Proceedings of the 7th International Conference on Functional-Structural Plant Models, Saariselkä, Finland, 9 - 14 June 2013. Eds. Risto Sievänen, Eero Nikinmaa, Christophe Godin, Anna Lintunen & Pekka Nygren. http://www.metla.fi/fspm2013/proceedings. ISBN 978-951-651-408-9.

Photosynthesis, Transpiration and LAI: scale effects of spatial patterns

Moritz Kupisch[1], **Anja Stadler**[1], **Matthias Langensiepen**[1] and **Frank Ewert**[1]

[1]*Institute of Crop Science and Resource Conservation, Katzenburgweg 5, D-53315 University of Bonn, Germany*

**correspondence:* mkupisch@uni-bonn.de

Highlights: Field level fluxes of CO_2 and H_2O as well as LAI are highly dependent on the underlying spatio-temporal patterns of environmental factors. Process models at the field scale have to consider the interaction with distribution and spatial patterns of input parameters applied on different plant response processes at the underlying leaf- and canopy-level.

Keywords: Photosynthesis, transpiration, spatial heterogeneity, GECROS model, upscaling

INTRODUCTION

Exchange of CO_2 and water vapor between plant surfaces and the atmosphere are important processes that determine plant growth and yield. They are affected by changes in physical boundary conditions and their magnitudes differ greatly between plant species (Arora *et al*., 2001; Monti *et al*., 2006). The temporal variability of gas exchange in crops has been extensively studied (Reicosky *et al*., 1994; Mo and Liu, 2001; Wang *et al*., 2006), but less is known about its spatial variability in fields. Understanding the spatio-temporal variability of gas exchange is necessary for modeling and estimating the dynamics of soil-vegetation-atmosphere processes at field and larger scales. Most crop modeling efforts ignore the spatial variability of gas exchange and plant structural development processes within fields which are influenced by heterogeneous soil conditions. Detailed representations of plant physiological processes at a single point within a field are typically assumed to represent the entire field. Little work has been done on scaling up from the single point to the entire field, not least due to the limited availability of experimental data.

Observations in wheat and sugar beet field experiments carried out in Western Germany at Selhausen (50° 52′ N, 6° 26′ E) during the 2010 and 2011 vegetation seasons revealed strong spatial heterogeneities in CO_2 and H_2O canopy fluxes across the fields. While canopy measurements showed temporal variability with distinct diurnal and seasonal patterns, the temporal and spatial variability of leaf level photosynthesis and transpiration rates were comparably small. Further analyses suggested that the observed spatial and seasonal variability of canopy measurements were mainly caused by field heterogeneities in LAI and less by gas exchange rates per unit leaf area. However, both crops differed in their responses to drought stress. While wheat responded mainly through irreversible reduction in green leaf area, the canopy assimilation rate of sugar beets decreases only temporarily with no observed effects in LAI.

The obtained datasets from both years are the basis for parameterizing different plant and crop growth models with varying complexities at the point level. The study below focuses on simulation experiments which characterize the effects of up-scaling methods on field level fluxes and their interaction with distribution and aggregation of spatial patterns of input parameters applied to different plant response processes at the underlying leaf- and canopy-levels.

SIMULATIONS

The simulations comprise calculations of instantaneous photosynthesis (Farquhar model, Farquhar *et al*. 1980) and transpiration (Penman-Monteith equation, Monteith 1973) rates at leaf and cannopy scales as well as an application of the crop growth model GECROS (Yin and van Laar, 2005) over the whole season in dependance on spatially varying inputs. Each simulation was executed for six different spatial patterns (Fig. 1) with different edge lengths resolutions, ranging from a minimum value of 1 m to 280 m, which is the mean of the whole field. The patterns differ only in their spatial arrangement but not with respect to their underlying frequency distributions. The distribution of the general patterns range from 0 to 1 and are subsequently applied to specific ranges of temperature, PAR, leaf nitrogen content and VPD. During each simulation run, all other parameters were kept constant, i. e. no co-variation was analysed. For the simulations with the crop model, only the amount of daily water supply was used as a spatial input parameter. For each simulation scenario, the corresponding models were run for every square meter, i. e. at the lowest resolution size, whereas the output was calculated as a mean value of the total field per m^2.

