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Viewpoint

The imprint of climate within Northern Hemisphere trees

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ABSTRACT

Here we show how the seasonality and strength of climate signals recorded by tree-ring widths changes across the Northern Hemisphere, and outline major regional differences in the climate ‘window’ sensed by trees that both constrain and augment our ability to interpret these records as paleoclimatic proxies. After surveying nearly 2200 ring-width records, we find the spatial structure of tree–climate relations across the hemisphere matches behavior predicted several decades ago very closely, confirming the principles that guide dendroclimatology are robust despite the complexity of interactions between climate, ecology and tree biology. We also show that climate filtering conducted by individual trees creates major regional differences in information that may be recovered from the hemispheric network. This behavior can introduce geographic biases to dendroclimatic reconstructions, but it also may be useful to evaluate the success of reconstruction techniques that explicitly represent the physical processes linking climate to tree growth.

Every year, trees in temperate and boreal forests go through a cycle of dormancy and activity that produces a new layer of tracheids, fibers and other woody cells around their stem. The end result of this process – a tree ring – is one of the most obvious signs in nature documenting the passage of time and the character of that year’s weather (Fritts, 1976). Measurements of tree-ring widths are the most widely-distributed and best replicated source of surrogate environmental information on the planet (Grissino-Mayer and Fritts, 1997), and are one of the main archives used to estimate changes in regional and global climate during the past several centuries or millennia (Solomon et al., 2007; Mann et al., 2008; PAGES 2k Consortium, 2013). Although these data all describe the same aspect of tree growth, the climate information encoded in tree-ring widths is known to vary across topographic and ecological gradients (Fritts et al., 1965) and can switch from one variable to another over short distances (Bunn et al., 2011). The principles that explain this behavior (Fritts et al., 1965; Fritts, 1976), which are essentially tailored variants of Liebig’s Law of the Minimum, have been used to guide the collection of tree-ring records at thousands of locations around the planet since the 1970s. Here we show how the seasonality and strength of climate signals recorded by tree-ring widths changes across much of the Northern Hemisphere, and outline major regional differences in the climate ‘window’ sensed by trees that both constrain and augment our ability to interpret these records as paleoclimatic proxies.

Prior studies (Briffa et al., 2002; Wettstein et al., 2011) have described regional or hemispheric-scale patterns in climate–tree growth relations, but these analyses have been conducted on relatively small subsets (hundreds of records) of the total data available and were often restricted to records previously screened for their association with a specific climate variable (most commonly, summer drought or annual temperature; Meko et al., 1993; D’Arrigo et al., 2006) or their location within a more specific geographic region (Wettstein et al., 2011). As a result, these summaries provide only a partial assessment of the breadth of climate signals recorded by ring widths. In order to produce a more comprehensive survey, we compute simple (Pearson) correlation coefficients between nearly 2200 tree-ring width records across the Northern Hemisphere and seasonal precipitation and temperature series from nearby climate records (see Supplementary information).

The imprint of summer (JJA) precipitation is strongest in the mid-latitudes, particularly in central and eastern North America and western Europe outside of the Alps (Fig. 1a). A very few records at high altitudes (the Alps and northern Rockies) or high latitudes (northeastern Canada, Scotland, and northern Fennoscandia) show an inverse association with summer precipitation. Associations with summer temperatures are mainly negative across the mid-latitudes, likely due to moisture stress caused by high evapotranspiration, and positive at high-latitude and high-elevation sites (Fig. 1b), with tree-ring records in Fennoscandia and north–central

