Multiple tree-ring parameters from Atlas cedar (Morocco) and their climatic signal

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Introduction

Cedrus atlantica ring width data from the site 'Col du Zad' southeast of the main range of the High Atlas (Fig. 1) are included in several regional and larger scale palaeoclimatic analyses (e.g. Chbouki et al. 1995, Glueck and Stockton 2001, Mann et al. 1999, Stockton 1988, Verstege et al. 2004). Ring width data recorded at this site – and basically at all cedar sites in Morocco – correlate with precipitation variation during winter and the vegetation period, allowing for reconstructions of the North Atlantic Oscillation via its fingerprint on regional winter rainfall in Morocco (e.g., Cook et al. 2002). Col du Zad is of particular interest, since individual cedar trees reach ages of 1000 years and more, making this site valuable for millennium long reconstructions of precipitation variability, and via synoptic relationships for long-term temperature estimations.

In an effort to survey the potential of using further measurements in addition to 'traditional' ring width data (TRW) for palaeoclimatic studies, we here assess the climatic signal of multiple tree-ring parameters recorded from *Cedrus atlantica* at Col du Zad: maximum latewood density (MXD), minimum density (MID), latewood width (LWW), and earlywood width (EWW). We present a comparison of these parameters and correlate them with regional temperature and precipitation data. The capability of *Cedrus atlantica* TRW measurements for long-term climate reconstructions is demonstrated by estimating October-September precipitation variations over the past 900 years using a combined 150+ core sample dataset integrating series from the sites Col du Zad and a nearby cedar site Tizi n' Tarhzeft, hereafter referred to as Col and Tiz, respectively.

Material and Methods

Col (32°58'N, 5°04'W) and Tiz (33°06'N, 4°54'W) are located in the Middle Atlas at ~2,150 m a.s.l. (Fig. 1). Tree coverage, influenced by the dry climate in the rain shadow of the first Middle Atlas ranges north of the sampling sites, ranges from 35% at Col to less than 10% at Tiz. 106 core samples from about 70 trees and 57 core samples from about 40 trees were taken at Col and Tiz, respectively. Maximum and mean lengths of the tree-ring series are 1024 and 299 years for Col, and 848 and 371 years for Tiz (Verstege et al. 2004).

We selected 20 core samples from 10 trees in Col to measure high resolution (10 µm) density variations over the past ~200 years using a Walesch-2003 X-ray densitometer (Schweingruber et al. 1978). Selected trees represent different age classes, i.e. young and old cedars were considered. High resolution density profiles were then utilized to derive five tree-ring parameters TRW, MXD, MID, LWW, and EWW (Schweingruber 1983) for comparison with regional climate data.

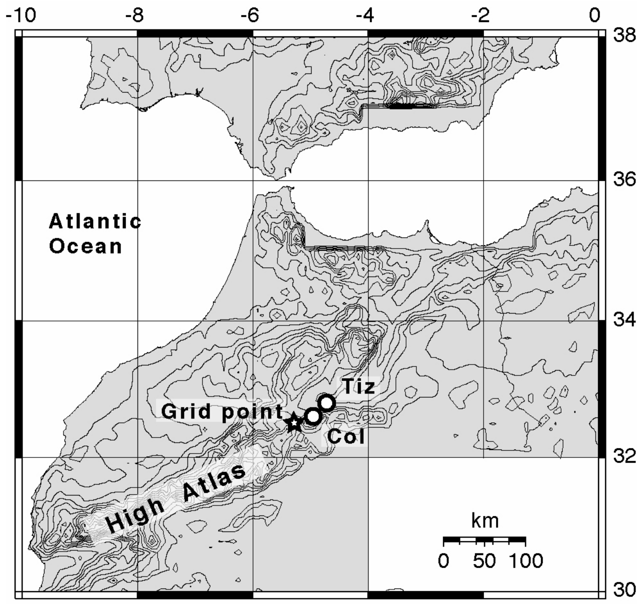

Figure 1: Map showing the tree-ring sampling sites Col and Tiz (circles), and the instrumental climate grid point location (star) in the Middle Atlas, Morocco.

