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RECONSTRUCTING PAST TEMPERATURE VARIATIONS: SOME METHODOLOGICAL ASPECTS

ABSTRACT

Three aspects essential for the paleoclimatic reconstructions are considered: calibration of proxy data on an example of tree-ring width records as the main source of proxy paleoclimatic information; taking into consideration an integral nonstationarity of multiscale climatic variations; and use of the empirical orthogonal function expansion for the goal of the past meteorological field reconstruction.

KEY WORDS: paleoclimatic reconstruction, tree-ring width data, past climate normals, empirical orthogonal functions.

INTRODUCTION

During the latest decade several groups of climatologists tried to reconstruct near surface air temperature variations averaged over the almost whole Northern Hemisphere area for the time period 1000–2000 BP [Wang et al., 1996; Mann et al., 1998; Jones et al., 1998; Mann et al., 1999; Crowley and Lowery, 2000; Briffa et al. 2001; Esper et al., 2002; Cook et al., 2004]. All their reconstructions look to be rather similar with each other. In particular, they show the Medieval Warm Period to be less strong in comparison with the Current Warming. The last IPCC report mentions this circumstance as an evidence of the Current Warming unique. But some doubts can be voiced as concern these reconstruction reliability.

Every kind of proxies is a thermometer with an unknown scale. Although these scales are very complex and nonlinear for certain, the above paleoclimatologists calibrated these scales in a simple linear manner comparing a proxy record used for a reconstruction with an instrumental temperature record over a time interval of their overlapping. This interval is short, and so it is quite clear that such calibrations can be meaningful for inter-annual and inter-decadal temperature variations. Spreading these calibrations onto lower-frequency parts of the proxy scales is an inadmissible extrapolation because responses of some proxies to longer-living external (climatic and environmental) variations can differ from those corresponding to the inter-annual and inter-decadal variations.

A PROBLEM OF THE PROXY DATA CALIBRATION ON AN EXAMPLE OF TREE-RING WIDTH RECORDS

Consider some consequences of such extrapolation on an example of tree-rings because it is widely accepted to use tree-ring width records as the main source of paleoclimatic information. Tree-rings are prominent by their annual resolution with a rather good timing, and tree-ring width record samples are very numerous and with broad geographic representative. In spite of these obvious merits, three-ring width proxy data have some drawbacks. In particular, some depressive tree growth observed in many geographic regions during a few recent decades [Briffa et al., 1998; Datsenko, 2005] seems to be a fingerprint of the aforementioned differentiation between higher- and lower-frequency parts of the tree-ring scales. Indeed, the germination of tree seeds is a climate (in particular temperature)-sensitive process. A small per cent of seed crops germinates near the northern and upper forest-limits where tree-rings usually are sampled by dendrochronologists now. Therefore distances between juvenile trees in such a location usually are large, and so other environmental conditions for the tree growth (the sun illumination, soil nutrition etc.) turn out to be rather favorable because of absence of any between-tree competition. However, one can suppose: if climate was much warmer in a past time period these locations were fare from the northern and upper limits of the tree growth, i.e. very within the tree areal of the tree species being sampled. Because of more favourable temperature, the germination of tree seeds became to be abundant, and the excessive forest density resulted from this abundant germination implied a deterioration of the followed tree growth. Thus, assuming a wide range of multiscale climatic variations, two processes of the tree growth must be taken into account: 1) thickening of tree-stems during a number of consequent years of tree life that is well-proportioned to instantaneous temperatures and under condition of an almost constant forest stand, and 2) thickening of tree-stems during essentially longer time intervals that is inversely-proportioned to longer-term forest stand changes.

The difficulty in the tree growth calibration increases even more because the traditional tree-ring width index is an inappropriate measure of the annual wood production. Indeed, the tree-ring width is an age-dependent quantity for both juvenile and mature trees. To remove this dependence the so-called tree-ring standardization is used. Any tree-ring standardization inevitable suppresses responses of trees to longer-living external variations at least partly. The known [Briffa, 1992; Visser, 1995] basal-area increment index (*BAI)* is a better measure in comparison with the standardized tree-ring width index. But *BAI* was used in no recent paleoclimatic reconstructions because, as a rule, there was no reliable information about the value of the innermost radius of tree-ring records (the so-called pith-offset) used, and because the nature of *BAI* is nonlinear and difficult to handle.

