PROPOSAL FOR FLUXNET SYNTHESIS PUBLICATION

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DATASET PROPOSED

Opened Access

TITLE OF PAPER AND OUTLINE

TITLE: The importance of realistically estimated aerodynamic conductance in studies of rainfall interception

Background

Rainfall interception (*I*) is the amount of rainfall (*P*) that is intercepted by a forest canopy and subsequently evaporated back into the atmosphere. Rainfall interception is typically 10-40% of *P*, and is, therefore, an important component of the water balance of forested areas (e.g. Rutter et al., 1975; Shuttleworth and Calder, 1979; Gash et al., 1980). By influencing water availability, *I* also affects biogeochemical processes such as carbon uptake (Lee et al., 2010). In all rainfall interception models, the most important parameters are evaporation from the wet-canopy (*E*) and canopy water storage capacity (e.g. Gash, 1979; Rutter et al., 1971, 1975). Wet-canopy evaporation is conventionally calculated using the Penman-Monteith (P-M) equation (Monteith, 1965; see Muzylo et al. (2008) for an overview of interception studies worldwide that have used the P-M equation). Values of *E* derived with the P-M equation are very sensitive to the value of the aerodynamic conductance (g_a) (cf. Teklehaimanot and Jarvis, 1991). With very few exceptions (Gash et al., 1999; Van der Tol et al., 2003; Cuartas et al., 2007; Herbst et al., 2008), rainfall interception studies have typically estimated g_a using the well-know momentum transfer equation (e.g. Thom, 1975), with estimated values for the zero-plane displacement (*d*) and roughness length for momentum ($z_{0,M}$). In more complex hydrological models, g_a is usually derived in a similar way for use in the P-M equation (e.g. Ewen et al., 2000; Schellekens, 2006; Gómez-Delgado et al., 2011).

It is pertinent to note that the momentum transfer equation is based on the Monin-Obukhov similarity theory, which only holds under conditions of an extended, uniform, and flat surface (e.g. Monteith and Unsworth, 2008). In addition, similarity theory is only valid for the inertial sub-layer of the atmospheric boundary-layer, whilst closer to the surface (i.e. in the roughness and transitional sub-layers) the similarity relationships tend to fail. The use of the aerodynamic conductance for momentum ($g_{a,M}$) in the calculation of *E* with the P-M equation is related to the 'breakdown' of the similarity theory for heat and water vapour transfer in the roughness sub-layer above forest, the latter of which results in an underestimation of the 'true' g_a by a factor 1-3 (cf. Thom et al., 1975; Chen and Schwerdtfeger, 1988; Simpson et al., 1998). Since values of $g_{a,M}$ as derived with the momentum transfer equation are typically 2-3 times the corresponding values for heat and water vapour transfer, the underestimation of g_a in the roughness sub-layer is (largely) offset by the use of the higher $g_{a,M}$ values (see Shuttleworth (1989) for further explanation).

For momentum, the sub-layer with similarity breakdown tends to become more extended as the topographic complexity of the terrain is more pronounced. In such environments, the friction velocity (u_*) is enhanced (compared to 'uniform' environments experiencing the same large-scale flow), whereas at the same time the wind speed (u) at the measurement level tends to decrease. The latter is related to the increase of the average du/dz above the measurement level, where du/dz scales with the increased u_*. The decrease in u is reflected in the decreased ratio of du/dz to u_* at the measurement level, and is always observed as the forest surface becomes less uniform (see survey by Chen and Schwerdtfeger (1989)). Hence, the conventional application of the momentum transfer equation to forests with increased surface complexity will give values of $g_{a,M}$, and consequently E, that are probably much too low.

