Quaternary Science Reviews 137 (2016) 200–208

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Periodicities in mid- to late-Holocene peatland hydrology identified from Swedish and Lithuanian tree-ring data

Johannes Edvardsson [a, b, *], Florian Adolphi [b], Hans W. Linderholm [c], Christophe Corona [d], Raimund Muscheler [b], Markus Stoffel [a, e, f]

[a] Dendrolab.ch, Institute of Geological Sciences, University of Bern, Baltzerstrasse 1+3, CH-3012 Bern, Switzerland
[b] Quaternary Sciences, Department of Geology, Lund University Sölvegatan 12, SE-223 62 Lund, Sweden
[c] Department of Earth Sciences, University of Gothenburg, Box 460, 405 30 Gothenburg, Sweden
[d] GEOLAB, UMR6042 CNRS and Blaise Pascal University, Maison des Sciences de l'Homme 4, Rue Ledru, F63057 Clermont-Ferrand Cedex 2, France
[e] Climatic Change and Climate Impacts, Institute for Environmental Sciences, University of Geneva, Boulevard Carl-Vogt 66, CH-1205 Geneva, Switzerland
[f] Department of Earth Sciences, University of Geneva, Rue des Maraîchers 13, CH-1205 Geneva, Switzerland

ARTICLE INFO

Article history:
Received 24 December 2015
Received in revised form
16 February 2016
Accepted 17 February 2016
Available online 27 February 2016

Keywords:
Wavelet analysis
Spectral analysis
NAO
AMO
Solar variability
Lunar nodal tides
Sweden
Lithuania

ABSTRACT

Twenty-five tree-ring width (TRW) chronologies, developed from moisture sensitive peatland trees in Sweden and Lithuania, and representing eight periods during the mid-Holocene to present, were analysed regarding common periodicities (cycles). Periods of 13–15, 20–22, and 30–35 years were found in most chronologies, while 8–10, 18–19, and 60–65 year periodicities were observed as well, but less commonly. Similar periodicities, especially about 15 and 30 years in duration, were detected in both living and subfossil trees, indicating that the trees have responded to similar forcing mechanisms on those timescales through time. Some of the detected periods may be related to solar variability and lunar nodal tides, but most of the detected periodicities are more likely linked to hydrological changes in the peatlands associated to atmospheric patterns such as the North Atlantic Oscillation (NAO), or variations in sea surface temperatures (i.e. the Atlantic Multidecadal Oscillation, AMO). However, no significant relationships between tree growth, NAO and AMO could be formally established, possibly due to hydrological lag and feedback effects which are typical for peatlands but render in-depth assessments rather difficult.

1. Introduction

The impact of climate change on ecosystems is a key issue for society requiring advanced knowledge about climate variability and its forcing mechanisms (Moss et al., 2010). In recent decades, improved palaeoclimatic methods have enabled more robust climate reconstructions (Wanner et al., 2008; Marcott et al., 2013; Stoffel et al., 2015), but there is still a critical need for proxy data providing precise and detailed information about long-term moisture variability (Wu et al., 2002; Edvardsson et al., 2016). Annual growth rings from peatland trees have proven to reflect moisture variability over both the recent past (Linderholm et al., 2002; Edvardsson et al., 2015) and the Holocene (Pilcher et al., 1984; Leuschner et al., 2002). Long distance cross-correlations between peatland tree-ring width (TRW) chronologies from different geographical settings suggest that common large-scale climate forcing often influenced tree growth (Leuschner et al., 2002; Edvardsson et al., 2012a). TRW data from peatland trees will, however, remain an underutilized source of long-term climate and environmental information for as long as the exact linkage between peatland tree growth, hydrology, and large-scale climate dynamics is not sufficiently understood. To access the full potential of data series obtained from peatland trees, further studies comparing tree growth to various climate proxies are critically needed, as are comparative studies between different geographical regions and periods of the Holocene.

Changes in solar activity (Babcock, 1961; Muscheler et al., 2007), the heat distribution between the ocean and the atmosphere (Justino and Peltier, 2005), the North Atlantic Oscillation (NAO; van Loon and Rodgers, 1978; Hurrell, 1995) and the Atlantic Multidecadal Oscillation (AMO; Keer, 2000; Sutton and Dong, 2012) have

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* Corresponding author. Dendrolab.ch, Institute of Geological Sciences, University of Bern, Baltzerstrasse 1+3, CH-3012 Bern, Switzerland.
E-mail address: johannes.edvardsson@dendrolab.ch (J. Edvardsson).

http://dx.doi.org/10.1016/j.quascirev.2016.02.020
0277-3791/

been shown to influence regional climate, but have been discussed to partly vary in a periodic (cyclic) or quasi-periodic manner which can be detected by frequency analyses. In this sense, the AMO has often been described as the observed pattern of multidecadal variations in North Atlantic sea surface temperatures (SSTs; Keer, 2000; Sutton and Dong, 2012), whereas the NAO is commonly defined as the leading mode of sea level pressure over the North Atlantic region (Hurrell et al., 2001); both oscillations are known to influence temperature and precipitation variability around the North Atlantic. As the moisture balance in peatlands depends on both precipitation and temperature-controlled evapotranspiration (Charman et al., 2009), tree growth in peatland ecosystems may reflect both local hydrology and regional climate variability (Edvardsson et al., 2015). Periodicities related to phenomena influencing the moisture status in peatlands are therefore likely to be traceable in annual growth patterns of peatland trees. Analysis of periodicities in TRW chronologies with different temporal and geographic distribution may thereby also be useful for the investigation of spatio-temporal hydroclimate variability.

