Maunder Minimum climate variability from wind and moisture-sensitive proxies and model simulations

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To assess ongoing and potential future climate change with confidence, it is necessary to put such changes into a long-term perspective. The only accessible information beyond instrumental records is proxy data. However, proxy data suffer from three shortcomings: (i) they are indirect measures of climate variability, (ii) they could represent a mixture of different signals (e.g., temperature and precipitation), and (iii) they are often sparsely resolved in time and space. Alternatively, climate models can be used. However, such models are afflicted with uncertainties related to their formulation and the processes they include. Moreover, the credibility of model simulations crucially depends on the availability and quality of forcing data (Rind et al., 2004), which is estimated from proxy data. Thus, a deeper insight into past climate changes can only be gained by an interdisciplinary effort.

The Maunder Minimum (MM; ca. 1645 – 1715) was a period of reduced solar irradiance and was characterized by prolonged cold conditions (Luterbacher et al., 2001). Therefore, it serves as an example period and enables understanding of forcing-induced variations on the climate, in particular atmospheric circulation and the hydrological cycle. For example, in ensemble simulations of the MM, Yoshimori et al. (2005) showed that natural forcing signals, like volcanic eruptions, are clearly represented in the modeled temperature, and partly in precipitation, on hemispheric scales. On regional scales, natural forcing signals could be masked by the unforced atmosphere-ocean variability. These regional results have important implications in identifying suitable locations to reconstruct climatic responses to external forcing functions.

Thus, the ensemble simulations of the MM provide a beneficial test-bed, which could improve our understanding of what is recorded in proxy data. Here, we aim to compare results obtained from these ensemble simulations of the MM and a present-day control simulation, with wind- and moisture-sensitive proxy data in order to show the model's ability to clarify discrepancies between proxy records and to help in the interpretation of proxy data.

