Delayed autumn phenology in the Northern Hemisphere is related to change in both climate and spring phenology

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The timing of the end of the vegetation growing season (EOS) plays a key role in terrestrial ecosystem carbon and nutrient cycles. Autumn phenology is, however, still poorly understood and previous studies generally focused on few species or were very limited in scale. In this study, we applied four methods to extract EOS dates from NDVI records between 1982 and 2011 for the northern hemisphere, and determined the temporal correlations between EOS and environmental factors (i.e. temperature, precipitation and insolation), as well as the correlation between spring and autumn phenology, using partial correlation analyses. Overall, we observed trend towards later EOS in $\sim 70\%$ of the pixels in Northern Hemisphere, with a mean rate of 0.18 ± 0.38 days per year. Warming preseason temperature was positively associated with the rate of EOS in most of our study area, except for arid/semi-arid regions, where the precipitation sum played a dominant positive role. Interestingly, increased preseason insolation sum might also lead to a later date of EOS. In addition to the climatic effects on EOS, we found an influence of spring vegetation green-up dates (SOS) on EOS, albeit biome dependent. Our study, therefore, suggests that both environmental factors and spring phenology should be included in the modeling of EOS to improve the predictions of autumn phenology as well as our understanding of the global carbon and nutrient balances.