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Volcanic Impacts on the Atlantic Multidecadal Oscillation and Initiation of the Little Ice Age

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Both external forcing (solar radiation, volcanic eruptions) and internal fluctuations have been proposed to explain the Little Ice Age. Confidence in these hypotheses is limited due to the high uncertainty and limited number of proxies, as well as only one observed realization of the Last Millennium. Here, we evaluate different hypotheses on origin of the Little Ice Age, focusing in particular on the long-term response of Arctic sea ice and oceanic circulation to solar and volcanic perturbations. For that, we analyze the Last Millennium Ensemble of climate model simulations carried out with the Community Earth System Model (CESM) at the National Center for Atmospheric Research, supplemented with a range of sensitivity tests performed by us with CESM. We identify the phase of the Atlantic Multidecadal Oscillation as well as the duration and strength of solar and volcanic perturbations favoring multi-centennial cooling and glaciation. By comparing climate response to various combinations of external perturbations, we demonstrate nonlinear interactions that are necessary to explain trends observed in the fully coupled system and discuss physical mechanisms through which these external forcings can lead to the Little Ice Age. For that, we capture and compare patterns of the coupled atmosphere-ocean response as revealed through a range of data analysis techniques. In particular, we apply a recently introduced technique called Nonlinear Laplacian Spectral Analysis, for which drawbacks associated with ad-hoc filtering are avoided as the extracted signals span many temporal scales without preprocessing the input data, enabling detection of low-frequency, low-amplitude and intermittent modes otherwise not accessible with classical approaches. We show that the large 1257 Samalas, 1452 Kuwae, and 1600 Huaynaputina volcanic eruptions were the main causes of the Little Ice Age.