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Interactive
Comment

Interactive comment on "Topography induced spatial variations in diurnal cycles of assimilation and latent heat of Mediterranean forest" *by* C. van der Tol et al.

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In our paper we have presented the results of a field and modelling study which focusses on the interactions between natural vegetation and micro-environment. We have chosen to devote most attention to the results, while describing the measurement techniques relatively tersely. This approach has given rise to doubts about the statistical significance of the results. With this response we wish to clarify the issues addressed by Leornardo Montagnani in his comment of 27 October 2006.

Perhaps the most relevant issue concerns the word 'topography' in the title (page S682). This term indeed purposely resembles a variety of factors. In the introduction,

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we gave a motivation for this choice, and I shall explain this in more detail.

Large areas in the Mediterranean (Italy, Spain and the peninsula of Istria) have indeed been reforested during the last decades. In the particular case of the Dragonja catchment the reforestation of the last 40 years has been accompanied by a 50 percent decrease in summer and winter river discharge. For this reason, transpiration measurements in the area are relevant. This is, however, not the only reason why the study was carried out. For climate models it is in particular important to understand how vegetation changes in response to climate. By selecting plots on slopes of contrasting aspect or plots with different soil water availability, as in the present case, it is possible to study the effects of specific climatic factors (here radiation and water input) on vegetation and the fluxes, while -due to the short distance between the plots- the climate in general is homogeneous.

The forests on the slopes in the flysch area are older than those in the carst area. Topography is responsible for structural spatial differences in microclimate and hydrology. Anthropogenic influence has been minimal, the parent material is rather homogeneous, and so are the soil texture and soil chemistry. Differences in vegetation between aspects are clearly visible on aerial photographs. Factors like canopy structure, vegetation height, species composition and stand density are not autonomous causes of differences among plots, but merely results of a different exposure and topographic position. For this reason, we have not focussed on differences in species etc., but used the term topography to encompass all we consider boundary conditions for vegetation growth and development.

Although topography is responsible for most of the differences among the plots, there is no warranty that other factors than topography (fires, diseases, stand age) have not played a role. The most important of these alternative factors is stand age. One of the plots, notably the east plot, had a younger vegetation than the others. For this reason and because the name ’east’ does not refer to its aspect, we agree with the remark that the name of this plot is confusing and propose to rename it ’south-young’.

Most of the other comments concern the measurement strategy and statistical aspects. We agree with the comment that it is necessary to limit the number of variables and to multiply independent samplings (page S682). In what follows I explain how we achieved this.

From a climatologist point of view, the two parameters that are relevant here are photosynthetic capacity and the ratio of carbon dioxide uptake to transpiration. Together they determine the fluxes of carbon dioxide and water. In order to estimate these parameters, one needs to integrate over the canopy. We focussed on these two parameters and used leaf nitrogen and 13C isotopes as measures. Another relevant process, soil respiration, has not been considered here.

In general, measurements in field conditions are inevitably more difficult than in controlled conditions. We have judged that, in spite of logistical limitations, measurements at natural and representative locations are more valuable than measurements at locations that are not representative. Care has been taken to meet statistical requirements as much as possible, and all uncertainties have been accounted for in the analysis.

We have calculated latent heat flux in two ways. The first way was using sap flux measurements. In the results section, we define the latent heat derived with this method as 'measured latent heat flux', hitherto referred to as 'sap flux based estimates'. The sap flux technique is to our knowledge more appropriate in the study area than the eddy covariance technique, which has problems of a variable footprint, advection, and the need for a slope correction. The sap flux sensors gave stable signals that were independent of wind direction.

Modelled latent heat was based on entirely different measurements, notably leaf nitrogen content, leaf gas exchange, 13C isotope discrimination and leaf area index. The sap flux measurements were not used in any way in this model. Sap flux measurements were carried out every minute, whereas biochemistry was measured only at the start and the end of the season. Both estimates of latent heat are based on independent measurements. In the model, canopy leaf nitrogen content and isotope discrimination have been calculated as an average of each species, weighted by the relative contribution of each species to the total sapwood area. It is noteworthy that only relative contributions were used, not the ratios of sapwood area to surface area as in the sap flux method. Errors in the sapwood area do not affect modelled latent heat as long as these errors do not affect the relative contribution of each species to the total sapwood area.

In what follow, I shall respond to the specific comments of the referee on pages S682-S685

1. Title: see discussion above

2. Radiation
The referee remarked that the measurements of radiation and surface temperature are missing in the methodology section. Incoming and outgoing short wave and long wave radiation were measured at one of the plots (south) with a Kipp CNR1 radiometer (Kipp and Zonen, Delft, Netherlands) mounted above the canopy. The temperature of the instrument itself was measured with a PT100 resistive temperature device. This setting provided accurate measurement of radiative temperature, which was used for validation of the model (Fig 11). In addition, radiative temperature was measured with a 4000.4ZH Everest radiometer (Everest Interscience, Inc.) Both instruments were pointed in NADIR. The radiative temperatures measured with the two instruments agreed very well, and only the data of the Kipp radiometer were used in the analysis. The Granier sap flux sensors are not suitable for surface temperature estimates, because they contain heating elements.