The aerodynamic conductance for momentum transfer can also be derived in more direct way using the friction velocity (u_*) as obtained from sonic anemometer measurements. So far, there have been very few interception studies that used measured values of $g_{a,M}$ in the calculation of E with the P-M equation (Gash et al., 1999; Van der Tol et al., 2003; Cuartas et al., 2007; Herbst et al., 2008; Holwerda et al., submitted). Not all these studies report calculated values of $g_{a,M}$ for comparison with measured values (Gash et al., 1999; Cuartas et al., 2007). However, the results of the studies that did suggest that calculated values of $g_{a,M}$ can be as low as 20% of the measured values in highly complex topography (Holwerda et al., submitted), and that even in gentle terrain calculated and measured $g_{a,M}$ can differ by a factor of almost two (Van der Tol et al., 2003). Furthermore, Herbst et al. (2008) showed that the aerodynamic conductance of their deciduous forest varied seasonally as a result of the growing and shedding of leaves, a pattern which is obviously not captured when using calculated values of $g_{a,M}$.

Wet-canopy evaporation can also be derived using the energy balance equation and the sensible heat flux measured by a sonic anemometer (H_s) (Mizutani et al., 1997; Gash et al., 1999; Van der Tol et al., 2003). Although the EC-EB method is the most direct way to estimate E, the determination of H_s in complex terrain and under rainy conditions is not without problems (Holwerda et al., submitted). For example, E is usually maintained by a negative (downward) H_s. If wind speeds are low, a negative H_s implies stable atmospheric conditions, and hence, suppressed turbulence. Under such conditions, the turbulence is often intermittent and non-stationary, and the value of H_s depends strongly on the flux-averaging period used (Acevedo et al., 2006).

Aim of the study

Hence, it is of interest to assess the uncertainty in interception modeling results caused by the conventional application of the momentum transfer equation to forests with enhanced surface complexity. Measured and calculated values of $g_{a,M}$ as derived under wet-canopy conditions will be compared for forests with different structural and topographical characteristics. The observed differences between measured and calculated $g_{a,M}$ will be related to forest structural characteristics (cf. Chen and Schwerdtfeger, 1991) and topographical features (e.g. slope and slope length), with the aim to develop (semi-empirical) relationships for the (improved) estimation of $g_{a,M}$ in complex environments.

Wet-canopy evaporation rates derived with the P-M equation using either calculated or measured values of $g_{a,M}$ will be compared. Comparison will also be made with E

derived from the energy balance equation and H_s, and where possible, with E inferred from throughfall and stemflow data. The performance of the EC-EB method will be evaluated for different atmospheric and topographic conditions.

The survey will be made using data sets owned by the authors of this proposal and FLUXNET data from forest sites in the opened data set.

PROPOSED SITES TO BE INVOLVED

Initially all forest sites, but the final data set is likely a selection from them.

PROPOSED RULES FOR CO-AUTHORSHIP

Site PIs are invited to collaborate and will be given co-authorship for providing scientific input and additional data such as throughfall and stemflow data, and information on forest structure and terrain characteristics.

REFERENCES

Acevedo, O.C., Moraes, O.L.L., Degrazia, G.A., Medeiros, L.E., 2006. Intermittency and the exchange of scalars in the nocturnal surface layer. Boundary-Layer Meteorology 119, 41–55.

Chen, F., Schwerdtfeger, P., 1989. Flux-gradient relationships for momentum and heat over a rough natural surface. Quarterly Journal of the Royal Meteorological Society 115, 335-352.

Cuartas, L.A., Tomasella, J., Nobre, A.D., Hodnett, M.G., Waterloo, M.J., Múnera, J.C., 2007. Interception water-partitioning dynamics for a pristine rainforest in Central Amazonia: Marked differences between normal and dry years. Agricultural and Forest Meteorology 145, 69-83.

Ewen, J., Parkin, G., O'Connell, P.E., 2000. SHETRAN: distributed river basin flow and transport modeling system. American Society of Civil Engineers Journal of Hydrologic Engineering 5, 250-258

Gash, J.H.C., Wright, I.R., Lloyd, C.R., 1980. Comparative estimates of interception loss from three coniferous forests in Great Britain. Journal of Hydrology 48, 89-105.

Gash, J.H.C., Valente, F., David, J.S., 1999. Estimates and measurements of evaporation from wet, sparse pine forest in Portugal. Agricultural and Forest Meteorology 94, 149-158.

