Geophysical Research Abstracts
Vol. 17, EGU2015-7697, 2015
EGU General Assembly 2015


# Understanding the Spatiotemporal Variability of Inherent Water Use Efficiency

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The global carbon and water cycles are coupled via plant physiology. However, the resulting spatial and temporal covariability of both fluxes on a global scale lacks sufficient understanding. This is required to estimate the impact of atmospheric drought on photosynthesis in water-limited ecosystems.

*Water use efficiency* (WUE) is an essential ecosystem diagnostic defined as the ratio between *gross primary productivity* (GPP) and *transpiration* (T). WUE is known to vary with *vapour-pressure deficit* (VPD) and therefore also in time. The *inherent water use efficiency* (iWUE) accounts for the VPD effect on WUE and aims at representing a largely time-invariant ecosystem property. However, different ways of describing the functional response of iWUE to VPD are found in the literature.

One established iWUE definition was proposed by Beer et al. (2009) and takes the form of

$$\mathrm{iWUE} = \frac{\mathrm{GPP} \cdot \mathrm{VPD}}{T} \,. \tag{1}$$

A similar definition can be derived from stomatal conductance theories such as Katul et al. (2010) and takes the form of

$$\mathrm{iWUE} = \frac{\mathrm{GPP} \cdot \sqrt{\mathrm{VPD}}}{T} \,. \tag{2}$$

Here, we use eddy covariance measurements from the FLUXNET database to evaluate both approaches for a globally representative set of biomes including tropical, temperate and semi-arid ecosystems. Testing both definitions in a model–data fusion setup indicated that (2) is more consistent with FLUXNET observations than (1). However, there still remains considerable temporal variability of iWUE which is linked to seasonal changes in VPD.

To explore up to which extent the temporal variability of iWUE may be related to the prescribed functional responses to VPD, we treated the exponent of VPD as a global parameter, here termed $\gamma$. When $\gamma = 1$ the functional response is equivalent to (1), while when $\gamma = 0.5$ it corresponds to formulation of model (2)). The global estimate was found to be significantly lower than 0.5, which would have been expected from stomatal conductance theory at leaf level.

We assessed whether adding $\gamma$ as site-specific parameter could be justified. The additional model complexity was warranted by an increased goodness-of-fit as quantified by the Akaike information criterion. However, temporal variations in iWUE persist. The structural adequacy of the models was assessed via the correlation structure of the residuals.

Ultimately, changing $\gamma$ in the definition impacts the between-site variability of iWUE. The iWUE estimates with $\gamma = 1.0$ were only weakly correlated with those with $\gamma = 0.5$. This has crucial implications for spatial analyses on the drought response of water-limited ecosystems.

We discuss uncertainties involved in the analysis and highlight possible mechanisms responsible for the remaining temporal variability of iWUE. The consequences of differing iWUE definitions for the analysis of global carbon and water cycles are explored.