The measurements showed that radiative temperature, here referred to as surface temperature, closely follows air temperature and is between 0 and 4 centigrade higher during than air temperature during the day. Surface temperature was also calculated in the model, neglecting soil heat flux and heat storage in the canopy. Storage in the canopy and soil heat flux should have some effect on surface temperatures. Storage in the canopy is relatively small, in the order of 10 kJ/K (based on a rough estimate of biomass). Soil temperature was measured at 4 different depths. Neglecting soil heat flux has some effect on the diurnal cycle of surface temperature, but not on the daily means. Because the surface temperature was so closely related to air temperature and the sensitivity of transpiration calculated by the model to variations in surface temperature was relatively small (page 19), we neglected this term, in order to avoid the introduction of unnecessary parameters for soil heat conductance and capacity, with no noticeable effect on the calculated fluxes.

3. Aerodynamic conductance
We used an empirical function which contains a convective and a turbulent term. Surely, these terms differ among the plots. For evaporation from a wet vegetation, the aerodynamic conductance is extremely important. We find its effect reflected in the differences in throughfall data. A proper quantification of the aerodynamic conductance can only be carried out using wind and temperature profile measurements. Fortunately, this was not necessary for this study. We consider transpiration of dry vegetation, where stomatal resistance is an order of magnitude higher than aerodynamic resistance. In the sensitivity study we have allowed for a significant uncertainty in the coefficients of the equation for aerodynamic conductance, with little effect on transpiration.

4. Translation from nitrogen content to V_{cm}
Light response curves of 6 leaves of *Fraxinus ornus* and 13 leaves of *Quercus pubescens* were measured. Due to technical limitations (access to the canopy), these measurements could not be carried out at the north and west facing plots. Unfortunately, the extrapolation of the relationship between leaf nitrogen and photosynthesis to other locations and another genus is rather coarse. V_{cm} is an important parameter, and the sensitivity analysis shows that this parameter causes the largest part of the uncertainty in the results, given by the bars in Fig. 9. For this reason, we have used

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literature data in support of the proposed relationship.

The 83 leaf samples used in the analysis were bulk samples of at least 4 to 15 leaves. We have only few measurements of leaf photosynthesis and leaf nitrogen for exactly the same leaf. We can add them to Fig. 6 and include them in the regression line with the same weight. Although a positive relationship between nitrogen content and photosynthetic capacity is evident, some uncertaintly will remain.

In climate models, photosynthetic capacity and its spatial distribution is always difficult to estimate. Radiative transfer models can be inverted to obtain estimates of leaf nitrogen content from remote sensing products, or parameters like fAPAR and NDVI can be used. What we showed in this study, is that a relatively coarse but easy to measure parameter as leaf nitrogen content together with leaf area index can be used to explain differences in the fluxes among locations. Although the absolute amounts are uncertain due to some uncertainty in nitrogen-V_{cm} relationship, the spatial patterns are evident. The sensitivity analysis shows the relative importance of this parameter compared to weather conditions. The procedure has the potential to estimate spatial patterns of the fluxes on the basis of remotely sensed estimates of leaf nitrogen content.

5. Temperature and vapour pressure deficit
Temperature and relative humidity were measured with aspirated, shielded humicaps (HMP45AC, Vaisala Oyj, Finland), which were calibrated against a wet and dry bulb copper-constantan thermocouples (Vrije Universiteit Amsterdam) before and after the study. Mean daytime temperature during the growing season at 2 m height was 22.8 C, 23.9 C, 21.4 C and 24.3 C for the north, south, west and east (south-young) plot, respectively, and mean vapour pressure deficit 11.0 hPa, 13.3 hPa, 9.6 hPa and 14.2 hPa for the same plots.

5. Juniperous communis
Juniperous cummunis is indeed a conifer, with needle shaped leaves. In our study area, they reached a height of 6 m. Vascular bundles in the xylem were visible under a

microscope.

6. Quercus is a genus: we mean Quercus pubescens and Quercus cerris.

7. Constant vegetation characteristics
Surely, electron transport (as well as leaf water potential, fluorescence, lumen pF etc.) vary during the day in response to environmental conditions. We have accounted for the variations in vegetation response using Cowan's model (which is similar to that of Leuning) for stomatal conductance. However, what we also observed is that every day, transpiration is similar at similar temperature, relative humidity and radiation, i.e. the response remains constant, and after a disturbance (clouds), the vegetation quickly returns to its original transpiration rate. Figure 9 was based on 20 clear days, with very small differences between them. Our approach works as long as leaf water potential remains relatively high and xylem embolism is avoided. The concept of a constant V_{cm} and J_m during the day is common practise in photosynthesis-energy balance models and has also been used by, among others, De Pury and Farquhar, 1997.

