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Biogeosciences Discussions

Interactive comment on "Improved understanding of drought controls on seasonal variation in Mediterranean forest canopy CO_2 and water fluxes through combined in situ measurements and ecosystem modelling" *by* T. Keenan et al.

T. Keenan

t.keenan@creaf.uab.es

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Reply to G. Wohlfahrt (Editor)

Thanks again for your comments. We are in agreement with the points you have raised, and have revised the calculations in the manuscript to take them into account. Below we address the points raised:

1) First, in Eq. 1 the units do not make sense. . .

Authors: This is correct. Units in Eq. 1: vpd should be kPa and should be in J kg-1.

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2) . . . and I do not really understand Eq. 1 because using Fick's law (which the authors seem to do) in my view Gc could be calculated simply as: Gc = LH * P /(VPD * lambda) LH : : : latent heat flux as measured by eddy covariance (J/(m2s)) P : : : atmospheric pressure (kPa) VPD : : : vapour pressure deficit (kPa) Lambda : : : latent heat of vaporisation (J/mol; 44100 J/mol @20degC) Gc : : : bulk conductance to water vapour (mol/(m2s))

Authors: To clarify, bulk canopy conductance (Gc) was calculated from the latent heat flux (LH, J m_2 s_1) using a commonly applied simplified form of the Penman–Monteith equation according to Pataki, Oren & Phillips (1998), and Keitel et al. (2003) (as used in, for example, Lluis et al., 2005, Wang et al., 2005, Breda et al., 2006, Brandes et al., 2007):

Gc = LH.e.lambda.psychro/(rho.Cp.vpd) (1)

where psychro is the psychrometric constant (kPa K_1), lambda is the latent heat of vaporization (J kg_1), rho is the density of moist air (kg m_3), Cp is the volumetric heat capacity of moist air at constant pressure (J kg_1 K_1), e is the coefficient for the conversion of latent heat to its water equivalent (giving actual evapotranspiration (Ea)) and VPD is the vapour pressure deficit (kPa). This simplification requires the following conditions: (i) boundary layer conductance is high; (ii) there is no vertical gradient in VPD through the crown. These conditions are normally satisfied in Mediterranean canopies which are tightly coupled to the atmosphere – see below for further elaboration of this point.

3) I do not understand why the authors mix the aerodynamic, quasi-laminar boundary layer and surface (stomatal) conductance into what they refer to as a bulk conductance. This is unnecessary as the surface (stomatal conductance) could be separated from the aerodynamic and quasi-laminar boundary layer conductance, giving a sort of big-leaf equivalent to leaf-scale stomatal conductance. This bears a conceptual problem, as the aerodynamic and quasi-boundary layer conductances are not under plant

control, unlike the stomatal conductance. If the controls (wind speed, friction velocity, atmospheric stability) on the aerodynamic and quasi-boundary layer conductance change with drought, this may bias the bulk conductance independent of stomatal control. In this context I am questioning the usefulness of the bulk conductance for parameterising the models, which very much likely (although this is not entirely clear to me from the paper) scale up 'pure' stomatal conductance to the canopy level, e.g. by accounting for sunlit and shaded fractions of the leaf area. If this is so, there is a mismatch in scale between what is derived from measurements and used to develop the parameterisation, and model structure.

Authors: The sum of aerodynamic and quasi-boundary layer conductances is between one and two (site dependent) orders of magnitude larger than the stomatal conductance calculated from Equation 1. For this reason we assumed their inclusion in the conductance formulation unnecessary (i.e. aerodynamic conductance (very large especially in dry conditions) does not mask the effect of canopy conductance). In addition, the canopy is always better coupled to the atmosphere in drier conditions (the main period of interest of this study is during such conditions), as the gradients are stronger. However, the editor has a point in that seasonal changes in aerodynamic conductances may not be simply linear with canopy conductance, and this could theoretically introduce some bias in our estimation of seasonal changes in parameters (though previous studies have reported that canopy resistance increases in proportion to the stomatal resistance during the year (including during summer drought periods), e.g., Tan & Black, 1976). The Editors point is reinforced by the fact that both GOTILWA+ and ORCHIDEE explicitly calculate aerodynamic conductance and use it for their calculation of canopy transpiration, and so aerodynamic conductance should be included in their parameterisation.

We found that the main driving variables of aerodynamic conductance (wind speed, friction velocity, atmospheric stability) do not change seasonally at the studied sites, but due to the large scatter in the data the statistics are not very convincing. This and the following point raised by the Editor regarding the assumption of close coupling between canopy and air temperature in the use of VPD, have led us to reconsider our methodology, and recalculate canopy conductance taking into account aerodynamic and quasi-boundary layer resistances and canopy leaf temperature. See appendix 1 for calculation details and results. We propose the introduction of this more detailed methodology in the revised version of the manuscript.

