Geophysical Research Abstracts
Vol. 19, EGU2017-13529, 2017
EGU General Assembly 2017

Theoretical and empirical evidence for the relationship between stem diameter variations and the water status of mature temperate trees

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Assessing a trees' water status is essential to evaluate its water status during drought. In particular for mature trees it is extremely difficult to monitor the water status throughout the growing season because of the difficulty of canopy access. Daily variations of stem diameter (SDV) are discussed to provide a powerful alternative in measuring a trees' water status. SDV have been shown to incorporate both radial growth and the diurnal shrinkage and swelling of bark tissue, which is caused by daytime transpiration and nighttime refilling, respectively. During dry periods, bark tissue that is depleted in water cannot entirely refill at night resulting in a progressive overall shrinkage of the tree's stem diameter often called tree water deficit (TWD). Comprehensive comparisons of SDV-based values for TWD and reliable values of stem water potential are yet missing for mature trees. As such, TWD has not yet been fully established as a simple and continuous proxy for a trees' water status. Using a canopy crane situated in Northern Switzerland, we calculated TWD based on SDV for six Central European forest tree species during one moist (2014) and one exceptionally dry (2015) growing season and compared these values to the trees' branch water potential.

We found a tight relationship between branch water potential and TWD in all six species. We further employed four different mathematical approaches to calculate TWD and tested what approach yielded the best relationship with water potential. Most approaches resulted in significant relationships ($p < 0.001$) for the different species. However, one TWD variable showed the highest explanatory power (R2) across the six species and both years (up to 86 % explained variation). Intriguingly, this variable does not account for radial growth during periods of shrinkage in its calculation indicating that plastic growth is impeded in such times.

The relationship between TWD and stem water potential can best be explained by logistic functions. We propose that, based on such a function, TWD can be employed to estimate stem water potential of trees for an entire growing season. We conclude from our data that TWD is tightly correlated to the stem water potential of mature tree species and can, thus, be used to describe continuous seasonal variations in a tree's water status. Because of its relatively easy application and deployment, there is high potential for this method to play a major role in future investigations of tree water relations.