Reconstructing the Global Climate from the mid-Holocene until Present from Paleoclimate Records and Transient GCM Integrations.

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Abstract

Relationships between ring width chronologies and atmospheric circulation are investigated with the aim of assimilating these patterns in the ECHAM4 coupled with the HOPE-G ocean model via upscaling methodologies. A reconstruction of the NAO index based on North American and Scandinavian chronologies yields good agreement with a reconstruction based on ice core data of Appenzeller *et al.* (1998).

Introduction

An improved understanding of natural climate variability, both spatial and temporal, on time scales from decades to centuries, is crucial to separate it from anthropogenic climate effects. In recent years many records containing paleoclimate proxy data have become available. Climatic information is recorded, for instance, in tree rings, ice cores, laminated sediments and coral reefs. However, the reconstruction of the past climate is hindered by the uncertainties of the paleoclimate data and by the fact that, to date, their sparse spatial coverage has made it impossible to obtain a spatially complete picture.

Our project aims to improve understanding of the global climate of the last millenium by reaching a synergy between proxy data collection and the numerical modelling of the ocean/atmosphere system. In addition to conducting free and externally forced GCM experiments, a newly developed method for proxy Data Assimilation Through Upscaling and Nudging (DATUN), will be a central element of the work. The GCM to be used is the ECHO model. It consists of ECHAM4 coupled with the HOPE-G ocean model. Three simulations shall be undertaken: a control integration with present external forcing, an integration with estimated historic external forcings, and an integration driven by climate variability as inferred from proxy records using the DATUN technique.

The results presented in this paper are the preliminary stages of developing these statistical upscaling models, one example from the Northern Hemisphere, the other from the Southern Hemisphere. The rationale behind this work is that if a proxy record responds to climate, e.g. tree ring width responding to temperature or precipitation, these variables can themselves be related to the larger-scale atmospheric circulation. This linkage between local and larger-scale climate has been utilised in numerous downscaling studies (e.g. Wilby et al., 1998; Hewitson and Crane, 1996). Upscaling is the inverse of such methods, i.e. reconstructing large scale climate from local scale predictors. It has also been used to produce reconstructions of indices representative of atmospheric circulation, for example the North Atlantic Oscillation from ice core data (Appenzeller *et al*., 1998) and from tree rings (Cook *et al*., 1998) and the Trans-Polar Index (Villalba *et al*., 1997). This work investigates the relationships between circulation *patterns* and climate proxy data, concentrating on ring width chronologies. This work will be expanded to assess the inclusion of tropical and polar ice core data, coral and historical data.

Northern Hemisphere

This work is focused on the reconstruction of the NAO intensity during the last four centuries. Canonical Correlation Analysis (CCA) is used to isolate the NAO signal in a data set of tree-ring chronologies over the USA and Eurasia, these being the predictor variables, and these used to reconstruct sea-level pressure over the North Atlantic region during the 20th century. The statistical links obtained through CCA are used to develop a reconstruction of the NAO intensity since 1650. D'Arrigo *et al.* (1993) showed that chronologies from Scandinavia respond well to variations of the NAO index (Rogers, 1994) and Cook *et al.* (1998) made a reconstruction of the NAO intensity for the period 1700 to 1980. Here, the reconstruction of the NAO intensity is attempted using sea level pressure (SLP) data over the North Atlantic region. The CCA allows not only the reconstruction of an intensity index but also associating spatial patterns that allow for a regional insight.

Winter seasonal means of SLP (Jones, 1997) for the period 1873 to 1970 have been used as predictand variables and a pool of 268 chronologies distributed over USA and Eurasia as proxy predictor variables (Woodhouse, 1998) with available data for the period 1650 to 1970.

