The REPLICATE project: Multi-parameter reconstruction of Carpathian temperatures from tree rings

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Introduction

Understanding past climate variability is of major importance due to the current scenario of global change and the resulting societal, economic, and political impacts (IPCC, 2014). Since instrumental climatic records rarely extend more than a couple of centuries into the past, natural proxy archives allow longer-term paleoclimatic information to be obtained, and tree rings can provide such insight into past climate over centennial to millennial timescales. The reconstruction of past climatic conditions helps constrain model estimates of possible future climate scenarios. While large-scale hemispheric reconstructions of climatic variability have received considerable attention, the importance of moving the focus towards the development of finer-scale, denser networks of regional reconstructions have been highlighted (Pages 2k Consortium, 2013). In this sense, to achieve a more accurate understanding of past local and regional-scale climate variability, it is necessary to improve the spatial resolution of reconstructions. With this approach, validation among reconstructions becomes possible and reduces reliance on a small number of records.
Although numerous proxy-based climate reconstructions have been developed and despite the prevalence of relatively long and generally reliable instrumental records throughout Europe, reliable information about past climate is still lacking in some regions, including central and eastern parts of the continent. This issue is predominantly linked to large uncertainty and limitations in data quality (i.e., climatic sensitivity). The REPLICATE project aims to fill this spatial paleoclimatic and data quality gap by applying a tree-ring multi-parameter approach to reconstruct climate using Norway spruce (*Picea abies* (L.) Karst) samples. In this way, we expect to develop a set of temperature reconstructions across the Carpathian Mountain arc, and, therefore, contribute to the advancement of our understanding of recent climatic variability in central-eastern Europe.
This is achieved by developing a set of annually resolved, robust, high-quality summer temperature reconstructions covering the past 300-400 years for four locations across the Carpathian sub-region based on tree-ring width (RW), blue intensity (BI) from scanned and microscope-based high-resolution images, and quantitative wood anatomy (QWA) characteristics from previously collected temperature-sensitive high elevation Norway spruce samples. To accomplish the primary aim, a series of subsidiary objectives are outlined as follows:

1) Examining the role of non-climatic factors influencing the structure of RW, BI, and QWA chronologies in space and over time;

2) Assessing the climatic response and reconstruction potential of RW, BI, and QWA chronologies, including their spatial and temporal relationships with climatic variables;

3) Evaluating the relative advantages, limitations, and inter-relationships of the RW, BI, and QWA parameters, and assessing methodological procedures to optimize data generation;

4) Developing optimized temperature reconstructions to improve the accuracy of past temperature estimates, evaluate existing central-eastern European reconstructions and instrumental records, and assess relationships with large-scale climatic drivers.

The multiparameter approach

Although RW has been the most commonly used parameter in tree ring research, alternative parameters such as wood density and stable isotopes have increasingly been utilized to investigate a range of climatological and ecological research topics. More specifically, maximum latewood density (MXD) measurements have generally been observed to respond more strongly to temperature than RW data (e.g., Briffa et al., 2002). However, the application of MXD has been restricted by the high costs associated with the production of such data (Wilson et al., 2014). A novel alternative parameter to MXD called Blue Intensity (BI) has been shown to provide very similar results at considerably lower cost (e.g., Campbell et al., 2007; Rydval et al., 2014). BI represents the measurement of reflected visible blue light from the surface of tree-ring samples, which is directly related to wood density and BI data have been shown to represent very similar information to the MXD parameter (Björklund et al., 2015; Campbell et al., 2007; McCarrol et al., 2002; Wilson et al., 2014). Similarly, QWA parameters, which encompass a range of wood anatomical properties (Scholz et al., 2013), have also shown great potential in terms of containing climatically sensitive information (e.g., Fonti et al., 2009; Liang et al., 2013). In addition to potentially containing strong climatic signals, QWA also has the additional advantage of representing intra-annual variation which could offer additional or more detailed climatic information not expressed by other parameters (Carrer et al., 2017). However, this potential has so far not been utilized extensively in climate reconstruction studies. Currently, only a few tree ring reconstructions based on (or which incorporate) BI data exist (e.g., Björklund et al., 2015; Rydval et al., 2017a; 2017b; Wilson et al., 2014), and even fewer incorporate QWA (e.g., Ziaco et al., 2016).
Climate signal improvement and improved calibration can be achieved by supplementing RW data with climatically more sensitive BI chronologies from scanned images, measurements based on high-resolution reflected light images from the surface of tree ring cores, as well as QWA parameters. The optimization of the climatic signal by integrating this range of tree-ring parameters can help reduce some of the limitations of each parameter related to chronology standardization, sample surface discoloration biases, and the influence of non-climatic perturbations (e.g., due to disturbance or pollution), providing a more accurate representation of long-term climatic trends and short-term extremes and resulting in the overall reduction of uncertainty.

