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Vegetation optical depth vs ecosystem water dynamics in a temperate forest

As climate continues to change, more warming is expected and is linked to drought which induces and promotes agents and factors that cause tree mortality. Droughts have the tendency to cause wide-reaching shifts in plant function, structure, and community dynamics as well as increased risk of fires due to increased fuel load. These capture the need for accurate monitoring and forecasting of tree mortality. Remote sensing has become a convenient tool for monitoring mortality as it clears some key disadvantages associated with traditional forest inventory techniques (that is labor-intensive, limited in both time and space).

Vegetation optical depth (VOD) is one such product and it measures the degree of attenuation of microwave waves within the canopy and relates to its above-ground biomass and relative water content. Although VOD represents a great opportunity to map forest mortality in terms of space and time, it is limited in terms of satisfactory evaluator indices. For instance, Rao et al (2019)* used a variety of vegetation, topographic and climatic variables to try to explain variations in VOD, while Konings and Gentine (2017)** utilized water use efficiency.

Despite the advancement in terrestrial and ecosystem modelling, models are unable to accurately represent or forecast mortality events. However, with more tree mortality being anticipated with climate change, model development is key to better understanding and forecasting.

Thus, the dynamic vegetation model, LPJ-GUESS has been updated with a plant hydraulics formulation to simulate leaf water potential, to improve simulations of drought-induced tree mortality.

To this end, the VOD of two deciduous broadleaf-dominated forests in North America were examined. One forest in the relatively low-lying eastern George Washington Forest (average height 650m) and another in the higher elevation south-western Uinta Wasatch Forest (2245m). The two study sites are continuous areas of deciduous broadleaf forests containing birch, oak, and maple, amongst others.

This research sought to explain variations in the VOD of the two deciduous broadleaf forests in North America, as a function of temperature, precipitation, vapor pressure deficit and LPJ-GUESS simulation of evapotranspiration and leaf water potential. This research marks the novel attempt to link simulated leaf water potential to VOD.

The statistical analysis was done on 23 years of data, spanning 1988-2010. Monthly, and daily analyses were performed. To investigate the association between VOD and the chosen variables, the monthly correlations were first considered to examine the

long-term patterns and how it follows the seasonal trends. Meanwhile the daily analyses sought to investigate the short-term variations in VOD following the daily alterations of temperature, precipitation, vapor pressure deficit, evapotranspiration, and leaf water potential. The Spearman Rho test and its p-value were used to test the strength of correlation between the VOD of each study site against its corresponding temperature, precipitation, vapor pressure deficit, evapotranspiration, and leaf water potential.

Climate model results indicate a stronger influence of temperature on VOD, followed by precipitation and then vapor pressure deficit. More often a combined influence of temperature and precipitation was seen. Process-based simulation of evapotranspiration and leaf water potential could not provide a relatively better correlation with VOD despite being more directly linked to plant water dynamics and this is suspected to be due to model deficiencies.

Analyses of the results show that VOD signals may be simple but the mechanisms that lead to the turgidity or wilting of tree structures are very complex. So much so that, a single variable or mechanism could not suffice satisfactorily in representing the VOD signals and thus tree mortality. Factors such as tree density, tree size, basal area, patch structure, genotype, slope, terrain, presence of pathogens such as bark beetles all play a role. This research reaffirmed the importance of temperature and moisture in temperate ecosystems and the need for more research on what controls exist in what location and how they interact. As this is key in dissecting VOD signals, understanding mortality, and parameterizing ecosystem models for better reproduction and forecasting of mortality scenarios.

Keywords: Physical geography; Ecosystem analysis; Vegetation optical depth; Temperate Forest; Climate; LPJ-GUESS; Evapotranspiration; Leaf water potential; Isohydricity; Hydraulic failure; Carbon starvation

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* Rao, K., W. R. L. Anderegg, A. Sala, J. Martínez-Vilalta, and A. G. Konings. 2019. Satellite-based vegetation optical depth as an indicator of drought-driven tree mortality. Remote Sensing of Environment 227: 125–136. doi:10.1016/j.rse.2019.03.026.

** Konings, A. G., and P. Gentine. 2017. Global variations in ecosystem-scale isohydricity. Global Change Biology 23. John Wiley & Sons, Ltd: 891–905. doi:10.1111/gcb.13389.