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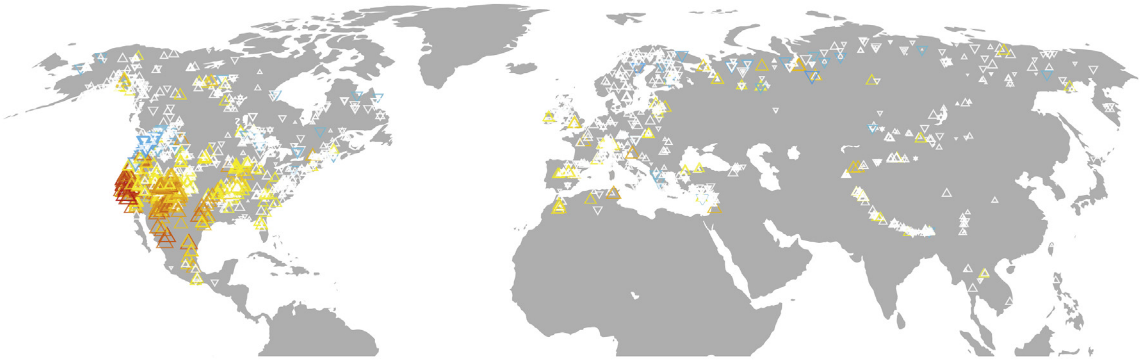
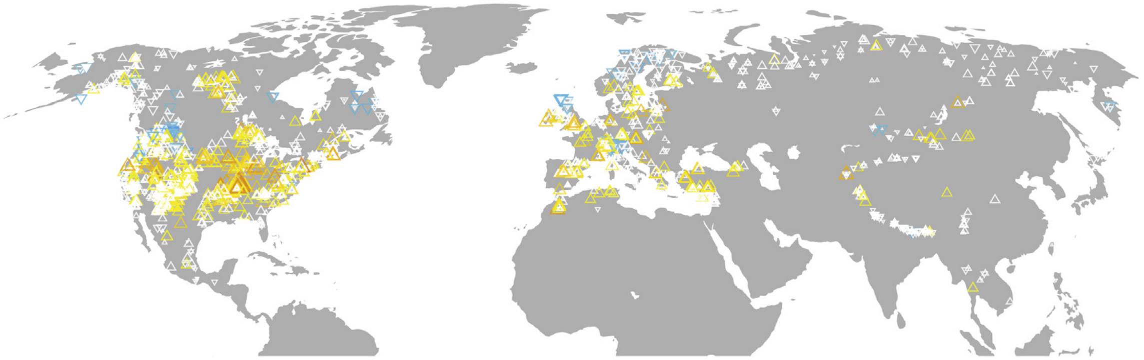
(a) Winter precipitation



(b) Summer precipitation



(c) Summer temperature

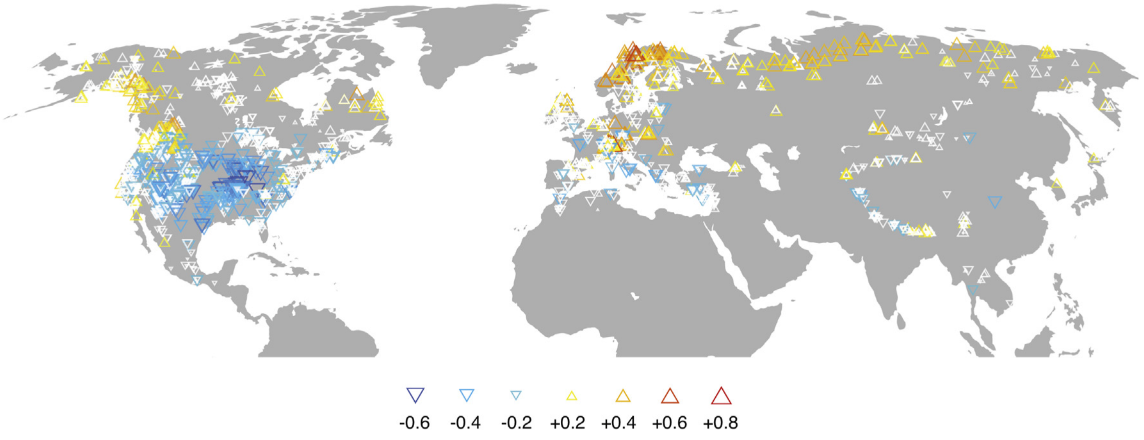


Fig. 1. Maps showing the strength and direction of seasonal climate signals recorded by tree-ring widths at sites across the Northern Hemisphere. Triangles represent correlation coefficients between tree-ring width at each location and (a) total summer (JJA) precipitation, (b) mean summer temperature, and (c) total winter (DJF) precipitation. White triangles represent correlation coefficients that are not locally significant at the $p = 0.05$ level.

Russia showing the highest correlations with summer temperature. In nival environments, winter (DJF) precipitation is able to influence tree vigor during the subsequent growing season because snowmelt delivers water to the root zone in late spring and early summer, which coincides with the onset of cambial activity. Winter precipitation is recorded most clearly by tree-ring records in the southwestern United States, California and the northern half of Mexico, with significant but lower positive correlations also present in the eastern continental United States and select sites in the Mediterranean (Fig. 1c). This response is largely absent from sites in the northern half of North America, but several records from the Pacific North-West (Oregon, Washington and British Columbia) exhibit a negative correlation with winter precipitation that reflects the adverse influence of snow cover on growing-season length at high elevations (Pederson et al., 2011).

We draw three conclusions from this survey. First, the clarity and strength of climate signals recorded by tree rings in the American Southwest is without peer across the hemisphere. Tree growth in this region is more closely associated with winter precipitation than any other part of the network, which explains why paleoclimate reconstructions of derived from these data (e.g., Woodhouse et al., 2006; Cook et al., 2007) are such exceptionally