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Simulation of extreme Arctic cyclones in IPCC AR5 experiments

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Although impending Arctic climate change is widely recognized, a wild card in its expression is how extreme weather events in this region will respond to greenhouse warming. Intense polar cyclones are one type of high-latitude phenomena falling into this category, including very deep synoptic-scale cyclones and mesoscale polar lows. These systems inflict damage through high winds, heavy precipitation, and wave action along coastlines, and their impact is expected to heighten in the future, when reduced sea ice cover allows enhanced wave energy. The loss of a buffering ice pack could greatly enhance the rate of coastal erosion, which has already been increasing in the Arctic. These and related threats may amplify if extreme Arctic cyclones become more frequent and/or intense in a warming climate with much more open water to fuel them. This possibility has merit on the basis of GCM experiments, which typically project that greenhouse forcing will cause lower mean Arctic sea level pressure (SLP) with the strongest response during the autumn-winter seasons when extreme cyclones typically occur. Although true polar lows are mesoscale features whose limited size makes them difficult for GCMs to resolve, the CCSM4 model at 1o horizontal resolution is able to simulate extremely deep cyclones in boreal high latitudes, including numerous cells with a daily mean SLP below 930 hPa and a megacyclone in its 21st-century run that drops to 915 hPa as it propagates into the Arctic. At its peak, this storm's geostrophic wind speeds were around 90 mph, making it a true "Arctic hurricane", and the simulated cyclone occurred over the Nordic Seas, where polar lows typically exist. In this study, I use the new Coupled Model Intercomparison Project (CMIP5) model output being used for the next IPCC assessment report to investigate the following questions. (1) How realistically do CCSM4 and other GCMs simulate the observed characteristics of extreme Arctic cyclones, and are these events sensitive to the horizontal resolution of the model?, (2) Does the preferred location of these systems shift as the cyclogenetic baroclinic zone induced by the sea ice margin migrates poleward with time?, and (3) What do these state-of-the-art climate models suggest about trends in the frequency vs. intensity of extreme Arctic cyclones? To address these questions, I conduct a retrospective analysis of the transient 20th century simulations among the CMIP5 GCMs (spanning years 1850-2005) and a prospective investigation of 21st-century conditions. These model simulations are evaluated using the new 20th-Century Reanalysis V2, which provides daily cyclone data back to 1871. I calculate the simulated frequency distribution of the lowest daily SLP value over the Arctic to identify extreme cyclones and then analyze the most extreme events with respect to their synoptic characteristics (spatial extent, duration, central pressure, etc.). Time series trend analyses allow inferences of how greenhouse forcing affects these extreme events and whether the GCMs agree with each other in the simulated changes in the frequency vs. intensity of intense Arctic cyclones.