However, it is easy to prove that a new modified, similar to *BAI*, index $dR(t) \cdot R(t)$ (where $dR(t)$ is the ring width in the year *t*, and $R(t)$ is the inner radius of this ring) is a rather good measure of the wood production. This quasi-linear quantity is robust to the geometry of the stem section. Moreover, this quantity seems to be age-independent for mature trees (see: [Biondy and Qeadan, 2008]), and so it can be used without any standardization in principle. Unfortunately, it is not so in reality because some tree species, reveal apparent increase of their uppermost ring widths. By this reason, a kind of standardization must be preserved even if the modified *BAI* is used instead of the traditional ring width index.

Fig. 1 shows a "toy"-chronology created with using this new index for the seven larches from the North-East Siberia (obtained from O.V. Sidorova – a member of E.A. Vaganov's Russian team of dendrochronologists). A comparison of this "toy"-chronology with instrumental temperatures of the region (extracted from [Briffa et al., 2002]) reveals its certain success in reproducing regional temperature variations as it is seen from the calibration graphs shown in Fig. 2. Note a parabolic calibration looks to be preferable in comparison with the linear calibration of this reconstruction. This fact corroborates the existence of two scales in tree growth responses to the external condition variations mentioned above. Even by eye this

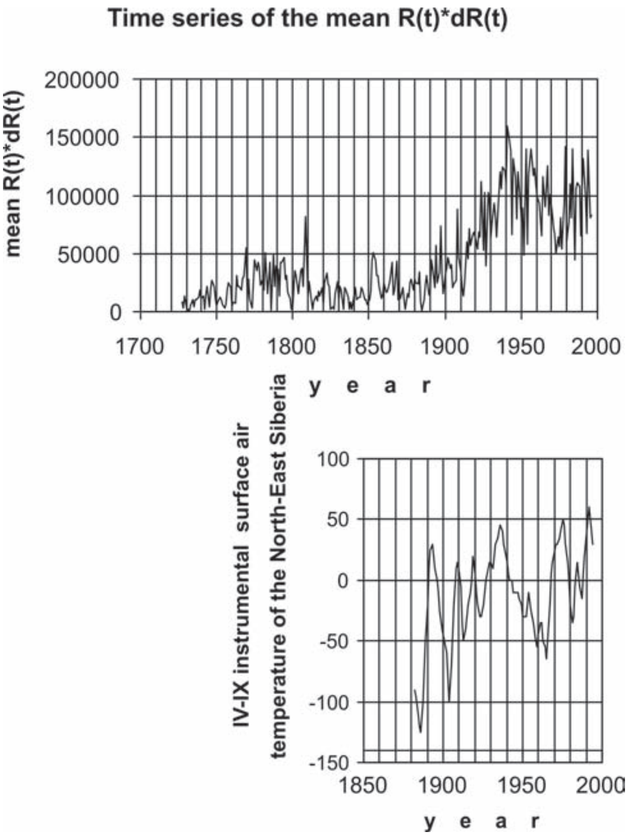

Fig. 1 A "toy"-chronology created with use of the *dR(t)8R(t)*-index time series for seven larches. A general similarity with the mean Northern Hemisphere temperature variations during the instrumental observation period can be seen even by eye

"toy"-chronology reproduces rather well the Northern Hemisphere temperature variations during the latest 270 years. Its correlation with the mean temperature of the Northern Hemisphere turns out even higher than with regional temperatures because station instrumental temperatures seem to be of rather bad quality. The station data of the region under consideration cover a shorter time intervals, reveal data gaps, and poor representative for their broader vicinity.

Worse quality of regional and local instrumental temperatures in comparison with hemispheric mean temperatures is the general case. By this reason and by the reason of linearity of the calibration procedure as well as the procedure of adding all proxies at the final stage of any reconstruction, it is perhaps better to calibrate proxies with respect to the mean hemispheric temperatures directly.

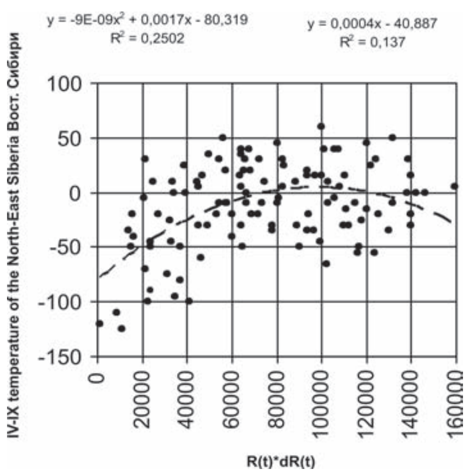

Fig. 2. A graph of correlation between the "toy"-chronology shown in Fig. 1 and the regional instrumental temperatures of the North-east Siberia. Linear and quadratic regression lines are shown together with the respective equations

A PROBLEM OF PRESENT-DAY AND PAST CLIMATIC NORMAL COORDINATION

The next important unsolved problem of the paleoclimatic reconstruction consists in the following. Each real climatic time series is of a finite length. But, the climate dynamics is an integrally nonstationary and locally chaotic process. Therefore, looking at any real climatic time series one can see a trend-like behavior of the moving average of this series almost for certain even if higher-frequency components of the series look to be statistically stationary. As a consequence, the first goal of paleoclimatic reconstruction is to reconstruct macroscale (temporally and spatially very averaged) paleoclimatic variations that can be named the paleoclimatic normal.