Tree-ring data were standardized by calculating residuals from 300-year fixed splines (Cook 1985), after stabilizing the 'spread-versus-level relationship' of individual measurements using a data adaptive power transformation to avoid potential end-effect problems in resulting chronologies (Cook and Peters 1997). Since little to no power was found for the MXD and MID density parameters, effectively no transformation occurred in these measurements. Chronologies were calculated using the arithmetic mean, and the chronologies' variance stabilized using a method outlined by Osborn et al. (1997). See also Frank et al. (2005), this volume. Signal strength of the arithmetic mean timeseries was estimated by calculating interseries correlations (RBAR) over 50-year intervals lagged by 25 years along the chronologies (Wigley et al. 1984).

To estimate the climatic signal in the proxy data, we correlated each parameter chronology with gridded observational temperature and precipitation data over the 1901-2000 period (Mitchell et al. 2004). The grid-point closest to the tree-ring sites at 32°50'N/5°50'W was considered (Fig. 1).

Results

Long-term negative trends in fitted growth curves (Fig. 2, 300-year splines), likely related to the aging of cedar trees, are similar between TRW, LWW and EWW. They, however, appear on differing levels related to the varying mean widths recorded for these parameters (Tab. 1, 0,73 mm for TRW, 0.13 mm for LWW, 0.60 for EWW). Visual inspection of the detrended measurement series indicates high common variance in TRW and EWW, and less common