Gómez-Delgado, F., Roupsard, O., Le Maire, G., Taugourdeau, S., Pérez, A., Van Oijen, M., Vaast, P., Rapidel, B., Harmand, J.M., Voltz, M., Bonnefond, J.M., Imbach, P., Moussa, R., 2011. Modelling the hydrological behaviour of a coffee agroforestry basin in Costa Rica. Hydrological Earth System Sciences 15, 369-392.

Herbst, M., Rosier, P.T.W., McNeil, D.D., Harding, R.J., Gowing, D.J., 2008. Seasonal variability of interception evaporation from the canopy of a mixed deciduous forest. Agricultural and Forest Meteorology 148, pp. 1655-1667.

Holwerda, F., Bruijnzeel, L.A., Scatena, F.N., Vugts, H.F., Meesters, A.G.C.A., submitted. Wet canopy evaporation from a Puerto Rican lower montane rain forest: the importance of realistically estimated aerodynamic conductance. Submitted to Journal of Hydrology.

Lee, D., Kim, J., Lee, K.S., Kim, S., 2010. Partitioning of catchment water budget and its implications for ecosystem carbon exchange. Biogeosciences 7, 1903-1914.

Mizutani, K., Yamanoi, K., Ikeda, T., Watanabe, T., 1997. Applicability of the eddy correlation method to measure sensible heat transfer to forest under rainfall conditions. Agricultural and Forest Meteorology 86, 193–203.

Monteith, J.L., 1965. Evaporation and the environment. Symposium of the Society for Experimental Biology 19, 245-269.

Monteith, J.L., Unsworth, M.H., 2008. Principles of Environmental Sciences, Elsevier, Amsterdam.

Muzylo, A., Llorens, P., Valente, F., Keizer, J.J., Domingo, F., Gash, J.H.C., 2009. A review of rainfall interception modeling. Journal of Hydrology 370, 191-206.

Rutter, A.J., Kershaw, K.A., Robins, P.C., Morton, A.J., 1971. A predictive model of rainfall interception in forests, 1. Derivation of the model from observations in a plantation of Corsican pine. Agricultural Meteorology 9, 367-384.

Rutter, A.J., Morton, A.J., Robins, P.C., 1975. A predictive model of rainfall interception in forests. II. Generalization of the model and comparison with observations in some coniferous and hardwood stands. The Journal of Applied Ecology 12, 367-380.

Schellekens, J., 2006. CQ-FLOW: A distributed hydrological model for the prediction of impacts of land-cover change, with special reference to the Rio Chiquito catchment, northwest Costa Rica. Annex 3 to Final Technical Report DFID-FRP Project no. R7991. VU University Amsterdam, The Netherlands. Available at: http://www.geo.vu.nl/~fiesta/

Shuttleworth, W.J., 1989. Micrometeorology of temperate and tropical forest. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 324, 299-334.

Shuttleworth, W.J., Calder, I.R., 1979. Has the Priestley-Taylor equation any relevance to forest evaporation? Journal of Applied Meteorology 18, 639-646.

Simpson, I.J., Thurtell, G.W., Nuemann, H.H., den Hartog, G., Edwards, G.C., 1998. The validity of similarity theory in the roughness sublayer above forests. Boundary-Layer Meteorology 87, 69-99.

Teklehaimanot, Z., Jarvis, P.G., 1991. Direct measurement of evaporation of intercepted water from forest canopies. Journal of Applied Ecology 28, 603-618.

Thom, A.S., 1975. Momentum, mass and heat exchange of plant communities. In: Monteith, J.L. (Ed.). Vegetation and the Atmosphere, 1. Principles. Academic Press, London, pp. 57-109.

Thom, A.S., Stewart, J.B., Oliver, H.R., Gash, J.H.C., 1975. Comparison of aerodynamic and energy budget estimates of fluxes over a pine forest. Quarterly Journal of the Royal Meteorological Society 101, 93-105.

Van der Tol, C., Gash, J.H.C., Grant, S.J., McNeil, D.D., Robinson, M., 2003. Average wet canopy evaporation for a Sitka spruce forest derived using the eddy correlation-energy balance technique. Journal of Hydrology 276, 12-19.