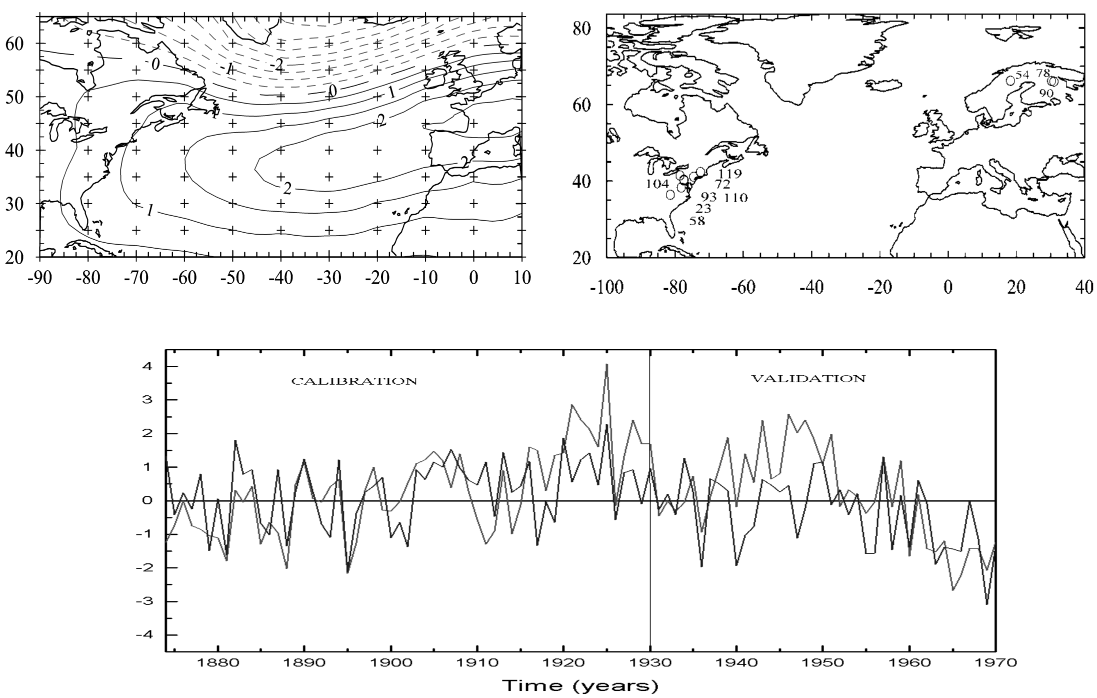

Figure 1. First pair of canonical vectors resulting from CCA of SLP and 10 chronologies (upper layer) and correspoding canonical components (lower layer; slp: dark and chronologies: light). The canonical correlation is 0.55 and the explained variances 28 % and 22 % for SLP and chronologies respectively.

Data were divided into calibration (1873-1930) and validation (1930-70) periods. The chronologies showing the strongest correlations with the first empirical orthogonal function (EOF) of SLP were retained. A principal component analysis was then applied to the predictor and predictand data sets in order to retain the most important variability modes. A CCA was then applied in order to obtain the linear combinations of principal components (canonical components) that show more correlation between SLP and chronologies.

The resultant first canonical component of the climate variable shows the variations in intensity of the NAO during the instrumental period. The chronology component shows the effect of the NOA on tree growth, and is reconstructed for the period 1650 to 1970 as an index of NAO variations in intensity during the pre-industrial era. This reconstruction was by made through minimising the error of the linear fit of the first canonical pattern of the chronologies and the original chronology field in each time step.

The results of the CCA between SLP and chronologies are shown in Figure 1. The SLP shows the typical distribution of anomalies of the NAO pattern (Hurrel, 1995). When the frequency of occurrence of this pattern increases there is a more intense zonal flux and vice versa. The canonical component shows a correlation of 0.86 with the NAO index. The chronologies which show the strongest relationships with this variability are in the eastern USA and northern Scandinavia, showing positive values of growth associated with the SLP pattern. This is a physically sensible relationship, since the SLP pattern advects mild oceanic masses to the east coast of USA and north of Scandinavia favouring mild temperatures and increased precipitation and therefore positive growth.

The reconstructed NAO intensities for the period 1650 to 1970 were obtained through projecting the original tree-ring width data onto the tree-ring canonical pattern in Figure 1. The obtained time series is shown in Figure 2 together with that of Appenzeller *et al*. (1998) obtained from ice core data, together with the variance spectrum and squared coherence. The results show remarkable agreement. The coherence spectrum shows that agreement is generally good at longer timescales. This supports our method to reconstruct large scale climate patterns and a first evidence of agreement between independent proxy data in reconstructing the NAO changes in the past.