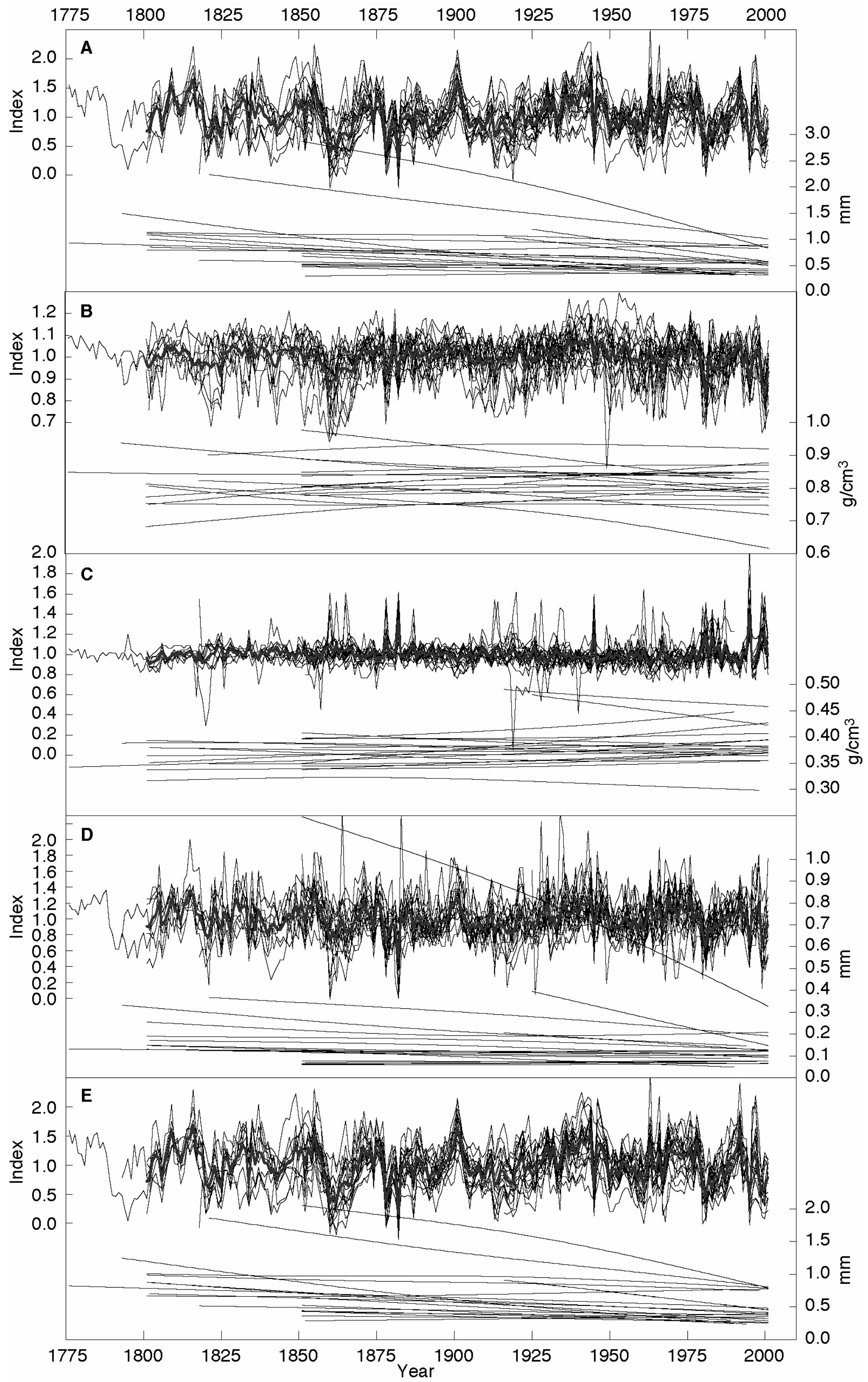

*Figure 2: Standardized tree-ring series and 300-year fixed spline growth curves used for detrending. Shown are the results for the 20 core samples from Col for **A**, TRW, **B**, MXD, **C**, MID, **D**, LWW, and **E**, EWW.*

variation in LWW (Fig. 2), with rich inter-annual to inter-decadal variability seen in all three width parameters.

Table 1: Col multiple tree-ring parameter growth statistics from 20 core samples (10 trees) spanning 1776-2001. 'Mean' is the arithmetic mean over all 3,341 tree-rings. AC (raw) and AC (detr) are the first order autocorrelations of the raw and 300-year spline detrended data, respectively. RBAR (raw) and RBAR (detr) are the interseries correlation of the raw and detrended data, respectively. AC (chron) is the first order autocorrelation of the spline detrended chronology calculated over the 1901-2000 period of overlap with instrumental data.

Parameter	Mean	AC (raw)	AC (detr)	RBAR (raw)	RBAR (detr)	AC (chron)
TRW	0.73 mm	0.70	0.63	0.43	0.41	0.49
MXD	0.82 g/cm^3	0.59	0.53	0.17	0.19	0.52
MID	0.31 g/cm^3	0.32	0.30	0.26	0.28	0.11
LWW	0.13 mm	0.54	0.44	0.24	0.24	0.35
EWW	0.60 mm	0.70	0.63	0.43	0.41	0.48

In comparison, the 300-year splines fitted to the density data indicate positive (MID) and no long-term trends (MXD). Detrended MXD data exhibit high variance between single series relative to the variations of the mean curve, i.e. increased spread between detrended measurements. The detrended MID data, however, behave different from all other parameters. These data show less decadal scale variation, accompanied by remarkably positive extreme values (pointer years). These findings, i.e., the differing low frequency biases in raw measurements (removed by 300-year spline fits), the higher low frequency loading of the standardized width parameters TRW and EWW, and the reduced common variance in the density parameters and LWW, are confirmed by the first order autocorrelations and RBAR statistics averaged over the individual measurement series (Tab. 1).

Interestingly, the chronologies of the width parameters TRW, EWW, LWW correlate >0.90 over the well-replicated 1801-2001 period (Fig. 3a), indicating little independence between these measurements. These high inter-parameter correlations occur even though the common variance in the detrended LWW data is lower than in the TRW and EWW data (Fig. 3b). The width parameter chronologies (TRW, EWW, LWW) are also similar to the MXD results (Fig. 3a) with correlations over the 1801-2001 period all >0.65. The comparison of multiple parameters further reveals that only the MID data shows somehow different information. MID variations correlate negatively with all other parameters. The lowest but still significant correlation (-0.50) is found between the MID and MXD chronologies (1801-2001 period). Common variance in the MID data is higher than in the MXD data (except for one segment centered around 1860, Fig. 3b).

