Ecophysiological responses to drought in Mediterranean forest ecosystems: data analysis and the evaluation of model predictions in drought prone environments

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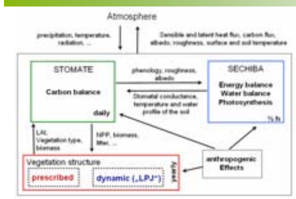
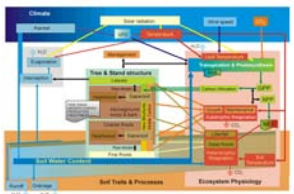
Abstract

Seasonal drought is characteristic of Mediterranean ecosystems, imposing significant constraints on ecosystem productivity. The sensitivity of vegetation to drought stress is key to understand the seasonality of land-atmosphere fluxes of energy, water and carbon, which in turn can have important effects on regional and global climate. However, projections of effects on forest growth and land-atmosphere fluxes are subject to large uncertainty, because current ecosystem models have a limited capacity to correctly account for the drought effects on vegetation growth. In this context, Dynamic global vegetation models (DGVMs) are important tools in analysing the potential future development of ecosystem structure and functioning under changed environmental conditions.

The relationships between water stress, stomatal conductance, and photosynthesis are key components of the responses of Mediterranean ecosystems to environmental stress. Improving our understanding of the ecophysiological response to extreme drought is therefore of great importance for a better assessment of the effects of global change on Mediterranean ecosystems. Our aim with this study was to use data to quantify drought effect on photosynthesis and latent heat fluxes, deriving a simple parameterisation and testing our results on regional scale. This work shows the relevance of this new parametisation for better prediction of climate change for Mediterranean ecosystems.

Models





ORCHIDEE

Orchidee (Krinner *et al.*, 2005) is a terrestrial biosphere model that simulates terrestrial energy, water and carbon fluxes driven by vegetation (based in plant fuctional types) and soil processes, and changes in vegetation structure and distribution in response to environmental parameters.

GOTILWA+

Gotilwa+ is a process based forest growth model that has been developed to simulate the processes underlying growth and to explore how these processes are influenced by climate, tree stand structure, management techniques, soil properties and climate change. It simulates carbon and water fluxes through forests in different environments, for different tree species.

Data - FluxNet

A global network of biosphere-atmosphere flux measurement sites. Eddy covariance is used to measure the exchanges of carbon dioxide, water vapour, and energy between terrestrial ecosystems and the atmosphere. FluxNet also compiles data on site vegetation, soil, hydrologic, and meteorological characteristics at the tower sites.

SITES

Puechabon: France (Quercus Ilex) TeBE
Location: 43°44'N, 3°35' E
Altitude: 270m

Collelongo: Italy (*Fagus Sylvatica) TeBS*
Location: 41°50'N, 13°35' E
Altitude:1560m

Rocarespampani: Italy (*Quercus Cerris) TeBS*
Location: 41°50'N, 13°35' E
Altitude:223m

Blodget: California (*Pinus Ponderosa) TeNE*
Location: 38°53'N, 120°37' W
Altitude:1315m

REFERENCES

[1] Krinner, G., N. Viovy, et al. (2005). Global Biogeochemical Cycles 19: doi.:10.1029/ 2003/GB002199.

[2] Gracia C.A., (1999). pp. 163-178. Springer, Berlin.

[3] Reichstein, M., (2003). *J. Geophys Res,* 108(D23),4726, doi:10.1029/2003JD003430

[4] Rambal S, (2003). *Global Change Biology* 9: 1813-1824.

[5] McMurtrie, R., (1990). Forest Ecology Management, 30, 381-413.

[6] Grassi, G., (2005). *Plant, Cell and Environment* 28

Methods

(1) Soil moisture at each site was reconstructed based on reported soil properties and observed precipitation and latent heat, using a simple soil water budget model. This allows us to build the energy balance from the beginning prescribing the availability of water for soil evaporation.

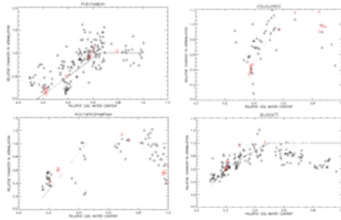
$$\Delta S_w = P - E - R$$

(2) In order to quantify photosynthesis limitations, we obtained the relative roles of stomatal versus non stomatal limitations on photosynthesis under soil moisture stress (elimination approach (Farquar & Sharkey, 1982).

(2a) Canopy conductance was calculated combining the McNaughton and Black equation [1] (simplification of the Penman-Monteith equation) with site water balance, by inverting FLUXNET latent heat flux measurements.

$$\lambda E = \left[\frac{(\rho c_p VPD)}{\gamma r_s}\right] \quad [1]$$

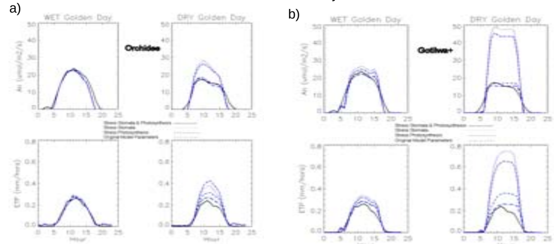
$$\lambda E = f(gs)$$



(above) Non stomatal control related responses in normalised net assimilation (An) relative to available soil water content. Solid line: water stress function; Red dots: Golden days for wet and dry conditions; Black dots: corresponds to non-stomatal conditions. Decrease for wet conditions denote autumn transition with different climatic demand.

