required of how these various phenomena act together, over a variety of timescales.

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Reconstructed and simulated Medieval Climate Anomaly in southern South America

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An austral summer temperature reconstruction for southern South America for the last millennium is compared to paleoclimate simulations provided by two Atmosphere-Ocean General Circulation Models with special emphasis on the Medieval Climate Anomaly.

The understanding of the current and future processes, and dynamics of the climate system can greatly benefit from the knowledge of past spatial patterns, trends, amplitudes, and frequencies of climatic variations (Jones et al., 2009, and references therein). Until recently, the rather low number and uneven spatial distribution of temporally highly resolved proxies from the Southern Hemisphere did not allow reliable continental scale reconstructions at interannual-to-interdecadal timescales (Neukom et al., 2010). Given the importance of the potential seesaw mechanism between the Northern and Southern Hemisphere (NH and SH) and the driving role of the SH oceans in regulating global climate variability, South America is a key region for the study of climate processes and dynamics. Climate in South America is influenced by a variety of oceanic and atmospheric patterns, such as the El Niño Southern Oscillation (ENSO) and the Southern Annular Mode (SAM; Garreaud et al., 2009). Thus, SH climate reconstructions covering the past centuries to millennia can provide insights into the underlying mechanisms of climate variability and forcing imprints. Such reconstructions are essential for data/climate model comparisons. Here, we present results from a new multiproxy-based austral summer (DJF) temperature reconstruction that covers the last 1000 years in southern South America (SSA) (Neukom et al., 2010). Special emphasis is given to the temperature difference between the periods 1001-1350 ("Medieval Climate Anomaly", MCA) and 1400-1700 ("Little Ice Age", LIA). Furthermore, austral summer temperature reconstructions are also compared with two coupled atmosphere-ocean general circulation models (AOGCMs): The two ECHO-G simulations Erik1 and Erik2 using identical external forcings, but different initial conditions (i.e., the initial conditions used in year 1000 AD in Erik2 where cooler than in Erik1; González-Rouco et al., 2006), and one simulation with CCSM3 (Hofer et al., 2010). The models use slightly different anthropogenic and natural forcings, including different levels of atmospheric concentrations of carbon dioxide, methane, and nitrous oxide, of solar activity, and of volcanic aerosols. We also provide austral summer temperature difference patterns (MCA minus LIA; 1001-1350 minus 1400-1700 AD) for both the multiproxy reconstruction with their associated uncertainties and the corresponding simulations from the three model simulations.

Austral summer temperature reconstructions back to the MCA and comparison with two AOGCMs

Figure 1 shows the austral summer (DJF) land-surface air temperature anomalies (with respect to the 1001-1700 AD reference period) for SSA (south of 20°S) both for the principal component-multiple regression based reconstructions (Neukom et al., 2010) and the three model simulations spanning the period 1001-1990 AD. The reconstruction generally points to warmer conditions during the MCA. A strong decrease in temperature is visible in the second half of the 14th century. The climate reconstruction for this period mainly relies on tree-ring information from the Andes, lake sediments from Central Chile and an ice core from the tropical Andes (Neukom et al., 2010; see Fig. 1 bottom left). Cooler conditions prevail throughout the late 17th century (LIA). The difference in mean austral summer temperature between the two periods (1001-1350 minus 1400-1700 AD) is approximately 0.39°C in the reconstruction, 0.14°C and 0.49°C in CCSM3 and Erik1, respectively. A possible explanation for the rather small difference in the CCSM3 simulation compared to the Erik1 simulation is the lower equilibrium climate sensitivity of CCSM3. The associated ±2 Standard Error (SE) uncertainties of this difference (based on the uncalibrated variance in the 20th century calibration period; see Neukom et al., 2010, for more details) for the MCA and the LIA are of the order of ± 0.3°C (shaded parts in Fig. 1 top panel). The interpretation for the sudden drop in the mean temperature during the "MCA-LIA" transition is not known yet.