To advance our knowledge about linkages between peatland tree growth and climate variability, TRW chronologies developed from Swedish and Lithuanian peatland trees were subjected to spectral and wavelet analyses. Fourier and wavelet transform spectral analyses (Jenkins and Watts, 1968; Torrence and Compo, 1998) were used to study periodicities in peatland tree growth. The Fourier transform spectra assess the power of a given frequency over an entire record and, thus, require a certain stability of the periodicities over time, whereas the wavelet power spectra allow for an investigation of non-persistent periodicities, i.e. they resolve the power of a given frequency at a given point in time (Torrence and Compo, 1998; Stoica and Moses, 2005).

Using the two different approaches, this paper therefore aims at (i) identifying potential periodicities (cycles) in the annual growth patterns of peatland trees, (ii) studying the spatial and temporal patterns of these periodic changes, and at (iii) discussing their potential origin.

2. Material and methods

2.1. Treatment of tree-ring width data

In total, 25 TRW chronologies from 11 Swedish and 5 Lithuanian peatlands were analysed for the purpose of this study (Table 1, Fig. 1). TRW chronologies were developed from 834 trees, covering about 4700 years separated into eight non-overlapping periods during the mid- and late-Holocene (Fig. 2). Apart from three oak chronologies (*Quercus robur* L.), the material consisted exclusively of Scots pine (*Pinus sylvestris* L.). The subfossil material originated from peatlands used for peat mining, whereas the living trees were sampled at raised bogs showing limited evidence of human activities. Accuracy of the cross-dating and TRW measurements were evaluated using the COFECHA software (Holmes, 1983). To minimize the influence of non-climatic variations and trends related to, for example, height within the stem and age, the TRW series from the individual trees were standardized and transformed into dimensionless indices (Fritts, 1976) before being averaged into chronologies. As the trees often showed growth trends with narrow rings during both juvenile and adolescent stages—as opposed to the negative exponential trend commonly observed in TRW series—various flexible standardization methods based on spline functions (Cook and Peters, 1981) or the Friedman variable span smoother (Friedman, 1984) were compared to make sure that detected periodicities were not artefacts from or lost in the standardization process. To highlight high- and low-frequency patterns in the data series respectively, the standardizations were also preformed using different bandwidths. A short bandwidth keeps the high-frequency variability in the data series whereas increasing bandwidth preserves low-frequency variations better (Esper et al., 2009). To assess the reliability of the TRW chronologies, we calculated the expressed population signal (EPS), a parameter that is dependent on the number of overlapping series and their mutual conformity. The limit at which the TRW chronologies were considered to be reliable and well replicated was set to the commonly applied threshold of EPS $\geq$ 0.85 (Wigley et al., 1984). Both standardization and calculation of EPS values were performed using the ARSTAN_41d software (Cook and Krusic, 2006).

2.2. Analyses of the tree-ring width data

The spectral frequencies were calculated using Fourier frequency spectra with the Tukey-Hanning window (Blackman and Tukey, 1958). To evaluate the spectra further and to test the significance of detected spectral peaks, we used the multi-taper method (Thomson, 1982; Rögnvaldsson, 1993). Detected periodicities were separated depending on their significance levels ($p < 0.001$, $p < 0.01$ or $p < 0.05$), whereas remaining periodicities ($p > 0.05$) were excluded from further analyses. Wavelet analysis was performed to visualize the temporal stability of detected periodicities over the entire time-span of each TRW chronology. The wavelet power spectrum was calculated and visualized using contour levels equal to 75%, 50%, 25%, and 5% of the normalized wavelet power, respectively. Significance levels were calculated using a red-noise (autoregressive lag1) background spectrum (Torrence and Compo, 1998) and periods showing wavelet power corresponding to significance level $p < 0.05$ were highlighted. Analyses were made using the AutoSignal v1.7 software (www.sigmaplot.com) and tools provided by the University of Colorado (Torrence and Compo, 1998). Four data series developed from subfossil trees did not pass the EPS threshold >0.85 for extended periods (Table 1). In order not to exclude these data series completely, analyses were performed over the entire length of the TRW chronologies and for periods representing EPS values > 0.85 separately. Results from those periods considered reliable (EPS > 0.85) were considered for the results and discussion, whereas the analyses of the complete chronologies was considered as a valuable addition.

To study common tree growth responses among the TRW chronologies, cluster analyses (CA) were conducted on all chronologies from living trees. Chronologies falling into common clusters were thereafter stacked and compared to meteorological variables from the 20th century reanalysis project (version V2c, Compo et al., 2011) and the reconstructed sea surface temperatures (SSTs) from the HadISST dataset (Rayner et al., 2003). In addition, we tested if similar periodicities between TRW chronologies and well-known climate indices such as the NAO and AMO could be found using wavelet coherence analysis (Grinsted et al., 2004). Hydroclimatic conditions prior to and during the growth season of the trees have been found to influence the radial growth of peatland trees from both Sweden (Linderholm et al., 2002; Edvardsson and Hansson, 2015) and Lithuania (Edvardsson et al., 2015). Comparisons between clustered TRW chronologies and climatic variables were therefore performed using monthly pre-growth season (January to April; or JFMA) as well as main growth season (June to August; or JJA) data individually.

2.3. Results and their implications

Close to identical spectral frequency peaks and significance values were obtained in the initial tests with the Tukey-Hanning (Blackman and Tukey, 1958) and Multi-taper (Thomson, 1982; Rögnvaldsson, 1993) window methods, and regardless of the