With respect to the limited independence between these various tree-ring parameters, it is not surprising that the correlations with monthly and seasonal temperature and precipitation data show similar patterns (Fig. 4a). Overall, temperature has no significant impact on any of the considered parameters. February precipitation sums correlate significantly with all parameters, and May and June sums with MID. MID correlations are opposite to the results obtained from all other parameters. These patterns are also valid for the seasonal precipitation records (Oct-Sep, Feb-Apr, Dec-Jul) that overall indicate the highest diagnostic skill of the tree-ring parameters (with the sign of the MID correlation again reversed). Highest correlations are found between MID and October-September (-0.54) and December-July (-0.55) precipitation sums. Visual inspection of the fit with October-September precipitation (Fig. 4b) indicates that both inter-annual and decadal scale variations are well captured in the MID data. This seems surprising, since MID generally appeared to possess lowered loading in the decadal scale frequency domain (Fig. 2).

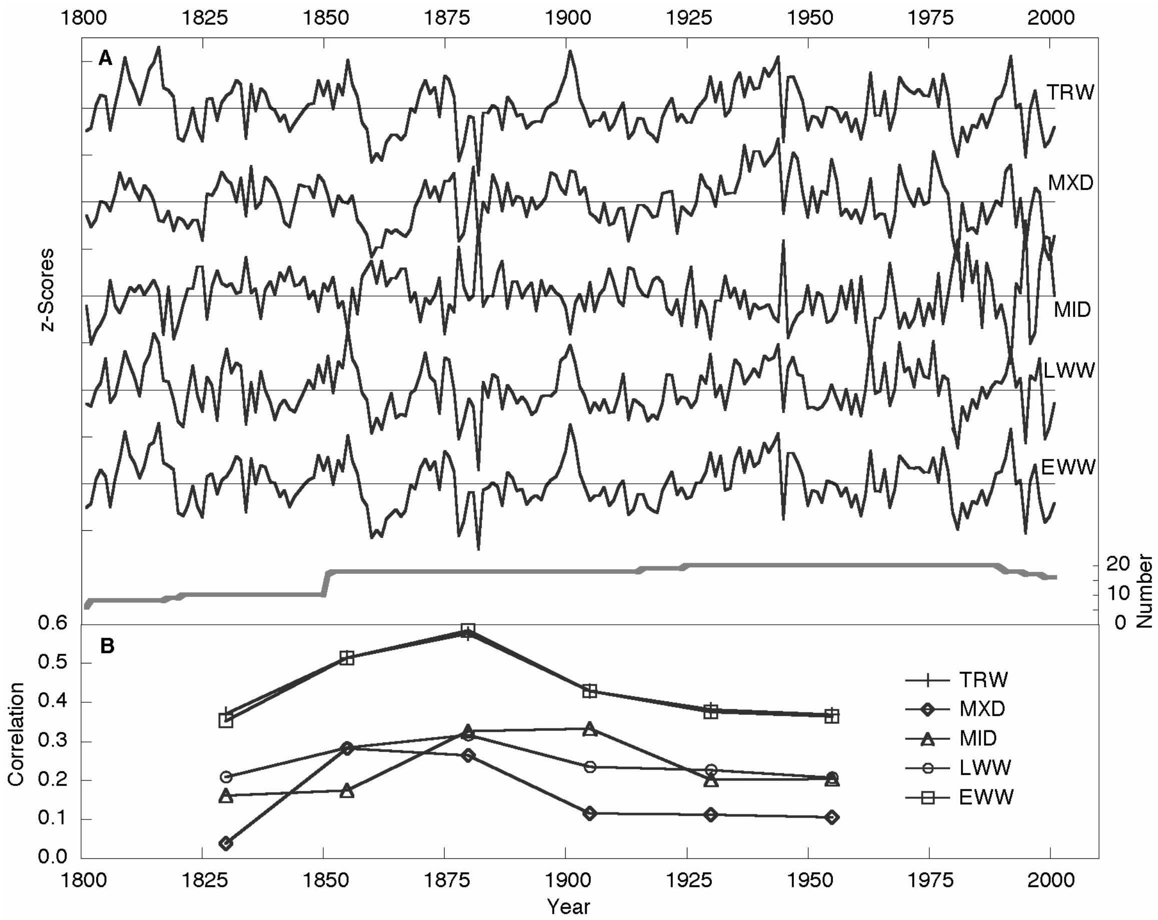

Figure 3: Tree-ring chronologies and common variance statistics. ***A****, 300-year spline detrended TRW, MXD, MID, LWW, and EWW tree-ring chronologies and sample replication (bottom).* ***B****, Interseries correlations (RBAR) calculated for 50-year segments lagged by 25 years.*

The correlation between MID and MXD data (r = -0.50, 1801-2001 period; Fig. 5) was rather unexpected, since no such relationship is reported for tree-ring data from high latitude, temperature sensitive sites (Briffa et al. 1998, Schweingruber et al. 1996). For the Moroccan data, it basically indicates that low MID values, seemingly caused by high precipitation sums (Fig. 4), are linked with high MXD values. The relationship is stronger in the higher frequency than in the lower frequency domains, i.e. is -0.59 for 10-year high-pass and -0.45 for 10-year low-pass filtered data, both calculated over the 1801-2001 period.

Since low MID values are indicative for wide earlywood cells, the MID data significantly correlate with the TRW (-0.64) and EWW (-0.64) chronologies, calculated over the 1801-2001 period. This dependency is again well known from high latitude tree sites (Schweingruber et al. 1996).

