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The spatial-temporal pattern of the Medieval Climate Anomaly and the Little Ice Age in the Northern Hemisphere

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Knowledge of how climate has changed in the past is essential for understanding present climate changes and for separating anthropogenic influence from natural variability. The amplitude and geographical coherency of the late-Holocene pre-industrial temperature variability have been much discussed and the occurrence of a distinct Medieval Climate Anomaly (c. AD 800–1300) and a Little Ice Age (c. AD 1300–1900) on a global or hemispheric scale has been repeatedly questioned. In order to assess the geographical coherency of pre-industrial climate changes we have mapped the spatial-temporal pattern of centennial temperature variability in the Northern hemisphere between the 9th and 20th century, by using all available palaeotemperature proxy records passing a few essential criteria. Our database comprises in total $\sim$150 proxy records from a wide range of archives including, but not limited to, ice-cores, marine sediments, lake sediments, tree-rings, speleothems and historical data. A large majority of records are terrestrial but the spatial distribution of records is non-homogeneous. The most data-rich regions are parts of Europe and North America. Very few or no records are available in parts of Siberia, northern Africa and the Middle East.

The temporal resolution of the records ranges from annual to centennial and our analysis is undertaken using centennial means. By allowing such a low resolution, we can allow substantially more records that extend back to the medieval period than in similar recent studies of climate variability in the last millennium. The disadvantage of allowing a low temporal resolution is that the records cannot be calibrated against instrumental temperature observations. Therefore our analysis uses normalized data, where the normalization is defined for centennial averages. Hence, we can investigate the magnitude of temperature variability relative to the long-term mean, but not the absolute amplitude of temperature changes.

To analyze the geographical pattern of temperatures depicted by the proxies, all centennial indices within a 1,500 km great circle distance, centered on each proxy site, are averaged. The statistical robustness of the averages within each search radius is also assessed. The results, both the normalized temperature anomalies and their probabilities, are then gridded and mapped onto a $1.5° \times 1.5°$ polar projection using nearest-neighbour estimation.

We find evidence of a widespread medieval warming culminating in the 10–11th centuries, followed by a gradual cooling into the 17th century, succeeded by a warming from the 18th century that accelerated in the 20th century. Our result also indicate that the warmth in the 10th and 11th centuries was as uniform as in the 20th century. However, with a resolution of only 100 years it is not possible to assess whether any decade in the past was as warm as any in the late 20th or early 21st century. Though the onset and duration of regional temperature fluctuations, at the sub-continental scale, are not always synchronized across the hemisphere, coherent temperature regime changes across the hemisphere are clear.

Our analysis of normalized temperature variability can serve as a test bed for comparing with results of palaeotemperature modelling experiments and thus for validating the ability of climate models to reproduce the spatio-temporal pattern of past temperature changes. Model studies could be used to answer questions like: To what extent can internal variability alone, generated by climate models, produce the large-scale long-term changes

we observe in the proxy data? Is considerable external forcing needed for models to reproduce the patterns we see? Answers to these questions will lead to a more solid understanding of the nature of low-frequency natural climate variability.