The reconstructions (Neukom et al., 2010) point to positive temperature anomalies in the 18th century, followed by a cooling phase that starts in the early 19th century. Since approximately the 1850s, SSA has experienced a long-term warming trend with superimposed shorter cooling periods. The multiproxy-based reconstruction and the AOGCMs generally agree on the centennial-scale warm and cold phases and their amplitude. However, there are differences between the reconstruction and the models in the timing of the MCA-LIA transition, which appears around 60 years later in the models. Additionally, the simulated transition is a two step process: a first step is initiated with

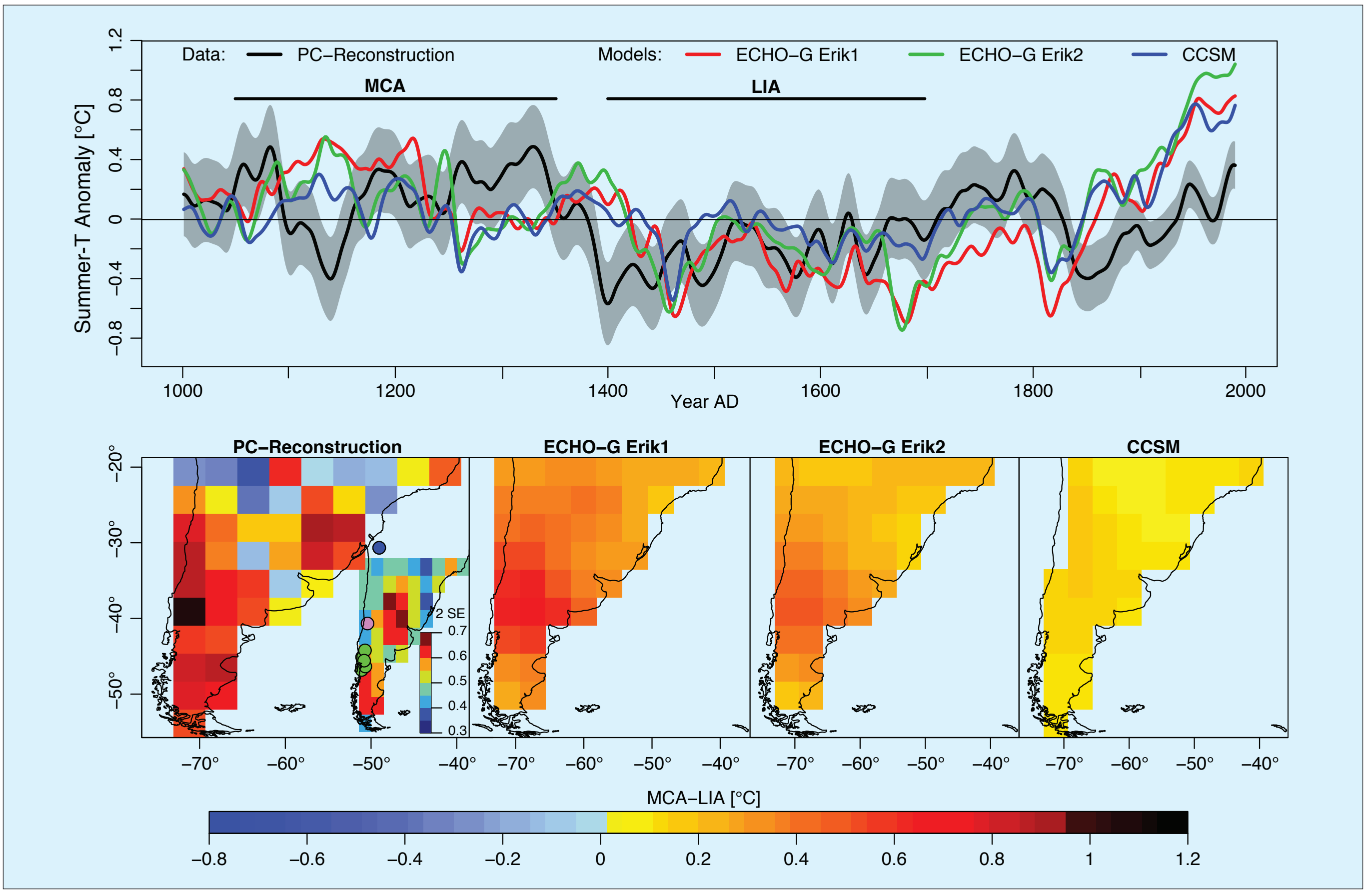

Figure 1: ***Top****: Austral summer (DJF) surface air temperature for southern South America (south of 20°S) for the period 1001-1990 AD (Neukom et al., 2010), expressed as 30-year Gaussian filtered anomalies with respect to the 1001-1700 AD climatology. Black: principal component-multiple regression based reconstructions and associated filtered ±2 SE uncertainty bands (shaded); red: ECHO-G Erik1, green: ECHO-G Erik2, blue: CCSM3 AOGCM simulations.* ***Bottom****: Spatial austral summer (DJF) surface air temperature difference patterns (MCA minus LIA; 1001-1350 minus 1400-1700 AD) for the multiproxy reconstruction (left; interpolated to the 3.75°x3.75° grid of the AOGCMs) and the AOGCMs simulations . The inset in the left panel represents the available proxy time series in the pre-1700 period (green: tree ring series; purple: lake sediment record; blue: ice core) and the 2 SE derived from the 20th century calibration period, averaged over the period 1001-1700 AD (Neukom et al., 2010).*

the strongest volcanic eruption of the last millennium around 1258 AD and a second step coincides with the Spörer solar Minimum (ca. 1460-1550 AD) . Thus the model simulations seem to be more sensitive to external forcings than the multiproxy reconstruction would suggest. This leads to larger model temperature amplitudes on decadal timescales, in particular for the ECHO-G simulations. The models overestimate the warming in industrial time with respect to the proxies, most likely because of aerosol forcing and land use changes which are not considered in the simulations.

