Assimilating the Southern Annular Mode over the Common Era using Drought Atlases and a Global Proxy Network

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The Southern Annular Mode (SAM) is the leading mode of atmospheric variability in the extratropical Southern Hemisphere, and its variations affect westerly winds, regional storm tracks, midlatitude wildfire activity, Antarctic and Southern Ocean dynamics, and surface mass balance. The SAM is therefore of high importance to both ecosystems and societies across the Southern Hemisphere. The behavior of the SAM has been extensively studied during the instrumental era, but there is substantially less confidence and considerable disagreement in its decadal to centennial-scale variability over the Common Era. Studying these longer time scales requires millennial-length reconstructions, but the sparsity of multi-century proxy records in the Southern Hemisphere has hindered the production of such reconstructions. Consequently, variability and trends in the SAM remain uncertain through most of the Common Era.

Here, we use paleoclimate data assimilation to reconstruct the austral summer (DJF) SAM index (SAMI) over the entire Common Era. Our method integrates the South American Drought Atlas, Australia-New Zealand Drought Atlas, and the PAGES2k temperature-sensitive proxy network with a multi-model ensemble of last millennium GCM simulations using an offline ensemble Kalman Filter with a stationary prior. We use a novel nested variance adjustment to correct for the effect of changing proxy availability through time. Our reconstruction is not calibrated to the observed SAMI, yet exhibits a correlation coefficient greater than 0.6 over the instrumental era. Using superposed-epoch and wavelet analyses, we find the reconstruction exhibits minimal response to volcanic and solar forcings and is instead dominated by internal climate variability until the late 20th century. Our data assimilation framework also facilitates the use of optimal-sensor analysis, which we use to identify key proxy sites at different time periods in the reconstruction. Prior to 1400 CE, the reconstruction is strongly influenced by two tree-ring records (Mt. Read, Tasmania and Oroko, New Zealand) and two ice-cores (WDC05A and Plateau Remote). Finally, we examine the coherence of our results against existing reconstructions and compare reconstructed 20th century trends with the instrumental record.