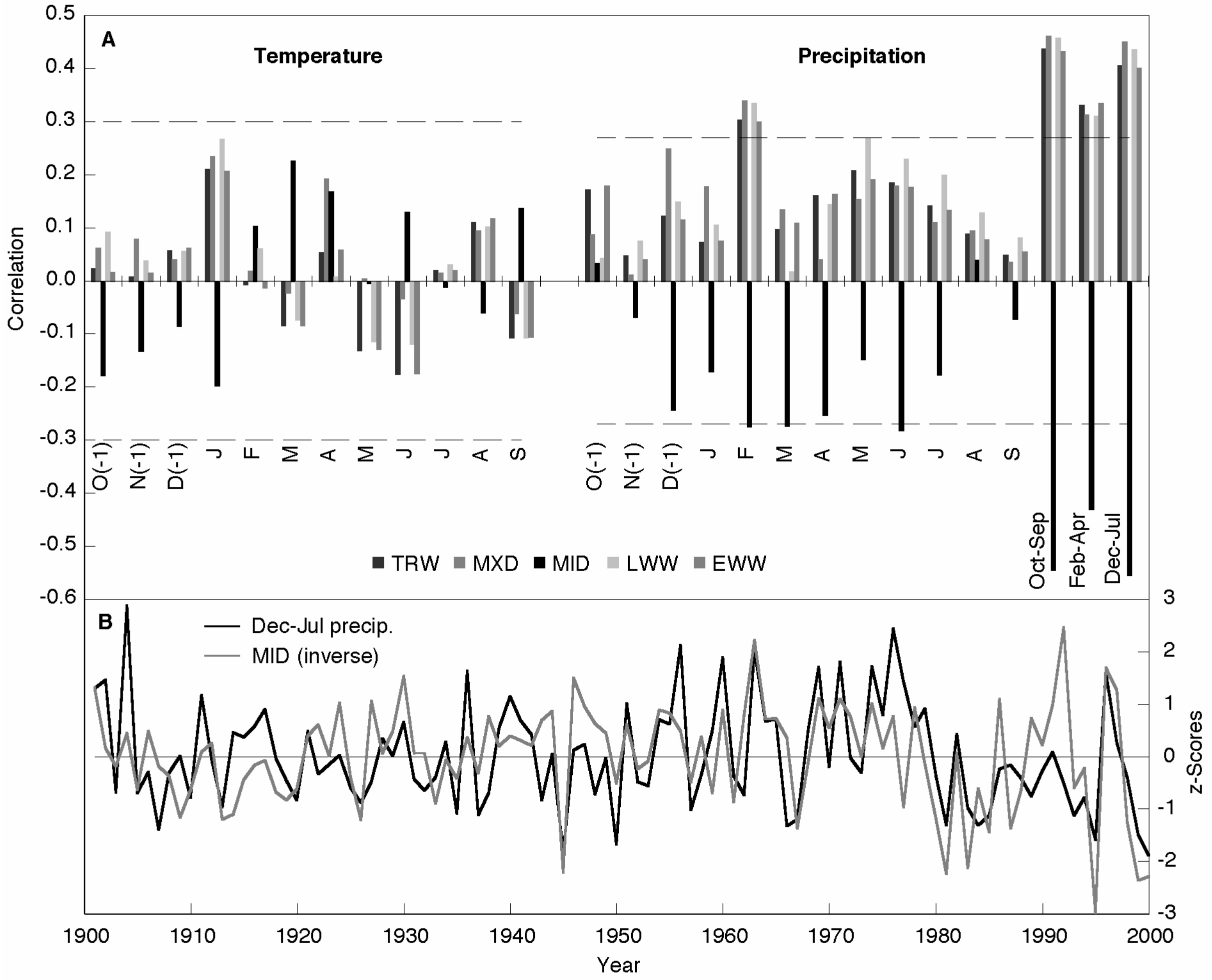

Figure 4: Climate signal of multiple tree-ring parameters, and MID versus precipitation comparison. ***A****, Pearson correlation coefficients between Col tree-ring parameters (TRW, MXD, MID, LWW, EWW) and temperature and precipitation data. Climate data represent the closest grid point provided by the Climatic Research Unit (Mitchell et al. 2004). Temperatures are monthly mean values, and precipitation monthly and seasonal sums. Horizontal lines indicate (maximum) p<0.01 significance levels, corrected for lag-1 autocorrelation considering the October-September climate data. For tree site and grid point locations see figure 1.* ***B****, Visualization of the fit between December-July precipitation and (inverse) MID data.*

To demonstrate the potential of these additional tree-ring parameters (particularly MID), for estimating past climate variability, a long-term reconstruction of October-September precipitation sums back to AD 1100 is shown (Fig. 6a). This record represents a combination of 157 TRW series from Col and Tiz, regressed against observational grid point data (Mitchell et al. 2004). The model explains 36% of the variance of instrumental data during the 1902-2000 period of overlap (r = 0.60). Linear regression, as applied here to transfer the proxy data into precipitation estimates, reduces the models' variance in the order of the unexplained variance (Fig. 6b), i.e. there is a tendency that the model underestimates the ‘true’ variance of precipitation sums over the past 900 years (Esper et al. 2005).

