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

Sandro R. Blumer (1,2), Christoph C. Raible (1), Flavio Lehner (3), Thomas F. Stocker (1,2)

(1) University of Bern, Physics Institute, Bern, Switzerland (blumer@climate.unibe.ch), (2) Oeschger Centre for Climate Change Research, Bern, Switzerland, (3) Climate and Global Dynamics Laboratory, National Center for Atmospheric Reserach, Boulder CO, USA

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 paleo-climatic information. Therefore, it can serve as a test bed for estimating natural forcing variations beyond the recent observational period and can deliver insight 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, and investigate phases which deviate more than one standard deviation. In particular the changes during prolonged cold and warm periods and the 21st century are analysed to assess the external forcing imprint.

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. Cyclones are then detected and tracked in 12-hourly output using an algorithm that is based on the geopotential height field on 1000 hPa. In addition to the tracking, a Gaussian function is fitted to the depressions in the geopotential height field at every time step in order to have a geometric representation of the low pressure systems. Additionally, two intensity indices 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 one standard deviation of the approximated Gaussian function around the cyclone. These criteria consider two aspects of cyclone's intensity: extremes in wind and precipitation.

A 30-yr running window is applied to the entire simulation. Within each window the cyclone frequency and the indices for extreme wind and extreme precipitation cyclones are averaged. This analysis reveals decadal to centennial variations during pre-industrial age (AD 1000 to 1850), with phases, strongly deviating from the mean, but without significant trends. As the greenhouse gas forcing rises within the years AD 1850 to 2099, the cyclone frequency as well as the index for the wind extreme cyclones show a strong and significant decreasing trend, whereas the index for the extreme precipitation cyclones shows a strong increasing trend. We investigate the underlying mechanisms by analysing fields of several atmospheric variables. The working hypothesis for the wind extremes is that the decreased meridional temperature gradient accompanied by decreased baroclinicity is responsible for the decrease. The increase in extreme precipitation cyclones changes on the basis of the Clausius-Clapeyron relationship in the 21st century.