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Modeling changes in European beech productivity precipitated by spring late-frost

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Forest ecosystems are known to be paramount in maintaining the terrestrial carbon sink by storing nearly half of all terrestrial carbon, with European beech dominating these ecosystems across many parts of Europe. As such, the state of the carbon sink is mediated to a large degree by the productivity of European beech forests. Dynamic global vegetation models (DGVMs) can be useful tools to explore changes in forest productivity caused by climate extremes. However, DGVMs often lack implementation of processes pertaining to specific extremes, such as spring late-frost.

Though counterintuitive, temperature increases associated with climate change may exacerbate spring late-frost risk in European beech. Defoliation from late-frost can have detrimental effects on forest productivity. Affected trees lose the ability to effectively perform photosynthesis until the canopy is regrown and must also rely on the expenditure of stored carbohydrate reserves to do so. Consequently, late-frost events often result in stark reductions of secondary growth in affected trees. This effect has been widely observed, primarily through tree rings. Tree rings provide a localized, retrospective examination of secondary tree growth in response to frost events, yet they do not allow for quantification of subsequent changes in tree productivity over larger areas let alone for future scenarios.

We bridge this gap by using a network of tree ring data covering past frost events in conjunction with a new version of the DGVM LPJ-GUESS which has been expanded to include representation of late-frost events. The tree ring data covers 30 sites across Bavaria and includes four separate, past late-frost events for which varying degrees of late-frost damage have been previously documented. Using historical climate data (LFU BayObs 5km x 5km spatial resolution) we run simulations at each of the tree ring sites to reproduce the observed data. Subsequently, we run simulations with two versions of LPJ-GUESS, one including the new late-frost module and one without, to directly quantify the changes in tree productivity (NPP) as a result of spring-late frost. Lastly, we force LPJ-GUESS using climate projections to examine how spring late-frost will govern European beech forest productivity under different future scenarios.

Our findings indicate that (1) we are able to accurately reproduce observed late-frost events using the new, late-frost capable version of LPJ-GUESS, (2) spring late-frost events alter productivity dynamics across geographic and climatic regions, and (3) will continue to play a role to varying degrees under different future climate scenarios.