Methodological innovations

Although BI data typically contain a strong climatic signal, accurately representing long-term trends and short-term extremes using conventional scanner-based BI data is challenging due to limited resolution and color biases. The generation of high-resolution (~8600 dpi) microscope-based data is made possible by recent methodological advances in sample surface preparation and imaging. Such series have fewer drawbacks compared to traditional BI data as they can capture information in considerably greater detail and make it possible to bypass

color-related limitations and biases by generating data from images with a binary representation of the wood anatomical structure.
The curve intervention detection (CID) method allows the detection and removal of non-climatic (disturbance) trends from RW series with the potential to improve climate signal representation in RW chronologies (Rydval et al., 2018). Thus far, the use of this novel technique has been limited, particularly in the context of assessing the dendroclimatic impact of disturbance on extensive networks of tree ring sites.
These methodological developments in surface imaging, non-climatic trend identification, and correction, along with the tandem utilization of multiple tree ring parameters, will ultimately make it possible to produce a set of robust high-quality paleoclimatic records with reduced uncertainty and improved spatial scope.

Dendrochronological samples and data

A collection of over 18 000 high-elevation Norway spruce tree ring samples from 560 inventory plots in 37 stands broadly grouped into four sub-regions (Slovakia, Ukraine, North, and Central Romania) were previously collected for dendroecological investigations, forming the REMOTE network (Figure 1). The samples were collected from a range of elevations (~1250–1450 m a.s.l.) representative of the treeline or near treeline population in the region (Kricsfalusy et al., 2008). It has been demonstrated that trees from this transect of Carpathian sites are climatically sensitive, with growth predominantly responding to temperature (Björklund et al., 2019; Rydval et al., 2018; Schurman et al., 2019).

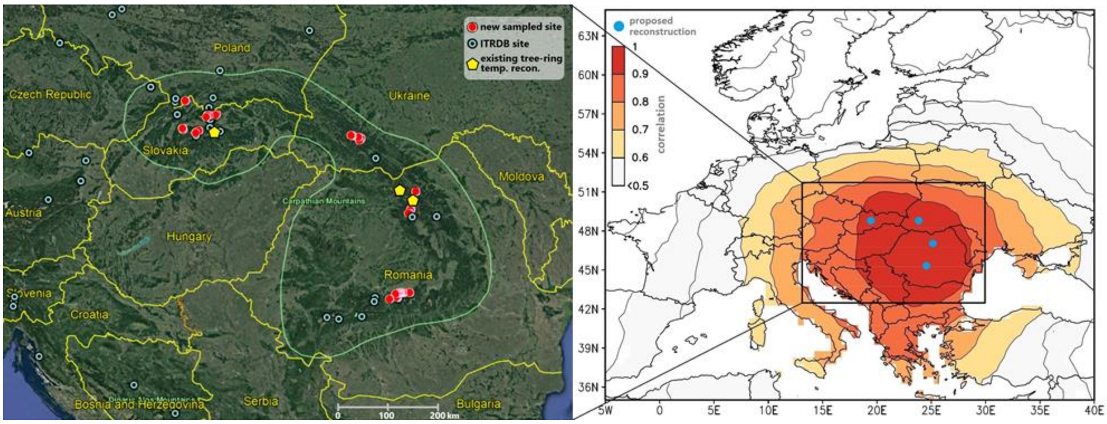

Figure 1 Location of previously sampled REMOTE network sites within the context of tree ring chronologies archived at the International Tree-Ring Data Bank (ITRDB) and existing Carpathian climatic reconstructions from tree rings (left). Spatial field correlation of summer (Jun-Aug) mean temperatures in eastern Europe from 1901 to 2019 indicating the spatial representativeness of the proposed temperature reconstructions (right).

