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Developing a triple tree-ring constraint for tree growth and physiology in a global land surface model

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Gradual anthropogenic warming and parallel changes in the major global biogeochemical cycles are slowly pushing forest ecosystems into novel growing conditions, with uncertain consequences for ecosystem dynamics and climate. Short-term forest responses (i.e., years to a decade) to global change factors are relatively well understood and skilfully simulated by land surface models (LSMs). However, confidence on model projections weaken towards longer time scales and to the future, mainly because the long-term responses (i.e., decade to century) of these models remain unconstrained. This issue limits confidence on climate model projections. Annually-resolved tree-ring records, extending back to pre-industrial conditions, have the potential to constrain model responses at interannual to centennial time scales. Here, we constrain the representation of tree growth and physiology in the ORCHIDEE global land surface model using the simulated interannual variability of tree-ring width and carbon ($\Delta^{13}C$) and oxygen ($\delta^{18}O$) stable isotopes in six sites in boreal and temperate Europe. The model simulates $\Delta^{13}C$ ($r = 0.31$-0.80) and $\delta^{18}O$ ($r = 0.36$-0.74) variability better than tree-ring width variability ($r < 0.55$), with an overall skill similar to that of other state-of-the-art models such as MAIDENiso and LPX-Bern. These results show that growth variability is not well represented, and that the parameterization of leaf-level physiological responses to drought stress in the temperate region can be improved with tree-ring data. The representation of carbon storage and remobilization dynamics is critical to improve the realism of simulated growth variability, temporal carrying over and recovery of forest ecosystems after climate extremes. The simulated physiological response to rising CO_2 over the 20th century is consistent with tree-ring data in the temperate region, despite an overestimation of seasonal drought stress and stomatal control on photosynthesis. Photosynthesis correlates directly with isotopic variability, but correlations with $\delta^{18}O$ combine physiological effects and climate variability impacts on source water signatures. The integration of tree-ring data (i.e. the triple constraint: width, $\Delta^{13}C$ and $\delta^{18}O$) and land surface models as demonstrated here should contribute towards reducing current uncertainties in forest carbon and water cycling.