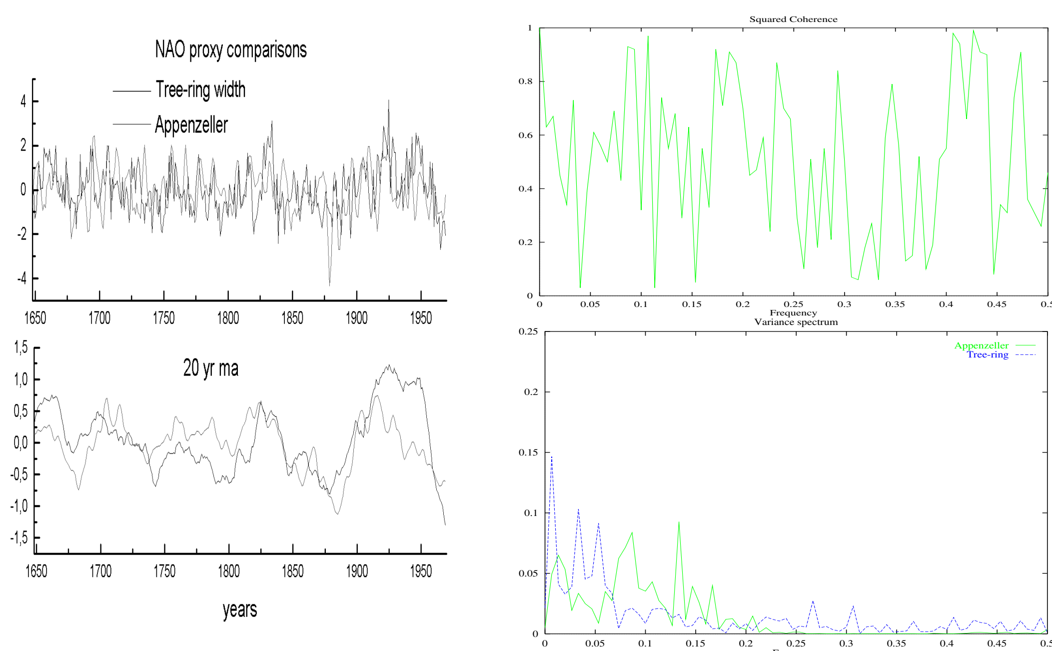

Figure 2. (Left upper panel) NAO intensities reconstructed from tree-ring data following the analysis described herein and from ice core data (Appenzeller et al., 1998), (left lower panel) 20-year moving average of the time series above. Squared coherence (right upper panel) and variance spectrum (right lower panel) of the two time series.

Southern Hemisphere

EOF analysis of annual mean sea level pressure (MSLP) anomalies from the NCEP/NCAR reanalysis dataset was undertaken. This was done for Southern Hemisphere summer (DJF), for the period 1951-1980. This corresponds to the growing season, and to the start of the reanalysis data and the common end date of the majority of the dendrochronologies. The domain chosen covered the Tropical Pacific 0^{o}S -60^{o}S, 120^{o}E-30^{o}W.

Eleven EOFs were retained, those explaining more than 1% of the original variance. To determine which chronologies show a relationship with pressure, and therefore are suitable for inclusion in the upscaling, correlations were calculated between ring width chronologies from and the principal components (PCs) of the EOFs. The chronologies were obtained from the International Tree Ring Databank, and were from Argentina (Holmes, 1976; Roig *et al*., 1992; Boninsegna *et al*.., 1989; Villalba *et al*, 1989), Chile (Roig and Boninsegna, 1992) and New Zealand (Norton, 1980; Palmer, 1986; Xiong and Palmer,1991).

Significant relationships between the PCs and the chronologies occurred for the first three EOFs, and are shown in Figure 3 below. Of the available chronologies, seven from Argentina, two from Chile and seven from New Zealand exhibited significant relationships, the locations of which are also shown in Figure 3.

