Coupling gross primary production and transpiration for a consistent estimate of apparent water use efficiency

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Abstract: Water use efficiency (WUE, the amount of transpiration or evapotranspiration per unit gross (GPP) or net CO_2 uptake) is key in all areas of plant production and forest management applications. Therefore, mutually consistent estimates of GPP and transpiration are needed to analysed WUE without introducing any artefacts that might arise by combining independently derived GPP and ET estimates. GPP and transpiration are physiologically linked at ecosystem level by the canopy conductance (G_c). Estimates of G_c can be obtained by scaling stomatal conductance (Kelliher et al. 1995) or inferred from ecosystem level measurements of gas exchange (Baldocchi et al., 2008). To derive large-scale or indeed global estimates of G_c, satellite remote sensing based methods are needed.

In a previous study, we used water vapour flux estimates derived from eddy covariance flux tower measurements at 16 Fluxnet sites world-wide to develop a method to estimate G_c using MODIS reflectance observations (Yebra et al. 2013). We combined those estimates with the Penman-Monteith combination equation to derive transpiration (T). The resulting T estimates compared favourably with flux tower estimates (R^2=0.82, RMSE=29.8 W m^{-2}). Moreover, the method allowed a single parameterisation for all land cover types, which avoids artefacts resulting from land cover classification. In subsequent research (Yebra et al, in preparation) we used the same satellite-derived G_c values within a process-based but simple canopy GPP model to constrain GPP predictions. The developed model uses a 'big-leaf' description of the plant canopy to estimate the mean GPP flux as the lesser of a conductance-limited and radiation-limited GPP rate. The conductance-limited rate was derived assuming that transport of CO_2 from the bulk air to the intercellular leaf space is limited by molecular diffusion through the stomata. The radiation-limited rate was estimated assuming that it is proportional to the absorbed photosynthetically active radiation (PAR), calculated as the product of the fraction of absorbed PAR (fPAR) and PAR flux. The proposed algorithm performs well when evaluated against flux tower GPP (R^2=0.79, RMSE= 1.93 µmol m^2 s^{-1}).

Here we use GPP and T estimates previously derived at the same 16 Fluxnet sites to analyse WUE. Specifically we are interested to check if satellite-derived WUE explains any of the variation in (long-term average) WUE among sites. The benefit of our approach is that it uses mutually consistent estimates of GPP and T to derive plant-level WUE (i.e. GPP/T) without any land cover classification artefacts. To estimate ecosystem level WUE (i.e., GPP/ET), evaporation from the soil and wet canopy would also need to estimated, e.g. by integrating G_c estimates within a water balance model. To estimate net WUE (NEE/ET), respiration would need to be estimated, requiring estimation of ecosystem respiration fluxes. These are the focus of future work.

References

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