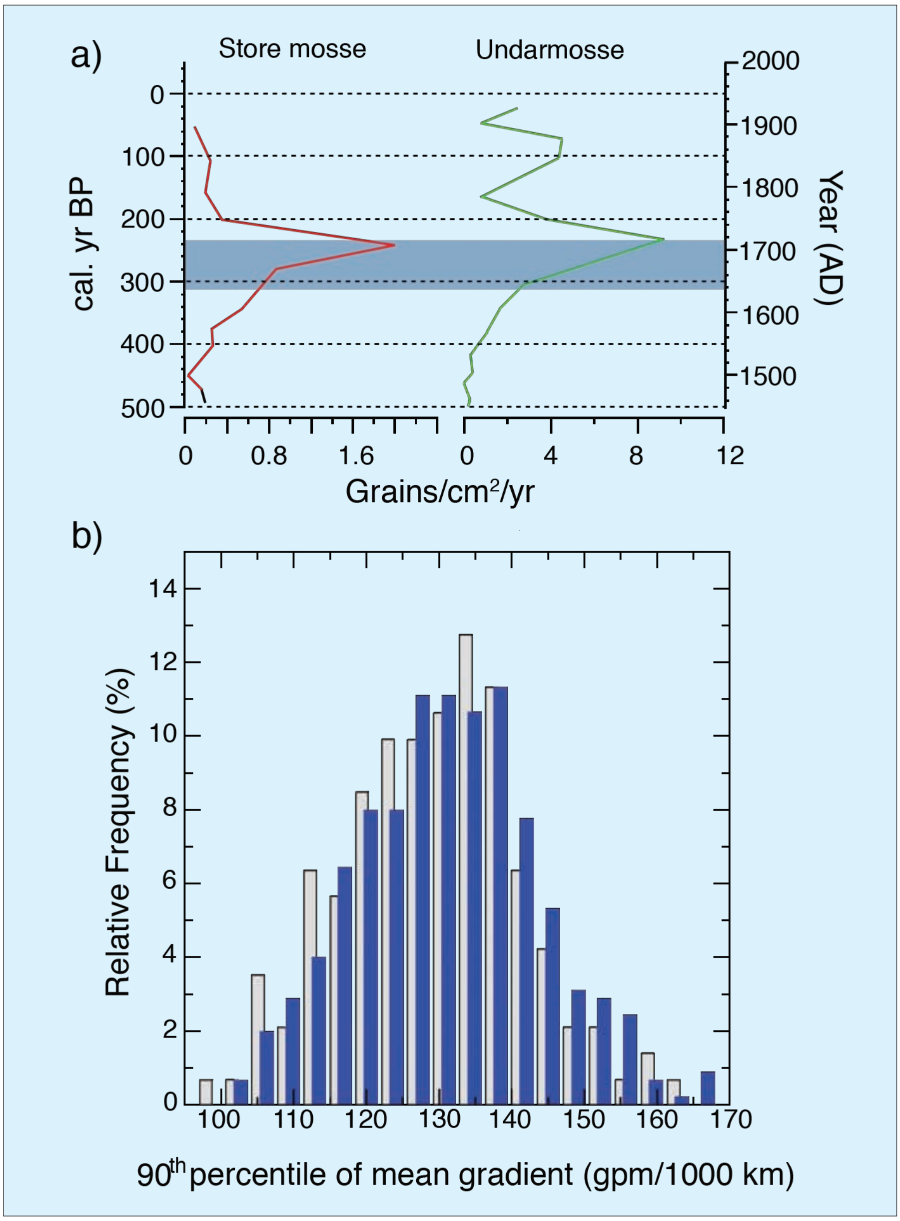

Figure 1: ***a****) Annual influx of sand grains (>200 µm) into the ombrotrophic peat bogs Store mosse and Undarmosse, southwest Sweden (De Jong et al., 2006; 2007) with shaded area indicating duration of the MM;* ***b****) Simulated distributions of extreme cyclone intensity in northern Europe (Raible et al., 2007) for the MM (blue) and present-day control simulations (grey) (gpm = geopotential meter).*

Wind sensitive proxies

Two ombrotrophic peat bogs in southwest Sweden were studied for the content of wind-transported sand grains (De Jong et al., 2006; 2007). High abundances of medium-large sand grains are related to winter storminess, thus the abundance of medium-large sand grains was used as a proxy for storm frequency and intensity (Fig. 1a). These studies provided strong indications that storminess substantially increased around the MM, compared with both earlier and later time periods. De Jong et al. (2006; 2007) also showed that increased storminess recorded at the two sites apparently coincided with storm events recorded at other sites in southwest Scandinavia, suggesting that these records reflect a regional-scale climatic signal. However, an independent climate field reconstruction of sea surface pressure (Luterbacher et al., 2001) shows a negative phase of the North Atlantic Oscillation (NAO), which implies on average weaker winds over Northern Europe.

At first glance, this is in contrast to the proxy data from southwest Sweden. To clarify the reasons for this discrepancy, the

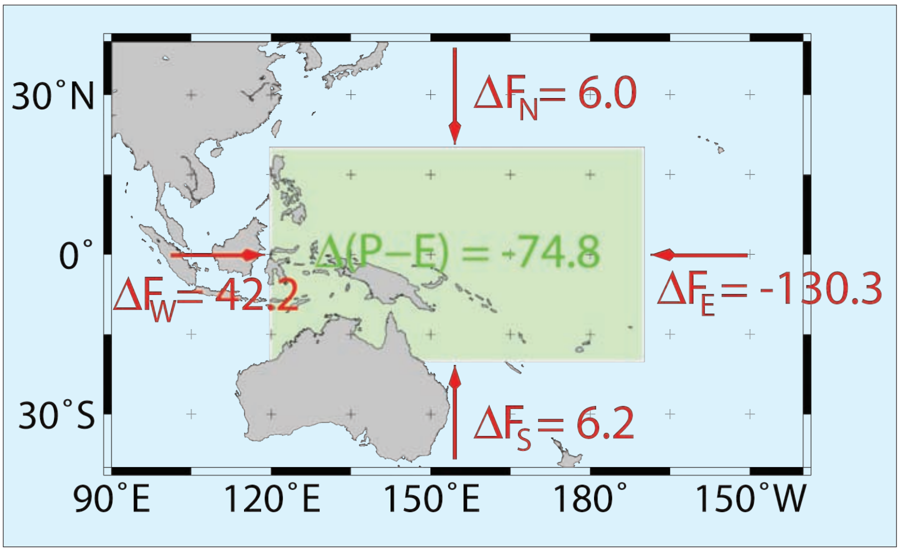

Figure 2: Annual vertically integrated moisture budget between MM simulations and the 1990 control simulation: ΔF are the moisture flux changes integrated over the corresponding boundaries (west, north, east, south) and Δ(P-E) is the change in the difference precipitation minus evaporation (Yoshimori et al., 2006). The unit is 10^6kg/s.

