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A model-data comparison of North Atlantic climate variability and its responses to natural forcing over the last millennium

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North Atlantic climate variability is to a large extent governed by the recurring modes of atmospheric circulation, also exhibiting impacts of volcanic and solar activities. These factors emphasize the importance of evaluating the leading variability modes and their responses to natural forcing in climate models for assessing the North Atlantic-European climate predictions. The recent availability of spatial field reconstructions of atmospheric circulation over the last millennium offers a unique opportunity for the paleo-evaluation of CMIP-PMIP models for these purposes across annual to centennial timescales. Particularly, with the possibility of comparing the spatial structure of variability.

In this study, we perform a model-data comparison of the North Atlantic climate focusing on the leading variability modes (North Atlantic Oscillation, NAO; East Atlantic Pattern, EA; Scandinavian Pattern, SCA) and the imprints of major natural forcing over the last millennium. We first develop an updated version of climate field reconstructions covering the past 700 years by assimilating proxy records into isotope-enabled simulations. This new version shows improved skills in reproducing the leading variability modes to serve as a reference for the comparisons with the past1000 runs. We then evaluate the multidecadal spatial variability in winter modes from the last millennium to the end of the 21st century. The models generally have a good representation of the average spatial structures of the NAO, EA and SCA patterns, but with persistent biases in their spatial variability. Particularly, the underestimated spatial shift in the NAO centres of action is directly related to the biases in regional temperature and precipitation changes. Furthermore, we examine the volcanic and solar imprints over the last millennium. Although not all the models can reproduce the significant NAO responses to volcanic eruptions as shown in the reconstructions, they do capture some NAO-like signals mixed with the EA and SCA patterns. Overall, our model-data comparison presents some potential uncertainties in climate projections over the North Atlantic sector, which remain challenging for the reliability of future projections. Also, this model-data comparison framework presents a pathway for future studies aiming to select the better-performing models for regional climate studies.