Reconstructing large-scale variability from palaeoclimatic evidence by means of Data Assimilation Through Upscaling and Nudging (DATUN)

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The detection of climatic changes during the last century and their attribution to inc concentrations of atmospheric greenhouse gases and other anthropogenic activities requir realistic estimation of the level of natural climate variability on decadal and longer time scal These estimates can be obtained in two ways. One approach is to perform climate simulation with numerical climate models. Since it is not exactly known how realistic these m empirically-based estimates of climate variability are also needed. These are obtained b analysing time series from climate proxies, natural archives that contain a climate signal, and thus information about past climate evolution. The extraction of climate information from prox data includes the analysis of data from tree rings (Schweingruber and Briffa, 1996), ice c (Fischer et al., 1998) and corals (Draschba et al., 2000). To gain maximum insight into pas climate variability, these records need to be integrated in a way that goes beyond a m fragmentary comparison. A first step in this direction is the development of climate reconstructions that are based on a statistical combination of multiple proxy data from multip sites (Mann et al., 1998, Luterbacher et al., 1999).

Our work, which is part of the project 'Klima In Historischen Zeiten' (KIHZ, Climate In Hist Times), aims at improving the methodology for extracting the climate signal from proxy records by bringing together proxy data and numerical climate modelling in a new way. This will achieved by using a coupled atmosphere-ocean General Circulation Model (GCM) to assim proxy data, with the goal of obtaining a physically consistent best guess for the large-scale states of the atmosphere during the Late Holocene with annual temporal resolution.

Assimilation of observations in GCMs, for instance from surface stations, balloon soundi satellites, has been operationally employed for many years to find the initial conditions needed for numerical weather prediction, as well as to obtain atmospheric reanalyses. In thes sophisticated multi-step schemes, which take into account the estimated errors and the correlation structure of the observations, and suppress unphysical high frequency varia employed. Data assimilation in GCMs has also been used for process studies and mod validation, usually using the simpler, so-called nudging method, which directly relaxes the model towards local observations or large-scale target fields (e. g. Timmreck et al., 1999, Murphy 2000). All of these strategies require a relatively precise knowledge of the target state and are not suited for assimilating proxy data or sparse instrumental data. Proxy data are available o from a few locations and typically represent climate signals that are integrated over severa months to decades. In addition large uncertainties exist due to the complex relationship between climate and proxy variables, as well as due to non-climatic influences on the proxy records.

Thus an assimilation method that is tailored towards applications in palaeoclimatology h developed (von Storch et al., 2000). This so-called DATUN technique (Data Assimilation Through Upscaling and Nudging) consists of two steps. The first step is the formulation statistical upscaling models, which link the local proxy data to large-scale circulation states, for example to the amplitudes of dominant atmospheric variability patterns, such as the North Atlantic Oscillation (NAO) (Gonzalez-Rouco et al., 2000) and the Antarctic Oscillation (AAO).

A reconstruction of the strength of the summer (DJF) AAO, which is the dominant variability pattern of southern hemisphere extratropical sea level pressure, has been undertaken using tree ring chronologies from Argentina, Chile, Tasmania and New Zealand. For the purposes of th work, the AAO has been defined as the first EOF of NCEP/NCAR reanalysis sea level press (SLP) for the domain 15°S - 60°S. Data further south were not used because of concerns abou the amount of input data to the reanalysis. The chronologies were obtained from the International Tree Ring Data Bank. To select those chronologies containing an AAO s chronologies were correlated with the principal component (PC) of this EOF, and those whic were significant at the 5 % level were retained for analysis, a total of 10 chronologies from a pool of 59.

In order to produce the reconstruction, canonical correlation analysis (CCA) was applied to th first five PCs of the chronologies and the first SLP PC, which explains 27 % of the variance of the SLP field. The first canonical pattern, which is identical to the first SLP EOF, is shown on the left side in Figure 1.

Fig. 1: The first canonical pattern (AAO). Circle size proportional to loading. Values in brackets = percentage variance explained.