proxy results were compared to modeling results obtained from a comparison of the ensemble simulations of the MM with a present-day control simulation (Raible et al., 2007). Initial results suggested that during MM, winter cyclones traveled more zonally and shifted southward relative to today. This means that the number of cyclones was, on average, decreased over northern Europe, leading to a simulated pressure difference between the MM and today, which represents the negative phase of the NAO (similar to Luterbacher et al., 2001).

To gain further insight, cyclones and their characteristics, such as extremes in cyclone intensity, were investigated in the ensemble simulations of the MM and compared with the present-day control simulation (Raible et al., 2007). The results show that even in areas where the number of cyclones is lower during the MM, such as in northern Europe, the extreme cyclone intensity is significantly higher in winter (Fig. 1b), compared to today. Raible et al. (2007) provided a hypothesis for the processes underlying this cyclone intensification. The meridional temperature gradient plays a key role in intensifying these extreme cyclones, as well as the increase of lower-level baroclinicity (a measure of stratification) in the North Atlantic, when comparing the MM with today.

Thus, the modeling results help to overcome this apparent contradiction, showing that a decrease in the number of storms in northern Europe during the MM was accompanied by an intensity increase. This suggests that the sand-grain proxy records (De Jong et al., 2006; 2007) are strongly influenced by extreme events rather than the pure number of storms. However, one should mention that these results are obtained from a single model and that the difference is only statistically significant between MM versus today, and not between MM versus a control simulation for 1640 AD conditions; the latter shows the influence of solar and volcanic forcing only during the years of the MM period.

Concept to interpret hydrological proxies

The interpretation of hydrological proxies provides another challenge, as such proxies can be sensitive to dynamic and/or thermodynamic effects. To overcome these difficulties, an analysis, which allowed the separation of the two effects, was applied to the same ensemble simulations of MM in Yoshimori et al. (2006).

The analysis of Yoshimori et al. (2006) focused on the western tropical Pacific, where coral proxy data (Hendy et al., 2002) indicated salinity changes in this region during the MM. Hendy et al. (2002) showed that the reconstructed salinity was increased during the MM, compared to today. They further hypothesized that these salinity changes were associated with changes in the Hadley circulation.

In Yoshimori et al. (2006) this hypothesis was investigated. The ensemble simulations of the MM show a salinity anomaly of the same positive sign in the western tropical Pacific as the coral proxy data. Moisture fluxes of these ensemble simulations of the MM are compared with a present-day control simulation. As shown in Figure 2, the salinity anomaly is primarily generated by an atmospheric moisture transport anomaly through the eastern boundary of the region. The humidity-change-related part of this flux dominates over the circulation-related part. The humidity change is generated by a temperature decrease due to a lower saturation pressure of water vapor, as the cold atmosphere of the MM held less moisture than the warm atmosphere of today.

From the study of Yoshimori et al. (2006) alone, the interpretation of the coral proxy record is inconclusive because of uncertainties in the model simulations and the coarse model grid, as discussed in detail in their paper. Nevertheless, the model output provides a consistent but different interpretation of the coral proxy data, i.e., thermodynamic vs. dynamic effects. It is clear that further studies and improved models are needed to further clarify these discrepancies.

Outlook

Bringing together proxy data and modeling results will help to overcome their individual caveats and obstacles. Studies presented here show that carefully interpreting such simulations can help to increase the understanding of wind and hydrologically sensitive proxy data and to put them into a dynamical context. The strength of modeling studies also lies in providing mechanisms that explain changes in proxy data. Moreover, a coordinated effort for multi-model ensemble simulations for the last millennium would be useful to highlight robust results. The steadily growing proxy data offers future opportunities for interdisciplinary collaborations, e.g., in South America (e.g., LOTRED-SA;www.pages-igbp.org/science/lotred-sa/) and the Mediterranean Basin (e.g., MedCLIVAR; www.medclivar.eu/); the latter is thought to be highly sensitive, particularly with regards to the hydrological cycle (IPCC, 2007).

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For full references please consult:

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