Geophysical Research Abstracts
Vol. 19, EGU2017-1405-2, 2017
EGU General Assembly 2017

Providing a more complete view of ice-age palaeoclimates using model inversion and data interpolation

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Site-based pollen records have been used to provide quantitative reconstructions of Last Glacial Maximum (LGM) climates, but there are too few such records to provide continuous climate fields for the evaluation of climate model simulations. Furthermore, many of the reconstructions were made using modern-analogue techniques, which do not account for the direct impact of CO_2 on water-use efficiency and therefore reconstruct considerably drier conditions under low CO_2 at the LGM than indicated by other sources of information. We have shown that it is possible to correct analogue-based moisture reconstructions for this effect by inverting a simple light-use efficiency model of productivity, based on the principle that the rate of water loss per unit carbon gain of a plant is the same under conditions of the true moisture, palaeotemperature and palaeo CO_2 concentration as under reconstructed moisture, modern CO_2 concentration and modern temperature (Prentice et al., 2016). In this study, we use data from the Bartlein el al. (2011) dataset, which provides reconstructions of one or more of six climate variables (mean annual temperature, mean temperature of the warmest and coldest months, the length of the growing seasons, mean annual precipitation, and the ratio of actual to potential evapotranspiration) at individual LGM sites. We use the SPLASH water-balance model to derive a moisture index (MI) at each site from mean annual precipitation and monthly values of sunshine fraction and average temperature, and correct this MI using the Prentice et al. (2016) inversion approach. We then use a three-dimensional variational (3D-Var) data assimilation scheme with the SPLASH model and Prentice et al. (2016) inversion approach to derive reconstructions of all six climate variables at each site, using the Bartlein et al. (2011) data set as a target. We use two alternative background climate states (or priors): modern climate derived from the CRU CL v2.0 data set (New et al., 2002) and LGM climate derived as an ensemble average of the CMIP5-PMIP3 LGM simulations (Harrison et al, 2015). This assimilation technique will ultimately be extended to include information from adjacent LGM sites through a distance-weighting function and constrained smoothing techniques to produce a spatially consistent reconstruction of LGM climate fields. The use of model inversion together with a 3D-Var assimilation scheme provides a well-formulated way of maximising the use of limited palaeoclimate data.