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Internal and Externally-forced Variability in the Ensemble Climate Simulations of the Maunder Minimum

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The Maunder Minimum (1645-1715 AD) is characterized as a globally distinct and prolonged cold period in recent centuries. It is well known that the sunspot number, a proxy for solar activity, is significantly low during this period. However, concurrent volcanic eruptions particularly in the Late Maunder Minimum (1675-1715 AD) and the presence of the internal climate variability complicate the picture. The relative importance and the combination of these effects are not yet fully understood. In addition, the relatively large external forcing perturbation during this period provides a good opportunity to examine model's viability in simulating the natural variability and to investigate the response mechanisms of the climate system.

First, we conduct a steady Maunder Minimum (MM) simulation, utilizing the comprehensive Community Climate System model from NCAR (National Center for Atmospheric Research, Boulder, USA), in which no time varying forcing is imposed (1640 AD conditions are used). Second, an ensemble of 6 transient MM simulations from 1640 1715 AD is performed. The forcing includes the effect of solar variations and large volcanic eruptions. The solar and volcanic forcing are crudely represented by changing the total solar irradiance. Greenhouse gas concentrations (CO_2, CH_4, and N_2O) are fixed at the level in 1640 AD. The temporal evolution of the simulated Northern Hemisphere temperature agrees well with proxy-based reconstructions. It exhibits several abrupt excursions caused by volcanic eruptions and superimposed multi-decadal variability presumably due to solar variations. We examine signal-noise relations on global to regional scales, in order to achieve a meaningful comparisons between model simulations and reconstructions. Here signal and noise denote the ex-

ternally forced response and the internal variability, respectively. The analysis shows, in some regions such as Europe, that it is very difficult to compare model simulations and proxy records because internal variability dominates the externally forced response in such regions. By carefully extracting the signal, however, we obtain a remarkable agreement in climatic patterns after volcanic eruptions between model simulations and regional reconstructions.