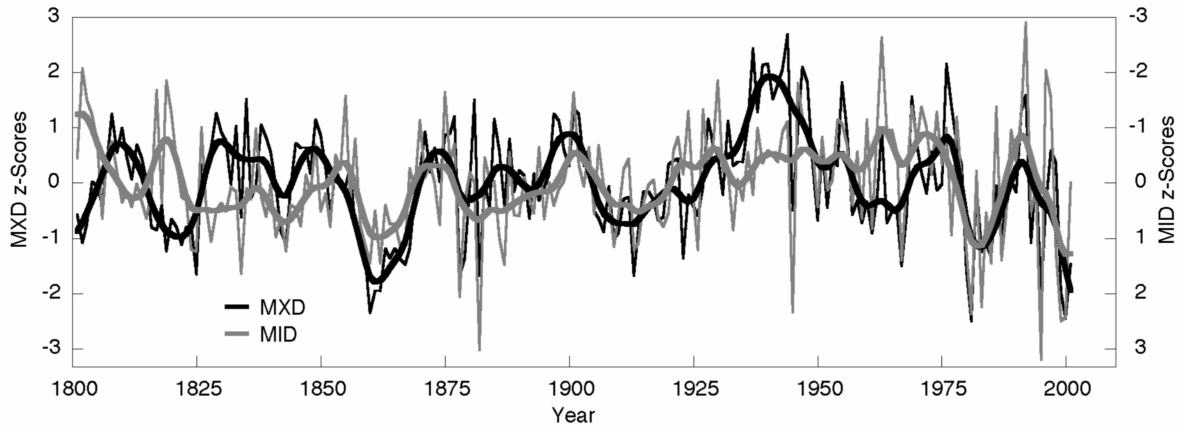

Figure 5: Comparison of the 300-year spline detrended MXD and MID chronologies. Data are normalized over the 1801-2001 period (correlation is –0.50). Bold curves are 10-year smoothed values. MID is inverted.

The precipitation reconstruction also seems to be biased by an increase in variance back in time. This change in variability appears, even though the variance of the TRW chronology was stabilized using the method outlined by Osborn et al. (1997). These variance changes are in part related to the decrease in sample replication back in time (minimum replication in AD 1100 is 3 core samples), accompanied by an increase in interseries correlation as expressed by the RBAR measurements (Fig. 6a). For details on this issue see Frank et al. in this volume.

Conclusions

The analysis of multiple tree-ring parameters from Moroccan *Cedrus atlantica* trees, including TRW, MXD, MID, LWW, and EWW, revealed little additional potential to estimate long-term climate variations that would exceed the existing evidence based on TRW only. This conclusion largely stems from the limited independence between several of the tested parameters, namely TRW, LWW, and EWW. For MXD, common variance is much lower than reported from temperature sensitive high latitude sites (e.g. Briffa et al. 1998). Also, the climatic signal (here only significant with precipitation) does not reach the strength as found in TRW data. The MID data, however, seems to provide additional information on past precipitation variations. This occurs despite the fact that the standardized MID series show little lower frequency variability, and reduced signal strength statistics in comparison to TRW and EWW. Due to the nature of MID data, the correlation with precipitation is opposite to TRW measurements. To robustly estimate the potential of MID for climate reconstructions, more data from ecologically differing sampling sites in the Middle and High Atlas would need to be measured. This current analysis suggests that such an effort would be worthwhile.

