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Extreme Winter Cyclones in the North Atlantic in a CESM1.0.1 Last Millennium Climate Simulation

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Extreme cyclones and their associated impacts are a major threat to mankind, as they often result in heavy precipitation events and severe winds. The last millennium is closest to the Anthropocene and has the best coverage of paleoclimatic information. Therefore, it could serve as a test bed for estimating natural forcing variations beyond the recent observational period and could deliver insights into the frequency and intensity of extreme events, including strong cyclones and their dependency on internal variability and external forcing.

The aim of this study is to investigate how the frequency and intensity of extreme cyclones in the North Atlantic have changed in the last millennium, in particular during prolonged cold and warm periods and which changes might be expected for the 21st century.

We use a comprehensive fully-coupled transient climate simulation of the last millennium (AD 1000-2100) with a relatively high spatial (0.9x1.25 degrees) resolution and define six climatic periods according to prolonged cold or warm phases: Medieval Climate Anomaly (MCA), AD 1150-1200, Little Ice Age (LIA), AD 1450-1500, Maunder Minimum (MMI), AD 1645-1720, Historical (HIS), AD 1850-2005, Modern (MOD), 1960-2010 and Projection (PRO), AD 2006-2099. Cyclones are then detected and tracked in 12-hourly output using an algorithm that is based on the geopotential height field on 1000 hPa. Additionally, two intensity criteria for extreme cyclones are defined: the 90 percentile of the mean gradient in geopotential and the 90 percentile of the precipitation within a radius of 500 km around the cyclone centre at every time step during the lifetime of a cyclone. These criteria consider two aspects of cyclone's intensity: extremes in wind and precipitation.

The results show that extremes of North Atlantic winter cyclone intensity are significantly stronger with respect to the geopotential height gradient during prolonged cold periods and weaker during prolonged warm periods. Especially, the projection for the 21st century shows a significant weakening as the mean of the 90 percentile of the geopotential height gradient decreases by 3.9 % from MOD to PRO. This intensification of extreme cyclones during relatively cold periods compared to relatively warm periods can be explained by an increased meridional temperature gradient accompanied by an increased baroclinicity. In contrast, the extremes of winter cyclones with respect to precipitation are weaker in the prolonged cold periods and stronger during warm periods, such that an increase of 6.3 % in the mean of the 90 percentile of total precipitation is estimated from MOD to PRO. This intensification is expected on the basis of the Clausius-Clapeyron relationship.