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Interannual influence of spring phenological transitions on the water use efficiency of forest ecosystem

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Climate change has significantly influenced the productivity of terrestrial ecosystems through water cycles. Understanding the phenological regulation mechanisms underlying coupled carbon-water cycles is important for improving ecological assessments and projecting terrestrial ecosystem responses and feedback to climate change. In this study, we present an analysis of the interannual relationships among flux-based spring phenological transitions (referred as photosynthetic onset) and water use efficiency (WUE) in North America and Europe using 166 site-years of data from 22 flux sites, including 10 deciduous broadleaf forest (DBF) and 12 evergreen needleleaf forest (ENF) ecosystems.

We found that the WUE responses to variations in spring phenological transitions differed substantially across plant functional types (PFTs) and growth periods. During the early spring (defined as one month from spring onset) in the DBF ecosystem, photosynthetic onset dominated changes in WUE by dominating gross primary production (GPP), with one day of advanced onset increasing the WUE by 0.037 gC kg-1H_2O in early spring. For the ENF sites, although advanced photosynthetic onset also significantly promoted GPP, earlier onset did not have a significant positive impact on WUE in early spring because it was not significantly correlated to evapotranspiration (ET), which is a more dominant factor for WUE than GPP across the ENF sites. Statistically significant correlations were not observed between interannual variability in photosynthetic onset and WUE for either the DBF or ENF ecosystems following a prolonged period after photosynthetic onset. For the DBF sites, the interannual variability of photosynthetic onset provided a better explanation of the variations in WUE (ca. 51.4%) compared with climatic factors, although this was only applicable to the early spring. For the ENF sites, photosynthetic onset variations did not provide a better explanation of the interannual WUE variations compared with climatic factors within any growth period. Notably, the negative correlation between the interannual variability of early spring WUE and photosynthetic onset gradually declined from boreal forests (r = -0.73) to subtropical Mediterranean forests (r = 0.35), indicating that the positive effect of earlier spring phenological transitions decreased or even reversed from cold climates to warm climates. This result suggests that the effect of the phenological regulatory mechanism on coupled carbon-water cycles is not only determined by the PFT but also by the habitat climate of an ecosystem. These observed differences between the ENF and DBF ecosystems will likely influence future phenological shifts related to competition for water and other resources in mixed species stands.