4) Third by using the VPD the authors assume the evaporating surface to be at air temperature, which is unlikely to be the case, in particular during conditions of low evapotranspiration. This problem could be overcome by using the Penman-Monteith combination equation for deriving Gc – in this case usually the aerodynamic and quasi boundary layer conductances are separated.

Authors: Please refer to response to point 3, and see appendix 1.

5) Fourth, the authors should assess and discuss the effects of any energy imbalance and thus a potential under/overestimation of LE on their conductance calculations, in particular if the energy imbalance changes with drought conditions, which might be the case – I have a paper in press at AFM on this issue which I would be happy to share with the authors.

Authors: We understand your concern regarding the potential effect of an energy balance. We would therefore be happy to include a discussion on the potential impact of any energy imbalance on our conclusions in the revised manuscript. There are difficulties in ascertaining the exact energy balance for the sites and periods studied, as all components of the energy balance are not freely available. It should, however, be highlighted in the discussion section as an additional uncertainty regarding exact parameter values and the slopes of responses to changes in soil water content.

Appendix 1.

Canopy conductance to water vapour (Gc) has been recalculated, using a modified

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version of the previously applied formulation, which takes into account the points raised by the Editor (additional conductances and canopy temperature). The new formulation for Gc is as in Eq. A1. Total (G) conductance is then calculated as in Eq. A2, taking into account Aerodynamic conductances (Ga) calculated as in Eq. A3:

Conductances calculated using this formulation were compared against the previous estimates included in the manuscript. A good agreement between the two methods was found at all sites (Fig. A1), due to the small aerodynamic resistance when compared to stomatal resistance. There were particularly good correlations at both the Puechabon and Roccarespampani sites, with slightly lower correlations at the Blodgett and Collelongo sites.

The use of the new conductance parameterisation had no effect on neither the calculated slope and intercept, nor on their response to changes in soil water. The same was true for the calculation of the canopy average Ci, and the subsequently detected changes in non-stomatal limitations. This is due to the close correlation between the results given between the two conductance calculations, but also to the large amount of scatter observed in the data used for extracting the slope, intercept, and non-stomatal limitations (Fig. 3 and 4 of the Discussion manuscript). In other words, the variance imposed by the choice of methodology is much less than the natural variance in the analysed data.

We propose to include the new methodology in the revised manuscript, giving the study a sturdier scientific basis, with additional discussion regarding the uncertainty related to the parameters (b, gs0, WfacStoma & WfacPhoto), and the slope of their responses to soil water stress, which we have extracted from the data.

Figure A2. Comparison of two different approaches for calculating bulk canopy conductance at each site. Gc (simplified equation) refers to conductances calculated using equation 1, whereas Gc (considering aerodynamic conductance) refers to the equation series A1:3. Lines represent linear regressions of the form y = a + b.x, with parameter

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values for a and b given in the figure.

References

Brandes, E., et al.: Assessing environmental and physiological controls over water relations in a Scots pine (Pinus sylvestris L.) stand through analyses of stable isotope composition of water and organic matter, Plant, Cell and Environment (2007) 30, 113–127

Breda, N., et al., Temperate forest trees and stands under severe drought: a review of ecophysiological responses, adaptation processes and long-term consequences, Ann. For. Sci. 63 (2006) 625–644

Keitel C., et al.: (2003) Carbon and oxygen isotope composition of organic compounds in the phloem sap provides a short-term measure for stomatal conductance of European beech (Fagus sylvatica L). Plant, Cell & Environment 26, 1157–1168.

Luis, V.C., et al.: Canopy transpiration of a Canary Islands pine forest, Agricultural and Forest Meteorology 135 (2005) 117–123

Owen, P. R., and W. R. Thomson, 1963: Heat transfer across rough surfaces. J. Fluid Mech., 15, 321–334.

Pataki D.E., Oren R. & Phillips N. (1998) Responses of sap flux and stomatal conductance of Pinus taeda L. trees to stepwise reductions in leaf area. Journal of Experimental Botany 49, 871–878.