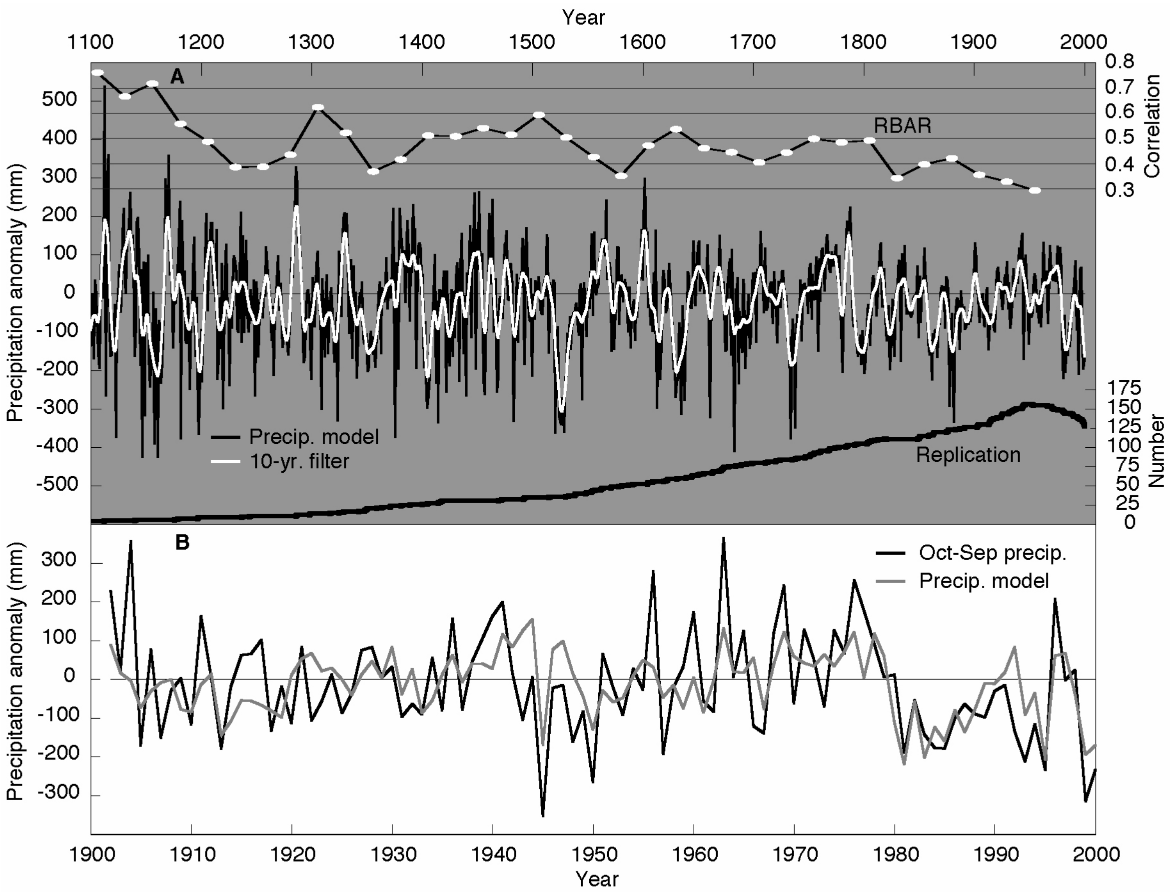

Figure 6: Long-term precipitation model. ***A****, October (previous year) to September precipitation reconstruction back to AD 1100 utilizing 157 ring width measurements from Col and Tiz. Measurements were detrended using a data adaptive power transform, and residuals from 300-year fixed splines calculated. The precipitation model is the variance corrected arithmetic mean of these index series regressed to grid point precipitation data over the 1902-2000 period, with 1902 considering the October to December rainfall sums recorded in 1901. Interseries correlation (RBAR) calculated over 50-year segments lagged by 25 years, and core sample replication are shown at the top and bottom, respectively.* ***B****, Visualization of the fit between the model and observational data in the 20th century. Correlation is 0.604.*

MID data also seem to be related to MXD data, a novel finding not reported from other density analysis (Schweingruber, pers. comm.). While this seems to be an interesting feature, we do not have a physical explanation for this dependency. The association between MID and MXD is mainly driven by the higher frequency, inter-annual component, and the level of correlation (-0.50 over the 1801-2001 period) seems to be robust enough to further investigate the association between these parameters.

The capability of cedar trees for climate reconstruction is revealed by a long-term precipitation model using TRW data. Artifacts resulting from changes in sample replication, inter-sample cross-correlation, and variance changes in the detrended single measurements, make this reconstruction to indicate an increase in precipitation variability back to AD 1100 (see Frank et al., this volume). The model also indicates that no long-term, centennial-scale precipitation variation is reconstructed over the past 900 years. This characteristic is likely related to the individual spline detrending procedure that removes lower frequency variation from the TRW data (Cook et al. 1995, Esper et al. 2003), i.e., the model as presented here does not allow for an evaluation of potential centennial scale variation, as, for example, recently reconstructed in Europe, the US, and Central Asia (Cook et al. 2004, Treydte et al. 2005, Wilson et al. 2005). These issues demonstrate the profound impacts that methodology can have on resulting reconstructions. More data and tests using differing detrending methods would be necessary to explore the low frequency spectrum of long-term precipitation variability in Morocco.

Acknowledgements

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