Figure 1 (bottom panels) shows the austral summer surface air temperature difference patterns (MCA minus LIA; 1001-1350 minus 1400-1700 AD) for the multiproxy reconstruction (left) and the three simulations. The inset in Figure 1 (bottom left) represents the available proxy records as well as the distribution of the ±2 SE over the period 1001-1700 AD. In the reconstructions, the MCA was up to 1.1°C (1.6°C in the non interpolated 0.5°×0.5° resolved version of Neukom et al., 2010) warmer compared to the LIA, which is apparent in the west and south and partly in the east of SSA. The reconstructions in those areas can be considered as reliable, as reflected by the low SE (Fig. 1, bottom inset). Less reliable are regions in the centre of SSA and parts of Patagonia. This is mainly due to the lack of proxy data in these regions and some quality issues in the instrumental calibration data. The reconstructed MCA conditions in the northwestern- and northeasternmost parts were slightly colder compared to the LIA.

ECHO-G simulations (Erik1 and 2) and to some extent also the CCSM3 simulation are generally in good agreement with the overall anomaly pattern of the reconstruction and both models show the anomalous warm conditions during the MCA period compared to the LIA with strongest anomalies in the southwest. The negative values in the northeast are not reproduced by the two models considered herein.

Conclusions

The paucity of high-resolution proxy data covering the early part of the last millennium results in uncertain multiproxy reconstructions for the medieval period. Though not homogeneous in time, this early period until approximately the mid 14th century is, on average, warmer than the subsequent period until around 1700 AD. There is a rather good agreement between the reconstruction and the two AOGCMs both in terms of mean conditions as well as the general spatial anomaly pattern. Future work based on more high-resolution proxy records, including detection and attribution studies, will help to refine these patterns, as well as the timing and causes of the MCA-LIA transition.

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