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A new theoretical approach to isolating the climate record from tree rings

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Several statistical methods have been used to remove ontogenetic and local environmental influences from tree-ring series. The choice of method however has a non-negligible impact on the derived tree-ring index. Here we develop a new, first-principles approach to derive a productivity index (P*) based on a generic model of tree growth. We first determine the critical stem diameter at which the initial rapid increase in radial growth, to support crown development, gives way to a gradual decrease, as sapwood respiration increases with height. This critical value can be predicted from the observed maximum diameter increment of a tree, together with generic values of key parameters that show only limited variation across species and sites. The subsequent dynamics of stem radial growth are assumed to be determined by tree diameter and height, P* (gross primary production discounted by "costs" proportional to leaf area), and sapwood respiration, which increases with the product of leaf area and height. We estimate P* using a non-linear mixed effects model from tree ring-width measurement on multiple trees, including a random effect of individual tree identity to account for the impact of local environmental variability (due to soil or hydrological conditions, shading and competition). The resulting reconstructions of changes in P* at a site should represent the influence of year-by-year changes in climate.

We have applied this approach to tree-ring records from two genera (Picea and Pinus) at many sites across the Northern Hemisphere extratropics. We have shown that annual tree growth of both genera responds positively to increases in accumulated photosynthetically active radiation during the growing season (PAR5) and an index of soil moisture limitation of productivity (α), and negatively to vapour pressure deficit (VPD). The impact of temperature change on P* depends on the mean temperature during the growing season (mGDD5), being positive in cold climates and negative in warmer climates. Comparison of the periods 1940-1969 and 1970-2000 showed that the relationships between these climate variables and tree growth are stable through time. A significant positive influence of increasing atmospheric CO_2 concentration on tree growth however is apparent only in the recent interval. These results imply that tree growth must be interpreted in terms of the combined influence of multiple environmental factors, and that it is possible to discern these influences even when there are large changes in other controls on growth. Thus, our approach has the potential to improve the interpretation of tree-ring records in terms of past environmental changes.