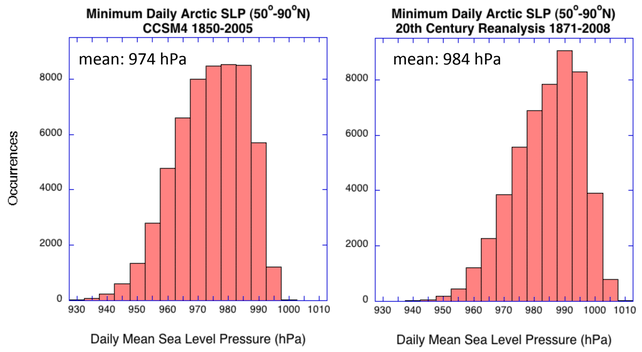

Figure 1. Frequency distribution of minimum daily sea level pressure (SLP) north of 50ºN since the mid-1800s, as represented by CCSM4 and the reanalysis.

Trends in Extreme Cyclones (CCSM4, Reanalysis)

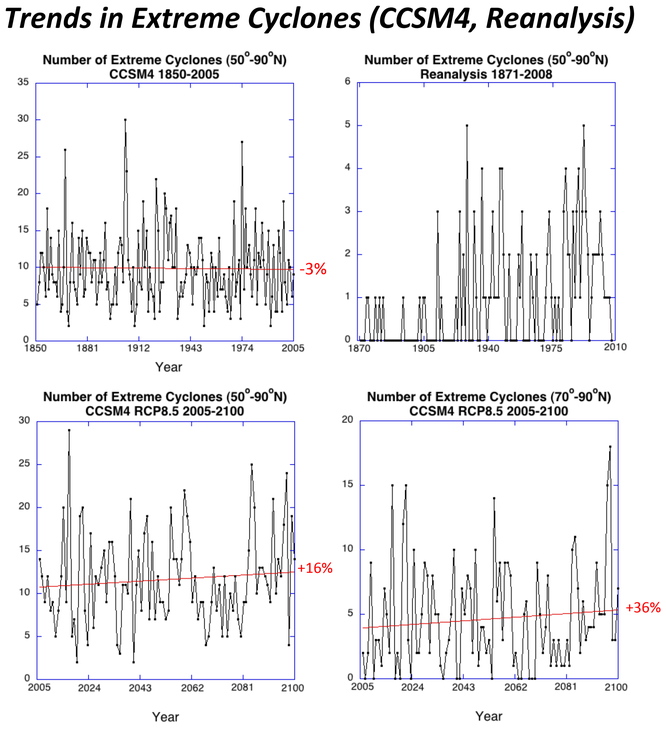

Figure 2. Trends in the annual number of extreme Arctic cyclones (< 950 hPa) (top) since the mid-1800s in CCSM4 & Reanalysis, and (bottom) projected 21st century poleward of 50ºN and 70ºN. Note the larger % rise in the central Arctic.

Trends in Extreme Minimum SLP (CCSM4)

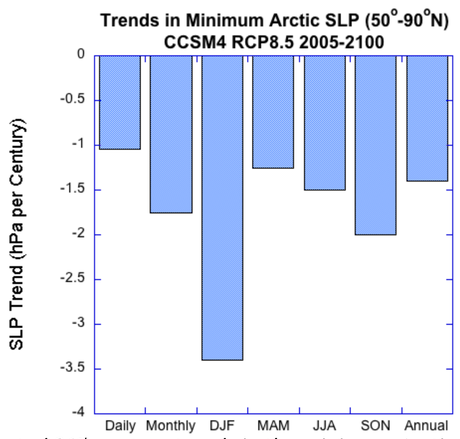

Figure 3. Projected 21st-century trends in the minimum Arctic SLP on various time scales. All trends are negative and statistically significant except spring. The largest simulated decreases in extreme SLP occur in winter and autumn.

Frequency of Extreme Cyclones in CCSM4

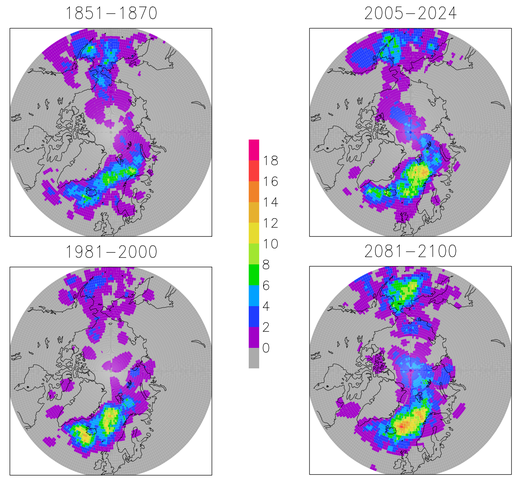

Figure 4. Changes in location and frequency of extreme cyclones. Under greenhouse forcing, these systems become more common and spread into the central Arctic.

