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Reconstruction of last-millennium atmosphere and ocean quantities and quantification of spatiotemporal uncertainty

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Reconstructing climate conditions over the last millennium (LM) provides a window into preindustrial climate variability that is important for understanding and predicting modern climate. By combining proxy observations with model-derived covariances in space and between climate variables, so-called “offline” data assimilation has proved powerful for reconstructing climate variables that are not measured directly by proxies and that are geographically remote from proxy locations.

However, different prevailing time scales in ocean and atmospheric dynamics and in the representativeness of marine and terrestrial proxy observations presents an outstanding challenge in extending skillful LM reconstructions beyond the atmosphere and into the ocean. For instance, reconstructions of regionally-averaged heat content from year-by-year offline assimilation of annually-resolved terrestrial proxies show interannual variability and large-scale correlations that are difficult to reconcile with ocean dynamics. Quantifying the uncertainty of these features and making better use of our knowledge of ocean dynamics in LM reconstructions is important for understanding the ocean’s role in coupled LM climate variability.

Here we present results from a reconstruction technique that permits observations spanning arbitrary time scales and includes model spatiotemporal covariances that can enforce persistence in ocean heat content and other quantities with interannual memory. The approach, which uses singular value decomposition to solve for climate variables at all times rather than year-by-year, also allows us to quantify reconstruction uncertainty as a function of spatial and temporal scales. The approach is illustrated using pseudoproxy experiments and applied to PAGES2k marine and terrestrial observations to reconstruct Atlantic Ocean heat content and its uncertainty on regional spatial scales and decadal time scales over the last 400 years.