CCA was applied to these data, retaining the first SLP PC, and the first five tree PCs. Due to the short 37 year overlap period of both datasets (1948 - 1984), the analysis was run 37 times, with a different year set aside for validation each time. Figure 1 shows the first canonical pattern fo the SLP and the trees from the final of the 37 runs. These are thus the anomalies of the two fields that are most strongly correlated with each other. The tree canonical patterns explains 34 % of the variance. The amplitudes of these patterns, the so-called canonical timeseries, ar shown in Figure 2. The correlation between the timeseries during the fitting period is 0 (statistically significant at the 1 % level). The correlation during the validation period is 0.61 and is also statistically significant at the 1 % level. Low frequency variability is relatively w reproduced, while some of the high frequency variability is not captured.

Fig. 2: Fitting (top) and validation (bottom) canonical timeseries (AAO). Black = sea level pressure, grey = chronologies.

To produce the reconstruction of the AAO index, anomalies of the tree ring width series projected onto the tree ring width canonical pattern. Figure 3 shows this series, the black li shows a 15 year running mean. A comparison of this reconstruction to another undertaken using observed southern hemisphere station data, currently in progress, will allow an assessment of the reliability of the reconstruction back to the mid-late nineteenth century. To enable assimilation of the reconstruction into a GCM, an extension of the upscaling model to mu patterns, as well as to middle-tropospheric geopotential height, relative vorticity and temperature, is underway.

Independent evaluation, where possible, is important, because it has been recently noted (Schmutz et al., 2000, Gonzalez-Rouco e al., 2000) that existing proxy-based NAO reconstructions disagree prior to the 20th century, indicating that use of different methodologies and/or data may affect the outcome o reconstruction. Agreement however, was found between the reconstruction of Gonzalez-Rouco et al. (2000), obtained also using CCA between the first SLP PC over the domain 90°W - 10°E, 20°N – 60°N and tree ring width chronologies, and that of Appenzeller et al. (1998), bas Greenland ice core data. Figure 4 shows a comparison of these reconstructions, and also with a reconstruction based on early instrumental data (Jones et al., 1997).

Fig. 3: The preliminary AAO index reconstruction obtained by projecting the tree ring width anomalies for the 10 selected chronologies onto the first canonical ring width pattern. Solid line is the 15 year running mean.

Fig. 4: A comparison of the Jones et. al. (1997), (NAO1), Appenzeller et. al. (1998), (A) and Gonzalez-Rouco et al. (2000), (TR) NAO index reconstructions, with a 30-year low pass filter applied (a filter with least squares coefficients was used with cutoff frequency 0.209 and 75 terms).

It can be seen from Figure 4 that the Jones instrumental reconstruction shows differences to the proxy-based NAO indices. Gonzalez-Rouco et al. (2000) suggest from these results tha agreement between independent proxy data bears potential for the development of reconstructions of past circulation indices, but that potentially important inconsistencies between proxy- and instrumental-based approaches are highlighted.
The second step of the DATUN method is the assimilation of the estimated large-scale patterns in a GCM. In order to keep the method simple, we use a nudging method, where model variables are directly forced towards prescribed values. However, the known nudging formulations can not systematically take into account the fact that the local variance explained by a given anomaly pattern varies between 0 and 1. This difficulty is overcome by a new designed technique, which is formulated entirely in a pattern space, and is able to nudge only the amplitude of the large-scale anomalies estimated from the proxy data. This so-called pattern nudging has been implemented in the ECHAM4 model. It is currently being tested using signatures of prescribed states of the Arctic Oscillation in the prognostic model variab temperature and relative vorticity on model levels between 900 hPa and 400 hPa, which hav been defined by means of regression maps. Figure 5 shows these states at the 800 hPa level for temperature and relative vorticity. The method should provide a physically consist interpolation between various forcing patterns, information propagation into regions where tl linear statistical methods do not pick up a signal from the proxy data, as well as inforr propagation to smaller spatial and temporal scales, which are not directly modified. Due to model physics these smaller scales are expected to respond consistently with the large-sc forcing.

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Fig. 5: Left: Temperature and right: relative vorticity signatures of the Arctic Oscillation on the 800 hPa level.

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