2b) Using the estimated canopy conductance, observed rates of net photosynthesis, and atmospheric CO2 concentrations, leaf internal carbon dioxide can be calculated using a simple supply and demand algorithm.

2c) Observed changes in assimilation rates during times when neither internal carbon, available light nor temperature, are limiting, can be attributed to non-stomatal limitations. Non-stomatal limitations to photosynthesis attributed to water stress were identified through the analysis of assimilation data at different levels of soil water availability.



above: 20 average Golden Day diurnal courses (days with good environmental conditions, no precipitation, good radiation) for the modelled (a) Orchidee+, (b) Gotilwa+) and observed photosynthesis (An, in umol/m2/s) and Actual Evapotranspiration (ETP, in mm/hour) for Roccarespampani, using four different modelling approaches, with the soil water content prescribed in each: 1) Applying factors from Table 2 to both Stomatal conductance and Photosynthetic potential, 2) Applying the factors to stomatal conductance only. 3) Applying the factors to Photosynthetic potential only, and 4) Applying the original parameterisations. On the left, well watered conditions. On the right, strongly water stressed periods.

Conclusions

✓ Assimilation vary with soil moisture in a predictable manner using observations from four sites. Incorporating this knowledge into process-based models leads to simulated of carbon and water fluxes during water stressed periods with a similar accuracy during well watered and water-stressed conditions.

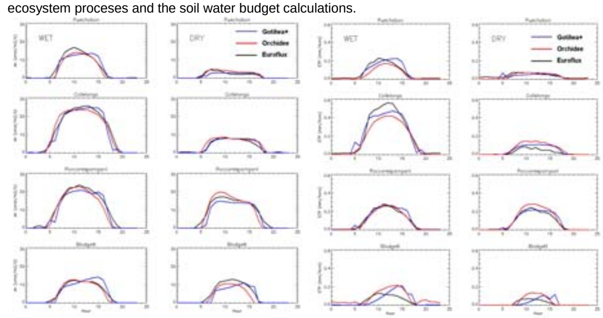
✓This was only possible through the application of water stress responses only on photosynthetic capacity independently. Both models compare well against the Fluxnet data, although Gotilwa+, being more detailed in design and initially developed specifically for the application in Mediterranean ecosystems, performed slightly better on average.

✓ The importance of an accurate description of water stress responses is demonstrated through a Mediterranean Basin simulation, showing in particular the sensitivity of mid latitudinal Europe to assumptions regarding water stress responses, GPP and NEE.

Results

✓ **What are the limitations of the approach, how certain are the factors obtained ?**

The response function values reported here could be subject to slightly changes, depending on the filtering criteria used. For example, using only mid-day values gave a slight change in the calculated minimum and maximum for the functions, as did using only values which relate to the Golden Days studied. Although there is a good deal of variability in the data, the parameter values extracted are quite robust. Gotilwa+ seems to be more sensitive for the different approaches, and shows more variability for wet-conditions The differences among the two models result mainly from the different descriptions of the ecosystem proceses and the soil water budget calculations.

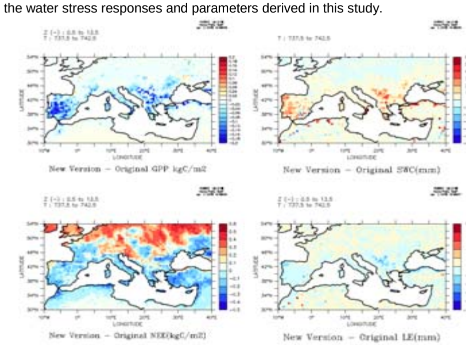


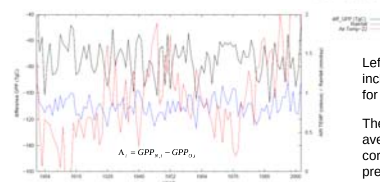
left: 20 average Golden Day diurnal courses for the modelled Orchidee+, Gotilwa+ for observed photosynthesis (An, in umol/m2/s) and Actual Evapotranspiration (ETP, in mm/hour) for all the sites [free simulations]

Regional Simulations

The greatest contribution to the Mediterranean basin is given by a large decrease in mean precipitation, an increase in dry (cold) season precipitation, and an increase in precipitation interannual. This makes the Mediterranean basin one important category Hot Spot. The main objective with this study was to show the effects of the inclusion of the new water uptake function in a regional scale in terms of GPP, NEE and water availability.
Regional simulations were carried out with ORCHIDEE model in the Mediterranean Basin using prescribed vegetation from the Olson vegetation types. Water balance consisted on two budget model with variable depth, precipitation balanced with drainage and runoff. ORCHIDEE was driven from 1901 to 2002. Two simulations were run, one applying the original model water stress function, and the other applying the water stress responses and parameters derived in this study.

Right: Average differences in summer GPP (June to September) between the simulation including the new water uptake function and the original function shows a decrease on GPP in West and Central Spain, South France, Italy and North Greece. Soil water content decreases in the South-East Spain.
With this approach there is a reduction in the net sink effect for all Mediterranean area. Precipitation reduction in the Eastern Europe spreads all through the basin from East to West, giving higher variability in the Western Mediteranenan basin.





Left: Differences in GPP from 1901-2002 between the simulation including the new water uptake function and the original function for (10º W–40ºE,30ºN–46º N).

There is a reduction of about 10% of the total summer GPP in average for the most drought years. These changes are directly-correlated with temperature and inversely-correlated with precipitation.

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