8. Sunlit and shaded leaves.
Of the 83 samples, 42 were collected in the upper half of the canopy, and 41 in the lower half. Samples collected in the upper half are called predominantly sunlit, samples collected in the lower half predominantly shaded. Because of several mechanisms operating at the same time (diffuse light is used more efficiently than direct light, young individuals with high nitrogen content are lower and thus more abundant in the lower part of the canopy), there is no unique relationship between height and nitrogen content.

9. 'Fitted' is indeed a better term (with the Nelder Mead method).

10. Taking a constant depth of sapwood results in a sapwood area that scales with the square root of stem cross sectonial area, instead of the hyperbolic equation of Medurst and Beadle. The sap flux sensors were installed in a heat conducting paste. They measure the average sap flux in the outer 20 mm of the tree. The scaling problem

only arises when sap wood depth exceeds 20 mm. In this study, the xylem was investigated of the 24 trees for which sap flux was measured. The number of 24 samples was indeed too small to establish relationships between species, diameter, height in the tree and aspect. As the referee suggests, such would be worth a separate investigation. There was no sharp transition between sapwood and hardwood, but most xylem vessels were present in the outer 20 mm. Based on the microscope images, it was estimated that 20% of the xylem vessels were present deeper than 20 mm. We allowed for a broad uncertainty of 50% of this value (i.e. between 10 and 30% of xylem is present deeper than 20 mm). Although this method is rather crude, it does not weaken the whole paper.

11. For PAR measurements along horizontal and vertical transects, a ceptometer (Decagon Instruments Inc.) was used, with 80 sensors covering a length of 80 cm. Each measurement point in Fig. 7 is the average of 430 measurements taken at regular intervals along a transect of 25 x 2 meters with this ceptometer, i.e. the average of $430 * 80 = 3 * 10^4$ individual PAR measurements. Measurements along the vertical transect consisted of 10 measurements with the ceptometer at each 1 m interval, i.e. 800 individual PAR measurements. Measurements were taken between 6 AM and 6 PM during the entire field campaign. Diffuse and direct light were separately measured at the meteorologic station, and a model was used which accounts for the extinction of both components as a function of azimuth, leaf area index, leaf angle distribution, and slope of the surface. This model is described in appendix B. In addition, canopy photographs were taken with a camera with fish-eye lens, pointing vertically upwards, mounted on a tripod. However, we decided to use light measurements with the ceptometer for leaf area index. Leaf area index is used in the model to calculate light distribution. For this reason, leaf area index calculated from ceptometer measurements is more relevant than leaf area index derived from canopy photographs.

12. The statistical setting of the experiment is indeed important for the accuracy of the results. We have not ignored this aspect. Some of the measurements are used

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as input, others for validation or to estimate parameter values. As such, the statistical setting of the experiment affects items (1), (2) and (3). That is the reason for carrying out a sensitivity analysis. This analysis showed, for example, that the model is relatively insensitive to aerodynamic conductance, and thus that a further improvement of turbulence measurements is unnecessary.

13. Daily mean temperature above the canopy was 0.25 °C higher than below, which is in agreement with the rule of thumb of 0.03 C m^{-1} vertical temperature difference. Night time temperatures were responsible for this difference, while afternoon temperatures above the canopy were 0.1 °C lower than below. Indeed, there is indeed a narrower thermal excursion above than below the canopy.

14. Ostrya carpinifolia was recorded at the north (9 percent of trees) and the south plot (7 percent of trees). Because they were relatively small individuals, their contributions to the stem basal area was less than 2 percent for the north and 4 percent for the south plot.

15. Nitrogen content is expressed in units of g/ 100g dry matter.

16. The Greek capital letter Lambda in Fig. 7 is a mistake and should be a small letter.

17. Radiative temperature was meant here.

Conclusion

The referee has pointed at the two main sources of uncertainty in the measurements: the scaling of sap flux to canopy level and the conversion from leaf nitrogen to photosynthetic capacity. They are indeed responsible for most of the uncertainty as represented by the bars in Fig. 9. An ideal experimental setup as in laboratory or easily accessible field sites was not feasible for technical and logistic reasons. However, we accounted for the uncertainty in a sensitivity analysis. The measurements were carried out in a representative sub-Mediterranean area, in a unique setting (natural vegetation developed on slopes of different aspect), and different independent measurements

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were combined. The study gives insight in the importance of long-term and short term effects of climate and topography on transpiration.

The title expresses our message. We do not agree with the referee that modelled and sap-flux based measurements are dependent. To our opinion, surface temperature and irradiance measurements, aerodynamic conductance and the sampling strategy have been covered with sufficient accuracy. Measurements were carried out with contemporary techniques. The description of measurement techniques in the 'Method and materials' section is perhaps too brief.

Interactive comment on Biogeosciences Discuss., 3, 1631, 2006.