From this collection, a subset of approximately 1000 samples was selected for BI measurement. The selection was based on detailed site and sample information about elevation, ecology, sample length, and the signal strength/climatic sensitivity of RW chronologies from previous work to help optimize the development of climate reconstructions. In each location, robust chronologies which extend back to the early to mid-17th century will be developed and we will utilize a range of age classes with a strong common signal rather than only very old samples. The mixture of age classes with a range of sample ages is preferable as it helps overcome the occurrence of undesirable (artificial) trend biases at the ends of chronologies, which may occur with detrending (i.e., age trend removal)

methods that are intended to retain multi-centennial climatic trends (e.g., regional curve standardization (RCS); Briffa et al., 1992).
From this subset of 1000 samples, a further subset of about 200 samples (roughly 50 for each sub-region) will be used to develop high-resolution, higher quality surface reflectance data from an optical microscope system. Approximately half of those samples will be used to also develop time-series of QWA properties for all sub-regions, which will allow direct comparisons of RW, BI, high-resolution surface imaging, and QWA chronologies. The additional BI chronologies will make it possible to perform a spatially broader signal strength and climate signal property assessment of BI chronologies, and also provide more robust reference chronologies to facilitate any future cross-dating of relict wood material.

Preliminary results

Although the climate signal contained in RW chronologies is relatively weak, the removal of non-climatic (disturbance) trends can help improve the climate signal and the utilization of BI data strengthens this signal considerably (Figure 2). Initial results indicate that temperature reconstructions from the Carpathians can be expected to yield paleoclimatic records with reduced uncertainty that explain between 50% and 60% of the regional temperature variability.

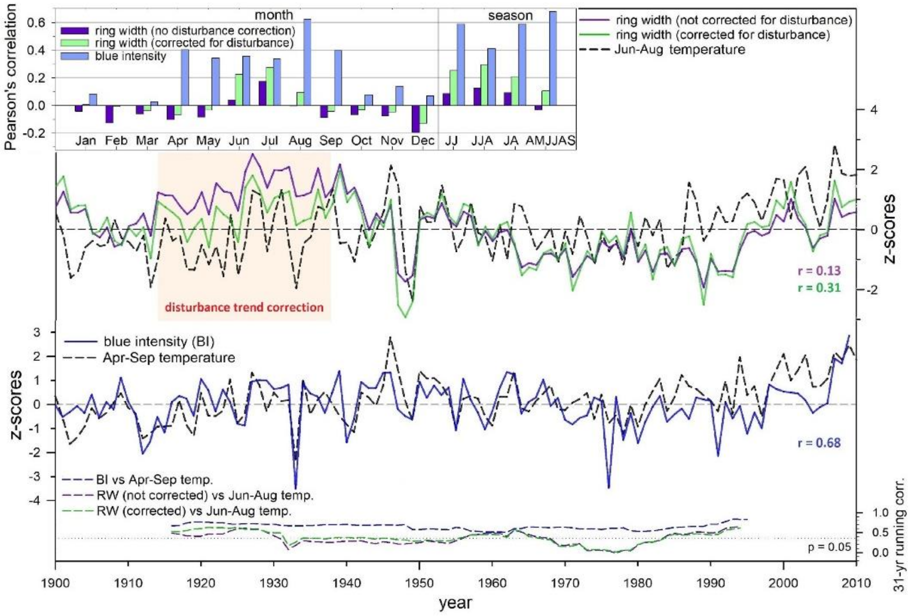

Figure 2 Relationship of blue intensity and tree ring width chronologies of Norway spruce from northern Romania (corrected and uncorrected for non-climatic disturbance trends) with instrumental temperatures from Sibiu, Romania. The example results highlight climate signal improvement after correcting ring width data for disturbance signatures and the distinctly stronger climatic signal of blue intensity chronologies.

Potential contribution

The new reconstructions will form the basis for further chronology extension into the past using samples from Carpathian historical wooden structures and other sources of relict wood. The combination of robust RW and BI chronologies will also help validate archaeological dating of historical wooden structures and relict material in the region, as BI data typically contains a stronger common high frequency (interannual) signal compared to RW (Rydval et al., 2014). The reconstructions will also contribute to a more highly resolved temperature dataset in a part of Europe with considerable research potential, providing improved spatial representation of past European temperature fluctuations. They will also provide historical context for evaluating return periods and magnitudes of temperature extremes, with potential socioeconomic relevance (e.g., for agriculture). Improved spatial information of the transition from the LIA to the modern warm period in the Carpathians is also important for tuning and downscaling climate models by providing constraints on climate model performance and thus improving prediction of future climate scenarios and reducing uncertainties in future projections.

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