Any estimation of such a normal is a kind of biased-, noisy-, and incomplete- data filtering. As a rule, such filtering leads to underestimation of the true magnitude of the normal variations because the spectra of these real variations and errors of proxy data records overlap in the frequency domain. One can suppose that the spectra of the proxy data errors are even redder than the real temperature spectra. By this reason a proclamation of Mann et al. [2005] of an essential lower-frequency temperature variability overestimation in the Moberg et al. [2005] reconstruction is not grounded completely. In order to prove their proclamation Mann et al. [2005] have created tree-ring-like pseudo-proxy records by simple summations of modeled temperature time series with white noise series, and used similar summations of firstly smoothed modeled series with other white noise series to create low-resolution pseudo-proxy records. Such technique of the pseudo-proxy creation is false.

A PROBLEM OF THE USE OF EMPIRICAL ORTHOGONAL FUNCTIONS IN THE PALEOCLIMATIC FIELD RECONSTRUCTION

Finally, it is a misuse to expand proxy records on spatial EOFs calculated on the base of instrumental temperature records by the following reasons:

1) EOFs is a tool to depict variations of anomalies calculated with respect to a certain climatic normal. Any normal as such is out of scope of the EOF-analysis. To overcome this obstacle some paleoclimatologists calculate a normal for the instrumental observation period, and then apply this normal to past climates. Unfortunately the present climate normal is a very bad surrogate of past climate normals. Moreover, it is impossible to hope that past anomalies calculated with respect of the present climate normal can be characterized by the same covariation function, and so the same EOFs which are actual for the present climate anomalies.

2) A covariation matrix of a finite order (instead of a continuous covariation function) can be estimated on the base of instrumental data. Such a matrix depicts covariations between temperatures in finite number of pairs of geographic points corresponding to the present-day meteorological station locations. As a rule, locations of proxy data differ from station locations. Their numbers are also different, and moreover, the proxy data net is temporally nonstationary. Thus, any kind of raw proxy data must be interpolated (extrapolated) into station points before any EOF-analysis can be applied to these proxy data.

3) Spatial covariations of real temperatures relax to almost zero over distances as small as 1000–2000 km [Datsenko et al., 2001]. Therefore, any covariation matrix turns out to be a sparse matrix, i.e. almost all of its elements out of the main diagonal are near zero. It is well known [Datsenko et al., 1983] that the eigen problem for such a matrix is ill-posed and practically unsolvable. It means any calculated set of EOFs is randomly rotated, and so any apparently fruitful approximation of the temperature field variability by a few first EOFs is an artefact of sampling and calculating.

In sum, all benefits of the EOFs use are illusory in the reconstruction problem. If we still wish to apply EOFs the reconstruction procedure must be improved.

Real temperature anomalies look to be more or less homogeneous. By this reason the shapes of their eigen functions corresponding larger eigen values look to be similar to a family of trigonometric functions like the two-dimensional Cos- and Sin- series in the traditional Fourier expansion [Sonechkin, 1971]. The first EOF usually is of the same sign over the entire area of interest. It seems to be an analog of the first constant term in the Fourier expansion. Of course, the eigen functions of real temperature anomalies corresponding smaller eigen values look like fractal fields. But these eigen functions are not essential for any reconstruction. An