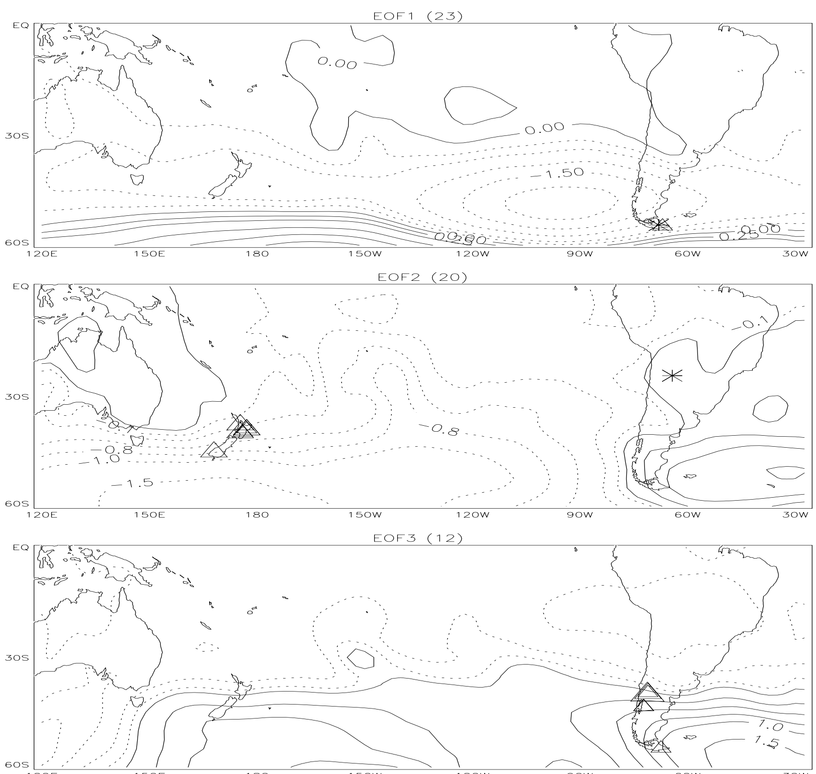

Figure 3. The first three EOFs of NCEP/NCAR reanalysis data DJF MSLP anomalies for the period 1951-1980. Explained variances are given in parenthesis. Symbols indicate chronologies showing a significant correlation with each EOF. A triangle (star) indicates positive (negative) correlation. Small symbol=0.46-0.50, medium=0.51-0.60, large=0.61-0.70.

The majority of relationships with the South American series are with the PC of EOF3, and are positive. Growth is therefore high when MSLP anomalies are negative over central and northern

South America, and positive to the south. These stations are situated on the eastern side, i.e. the rain shadow, of the Andes. The positive phase of this EOF is a strengthening of easterly flow, bringing relatively moist air from the Atlantic, thus high tree growth, contrasted with westerly flow and dry air in the opposite phase. To aid interpretation of the EOFs, correlations were calculated between the PCs and the Trans Polar Index (TPI) of Jones *et al*. (1999). This index was developed by Pittock (1980) and is based on the MSLP difference between Hobart (52^{o}S, 58^{o}W) and Stanley (43^{o}S, 147^{o}E). It describes the tendency of the polar vortex to be displaced towards either station, i.e. the Australian/New Zealand sector (negative index), or the South America/South Atlantic sector (positive index). Both EOF2 and EOF3 show opposing pressure anomalies over these stations. Highest correlations occur with the PC of EOF3, although the value of -0.28 is not statistically significant at the 95% level.

All New Zealand correlations are with the second PC. These are positive, thus the EOF pattern indicates that tree growth is higher with westerly flow to, and low pressure over, New Zealand. This circulation would bring of cyclones, and hence increased precipitation. Salinger (1980) found station precipitation in New Zealand to be related to zonal circulation strength over the country, although with localized anomalies.

A perplexing result is the opposing relationship between PC1 and the two southernmost chronologies, one positive and one negative. The chronologies themselves are negatively correlated over the 1952-1980 period (-0.46). The explanation thus lies with the chronologies, possibly local effects, such as topography, or possibly errors in dating of the chronologies.

Conclusions

A reconstruction of the North Atlantic Oscillation was developed using Scandinavian and Eastern North American ring width chronologies. This compared very well to the reconstruction developed by Appenzeler et. al. (1998) based on ice core data, supporting this method of climate pattern reconstruction.

An equivalent analysis undertaken using tree ring chronologies from Chile, Argentina and New Zealand, exhibited statistically significant relationships with circulation variations as represented by EOFs of NCEP/NCAR reanalysis data MSLP. Those chronologies for which a physically sensible explanation of these relationships is available shall subsequently be used as predictors for reconstruction of the forcing MSLP variations, together with assessment of the inclusion of other proxy data types such as ice core and coral series.

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