Wintertime SLP in CCSM4: Past and Future

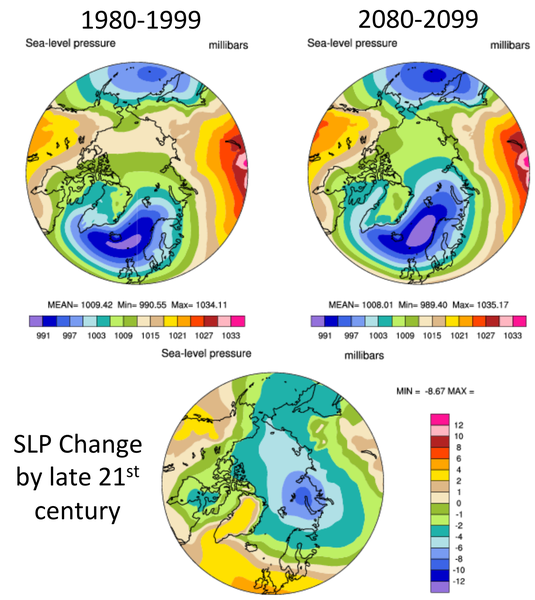

Figure 5. High-latitude SLP during winter as simulated by CCSM4 during the late 20th and late 21st centuries. Note the large future decrease in SLP in the central Arctic that extends from the North Atlantic storm track.

Autumn-Winter Sea Ice in CCSM4: Past and Future

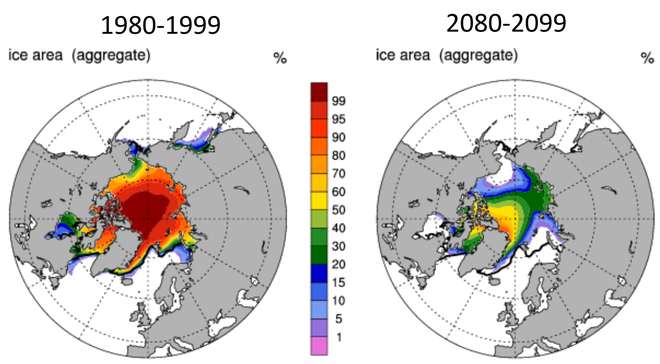

Figure 6. Changes in October-December sea ice coverage as simulated by CCSM4 during the late 20th and 21st centuries. The large reduction of ice cover is associated with more cyclonic activity, especially in the central Arctic.

CCSM4 Simulation of an Arctic Megacyclone

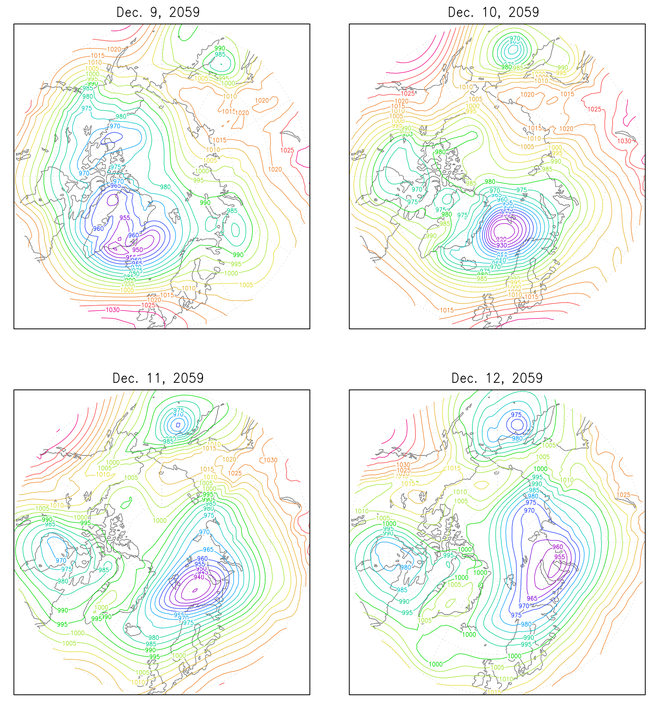

Figure 7. Simulation of an intense Arctic cyclone in CCSM4's 21st-century run. Central pressure reached 915 hPa and produced geostrophic wind speeds of 90 mph (145 km/hr), making this an Arctic hurricane. The model's 1º horizontal resolution is therefore sufficient to resolve such intense storms.

Conclusions

1. CCSM4 generates many more extreme Arctic cyclones than the 20th Century Reanalysis---but is the reanalysis hindered by its coarser (2º) resolution?
2. Strong greenhouse warming in the 21st century leads to more and stronger extreme Arctic cyclones, especially during autumn and winter
3. But this trend does not emerge through the 20th century---was there not enough warming and ice loss to effect this dynamical change?
4. CCSM4 simulates a poleward shift of extreme cyclones into the central Arctic with time that appears to be linked with declining sea ice cover
5. Collectively, these results support the hypothesis but analysis of additional CMIP5 models is needed

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