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Proxy-based climate reconstructions during the last millennium and their assimilation in the climate models : from empirical to mechanistic methods

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A gridded reconstruction of April to September temperature was produced for Europe based on tree-rings, documentaries, pollen and ice cores (Guiot *et al*, 2010). The majority of the proxy series have an annual resolution. For a better inference of long-term climate variations, they were completed by number of low resolution data (decadal or more), mostly on pollen and ice-core data. An original spectral analogue method (estimates are based on similarities between the years in the proxy space and low and high frequencies are processed separately) was devised to deal with this heterogeneous dataset, and especially to preserve the long-term variations and the variability of the temperature series. It is the condition to make pertinent the comparison of the recent climate changes to a broader context of 1400 years. The reconstruction of the April-September temperature was validated with a Jack-knife technique, and it was also compared with other spatially gridded temperature reconstructions, literature data, and glacier advance and retreat curves. We also attempted to relate the spatial distribution of European temperature anomalies to known solar and volcanic forcings.

In order to obtain a better and more coherent climate reconstruction, a new approach is data assimilation in climate models. This temperature reconstruction was compared to simulations performed with the climate model LOVECLIM constrained to follow those reconstructions using a data assimilation technique based on particle filter (Goosse *et al*, in prep). The data assimilation covering the past millennium allow combining information from different sources in a clear and consistent framework. It also provides clear hypotheses that can be tested with additional model simulation and independent proxy data. It underlines the open questions that remain because of the uncertainties in the models, in the reconstructions and of the limitations of the technique itself. It enables also to check the physical consistency of the proxy-based reconstructions. So imperfect data and imperfect models are combined to provide improved reconstruction and to better asses the uncertainties.

Empirical approaches, even with the most powerful statistics, have some limitations such as the effect of external variables, not reconstructed but influencing the proxy. These external variables can become dominant in some periods of the past when the reconstructed variable is not anymore limiting. The effect may become reversed : for example, a increased temperature may

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have a positive effect on high altitude trees, but when it is too high, it may become limiting because of an increased evapotranspiration. Other limitations can come from the fact that factors considered as constant are not so in reality (atmospheric CO_2 strongly increases since the industrial era and has an effect on the water use efficiency in the tree-growth). It has been suggested (Hughes *et al*, 2010) to use mechanistic models not only to better understand the tree-growth processes, but also to reconstruct climate by inversion of these models. This inversion in done in the framework of Bayesian statistics (Garreta *et al*, 2010). This will be illustrated by the tree-ring simulator MAIDENiso.

MAIDENiso is a new version of the process-based biogeochemical model MAIDEN of tree-growth (Danis *et al*, in prep). Isotopic modules have been implemented to simulate stable oxygen and carbon isotopes in tree ring cellulose (TRC). In addition to annual increment biomass, this new model estimates δ^{18}O and δ^{13}C associated with the daily amount of carbon allocated to the trunk. MAIDENiso requires daily input data : minimal and maximal air temperatures, amount of precipitation (P) with isotopic content δ^{18}OP, CO_2 atmospheric concentration and δ^{13}C of CO_2. Its weather generator allows running the model with the only daily air temperature and amount of precipitation, which considerably reduces the amount of data needed to simulate tree growth. It simulates tree ring width, δ^{18}O in soil water, δ^{18}O in xylem water, δ^{18}O in cellulose, and δ^{13}C in the cellulose. It was tested and validated with oak data from the Fontainebleau forest in France. Correlations between simulations and data range between 0.5 and 0.7. This makes possible to use it in an inverse mode (Guiot *et al*, 2000) to reconstruct climate from tree-ring width, density and isotopic series. The first results will be shown to illustrate the procedure.

In a more distant future, we must consider to couple proxy models to climate models (through a proper downscaling scheme) and to assimilate directly proxy data (and not the reconstructions inferred from them) into this coupled model. This will constrain the simulations to be realistic, i.e. in agreement with the existing proxy data, and to minimise the uncertainties necessarily amplified by the empirical climatic reconstruction methods.

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