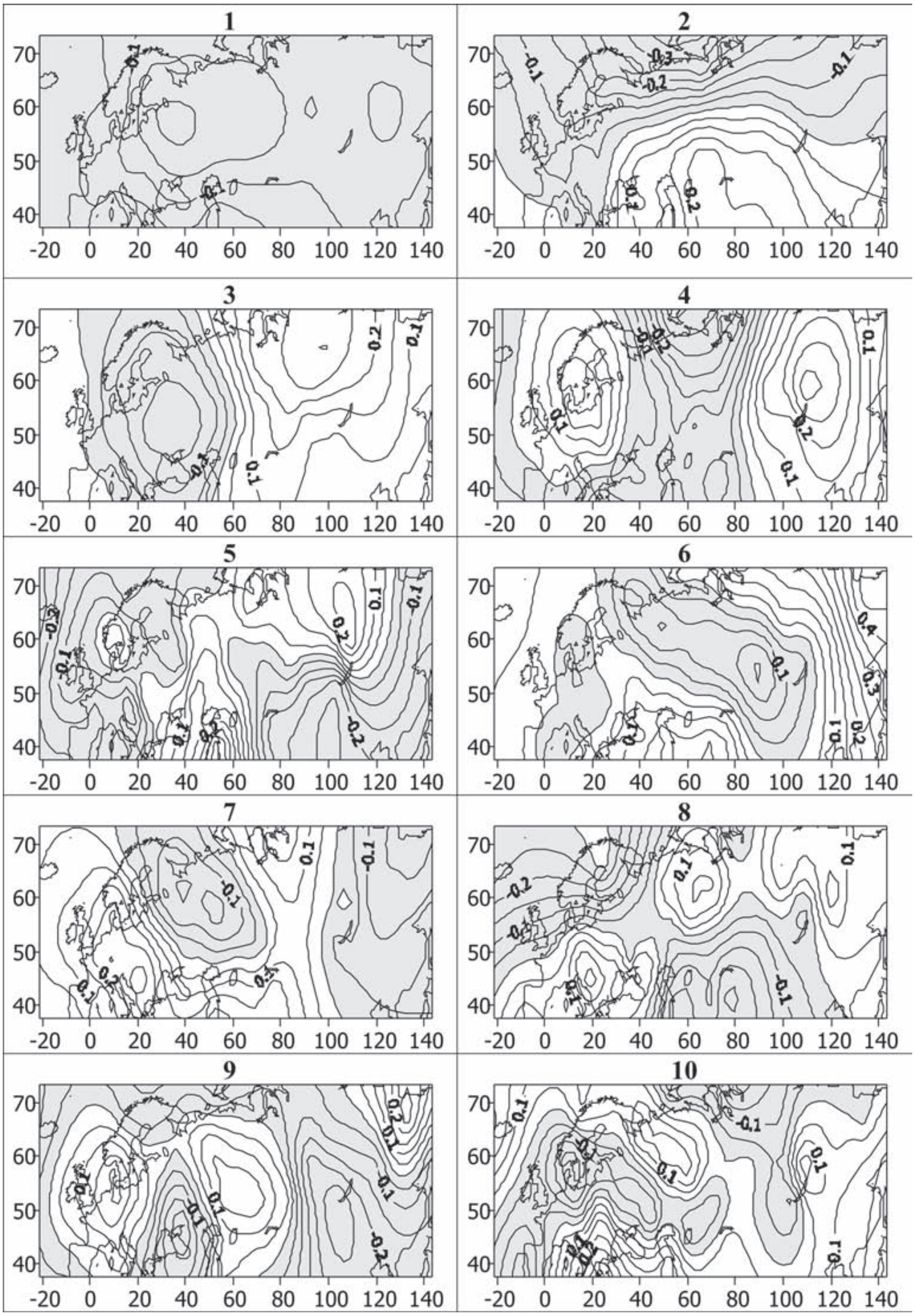

Fig. 3. 1–10: EOFs of the monthly mean temperatures calculated on the base of instrumental observations of the near surface air temperature at 55 stations of the North Atlantic–Europe –North Asia area during the XX century. A similarity of several first EOFs with a family of two-dimensional Cos- and Sin- are evident. The shapes of consequent EOFs look to be more and more dissimilar to the trigonometric functions

example of the 1–10 EOFs for the monthly mean temperatures of the North Atlantic–Europe–North Asia area (from [Monin and Sonechkin, 2005]) illustrating these facts is shown in Fig. 3.

The most important consequence of the trigonometric expansion use consists of a possibility to estimate past climatic normals independently from any present-day normal. It is because the trigonometric family constitutes a function basis. The first (most spatially smooth member of this basis or, it may be, a few number of the first members) can be used to obtain the first guess reconstruction of past climate normals. Some next members can be used for the second guess reconstruction of past climate patterns. There is no problem with temporal nonstationarity of the proxy data nets at this step of reconstructing because a routine least-square procedure can be used to invert the raw proxy data to the trigonometric coefficients. Instead of this latter procedure it is possible firstly to calculate a covariation matrix of coefficients of the trigonometric expansion for the anomalies with respect to earlier reconstructed past climate normals, and secondly to calculate EOFs of this matrix. There is no problem with the ill-posed solubility of the numerical computation of the eigen problem for this matrix because the number of trigonometric coefficients taken into consideration can be limited in advance. Only then the EOF-coefficients (PC) can be calculated and used to reconstruct past climate patterns.

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