Reconstructions of the climate states over last centuries using particle filtering

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In contrast to meteorology, data assimilation in paleoclimatology is relatively new, but the interest in it is growing as it gives a more reliable state estimation of the past climate changes. Data assimilation enables reconstructions of the climate of past centuries to be consistent with the model physics and proxy data (indirect reconstructions based on tree rings, ice cores, sediments), and it assists in estimating uncertain model parameters, e.g., forcing estimations. But it is not straightforward to implement a data-assimilation method developed for weather forecasting for paleoclimatological applications, since the observations in paleoclimatology have a sparse spatial distribution, the time resolution of proxies becomes lower as the record goes further back in time, and there are non-climatic uncertainties associated with the reconstructions based on proxies. On the other hand, in paleoclimatology, a description of the state of the system does not need to be as detailed as in meteorology. In many cases, large-scale averages on seasonal to annual means give already very valuable information, while data assimilation for weather forecasting requires reconstructions every six hours at the scale of a few tenth of kilometers at most.

In order to test data assimilation approaches adapted to paleoclimatology, we conduct experiments with the three-dimensional Earth system model of intermediate complexity LOVECLIM using particle filtering to reconstruct past climate states over the last 150 years. LOVECLIM was chosen due to its computational costs, and particle filtering was chosen due to its simplicity of implementation and because it adequately handles nonlinearities. LOVECLIM consists of an atmospheric model, a sea-ice model, an ocean general circulation model, and a vegetation model. Using particle filtering, we assimilate surface temperature over southern hemisphere with assimilation period of three months.

We consider two particle filtering methods: sequential importance resampling and an extremely efficient particle filter. In sequential importance resampling, a set of particles, where a particle is a realization of the model with random perturbation of initial conditions, is integrated over a season. Then, when observations of sea surface temperature become available, the set is resampled according to an importance weight of each particle. This importance weight comes from computation of the likelihood of the state obtained by each particle. The extremely efficient particle filter used here is based on sequential importance resampling and nudging. In addition to the assimilation of surface temperature each three months, sea surface temperature is nudged every day through the fluxes coming from the atmosphere to the ocean such that it is slightly pulled towards the seasonal/monthly mean calculated from observations. This method was originally proposed for high-dimensional problems to take care of filter degeneracy. We, however, when using this method, pursue a different object–to accomplish a better reconstruction of the climate states.

We compare results of the simulations obtained using LOVECLIM only, LOVECLIM constrained by sequential importance resampling, and LOVECLIM constrained by the extremely efficient particle filter. In the last two simulations, surface temperature from a twin experiment is assimilated over southern hemisphere. As a mean of comparison we choose surface temperature over the northern hemisphere and reconstruction of sea ice extent and sea ice concentration in the southern hemisphere.

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