Qualls, R., and Hopson, T.: Combined Use of Vegetation Density, Friction Velocity, and Solar Elevation to Parameterize the Scalar Roughness for Sensible Heat. Journal of the Atmospheric Sciences, 55, 1198–1208

Tan & Black: Factors affecting the canopy resistance of a Douglas-fir forest, Boundary layer meteorology, 10, 475-488, 1976

Wang, K., et al.: Annual and seasonal variation of sap flow and conductance of pine trees grown in elevated carbon dioxide and temperature, Journal of Experimental Botany, Vol. 56, No. 409, pp. 155–165,

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Appendix 1.

$$\frac{1}{Gc} = \frac{1}{G} - \frac{1}{Ga} \qquad \text{(A1)}$$

where the total (G) conductance was calculated as in Eq. A2:

$$\frac{1}{G} = \frac{\rho.Cp}{\gamma} \cdot \frac{[e*(T_C) - e_{zR}]}{\lambda.\varepsilon.LH} \qquad \text{(A2)}$$

where $e*(T_C)$ is the saturation vapour pressure at canopy temperature (T_C), e is the ambient vapour pressure at reference height z, γ is the psychometric constant, lambda is the latent heat of vaporization, rho is the density of moist air, Cp is the volumetric heat capacity of moist air at constant pressure, e is the coefficient for the conversion of latent heat to its water equivalent (giving actual evapotranspiration (E_a). Canopy temperature, T_C, was solved for by closing the plant atmosphere energy balance.

Aerodynamic conductances (Ga) were calculated as in Eq. A3:

$$\frac{1}{Ga} = \frac{1}{Ge} + \frac{1}{Gb} = \frac{k^2 u(z)}{\ln^2[(z-d)/z_0]} - \frac{B^{-1}}{u^*} \qquad \text{(A3)}$$

where Ge is the eddy diffusive aerodynamic conductance between the measurement height and the canopy surface. z is the reference height of the energy balance measurements, Z_0 is the surface roughness length, estimated to be proportional to the stand height (the average conductance was calculated for a range of different estimates of Z_0), d is the zero plane displacement (estimated as d = z-z0*exp(U.k/U*)), and k is von Karman's constant. U(z) is the measured wind speed at measurement height z. Gb is the excess leaf boundary layer conductance, B-1 is the dimensionless sublayer Stanton number [Owen and Thompson, 1963; but see Qualls and Hopson, 1998]. U* is the friction velocity.

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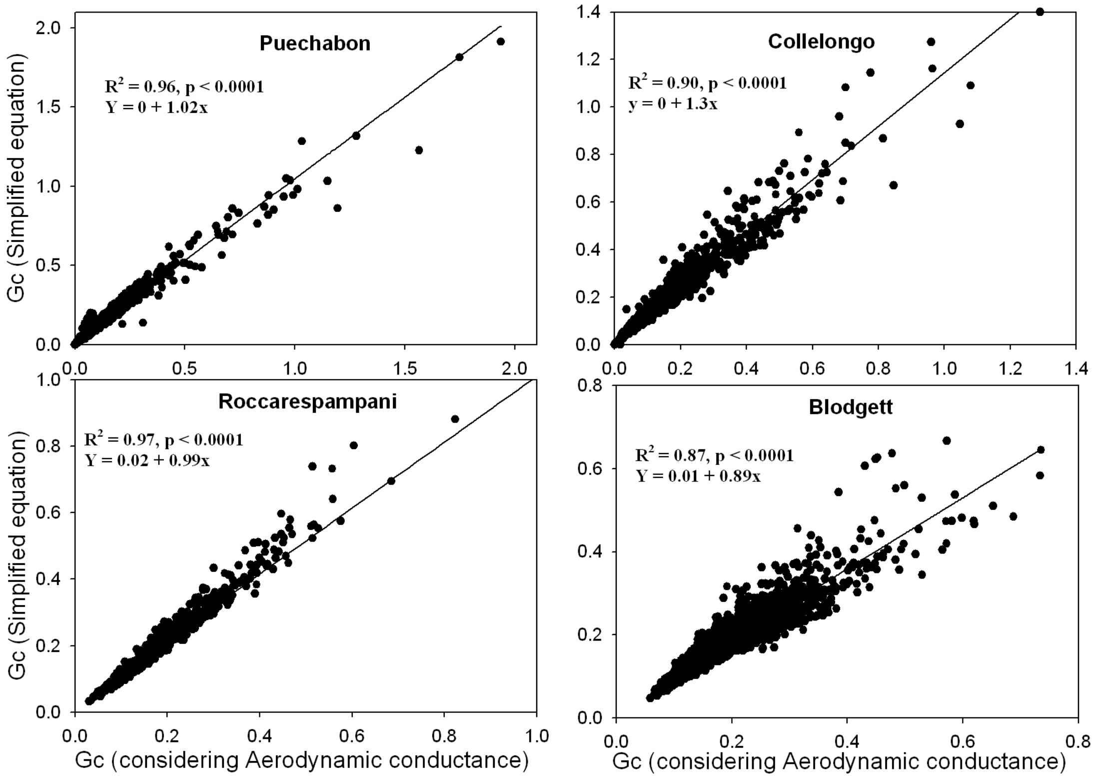

Fig. 2. Figure 1: Comparison of two different approaches (non-aerodynamic vs aerodynamic) for calculating bulk canopy conductance at each site.