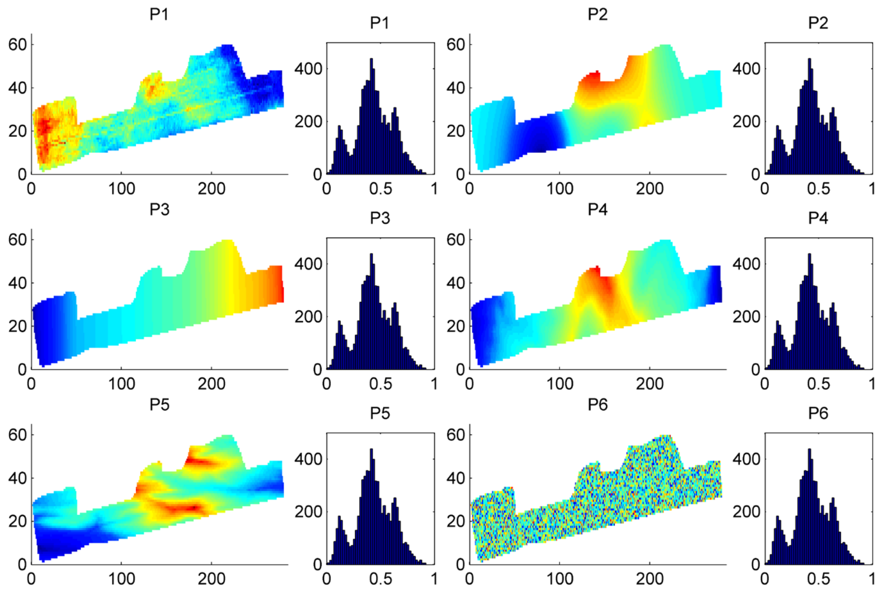

Fig. 1. Spatial patterns P1 – P6 with the same underlying frequency distribution applied to different parameters (temperature, VPD, daily water supply) used as inputs for models at the leaf-, canopy- and seasonal crop scale.

RESULTS AND DISCUSSION

Simulations resulted in highly fluctuating responses of photosynthesis, transpiration and LAI, depending on the aggregation of input parameter step-sizes (Fig. 2 and 3). The first and the last value of all scenarios were the same for all input patterns as they represented either the response to the original frequency distribution (cf. Fig. 1) or the mean of the total field. The values in between represented the response to the changed distribution due to the effect of aggregating different spatial patterns. Regarding fluxes of CO_2 and H_2O one could observe significant similarities in the courses relating to one input pattern, although applied to different parameters (temperature, VPD and water supply) and functional scale (leaf, canopy and crop growth). At the level of seasonal crop growth, the output patterns of maximum LAI were decoupled from the patterns of photosynthesis and transpiration. Model responses to other distributions showed also effects of spatial patterns, but with a different extent (not shown here). No effects of input aggregation has been observed if the response variable was linearily dependent on the input, e. g. leaf nitrogen content (not shown here).

Results indicated that it is important to consider field heterogeneity for parameterizing plant, crop and large-scale soil-vegetation-atmosphere-transport models. Moreover, the spatial pattern of a given distribution has a significant effect on overall field level fluxes. Ongoing work will focus on the interaction of spatial patterns and multiple input parameters with models of varying complexity.

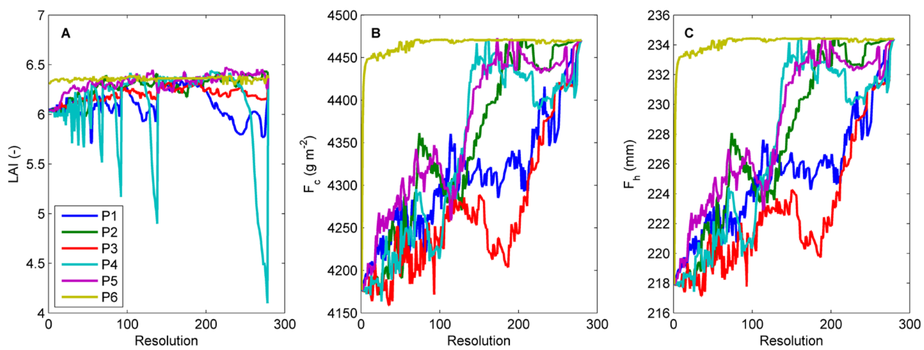

Fig. 2. Mean maximum LAI (A), mean cumulative gross canopy photosynthesis (B) and transpiration (C) as calculated by GECROS model in dependance on the resolution of the underlying input patterns applied to daily water supply.

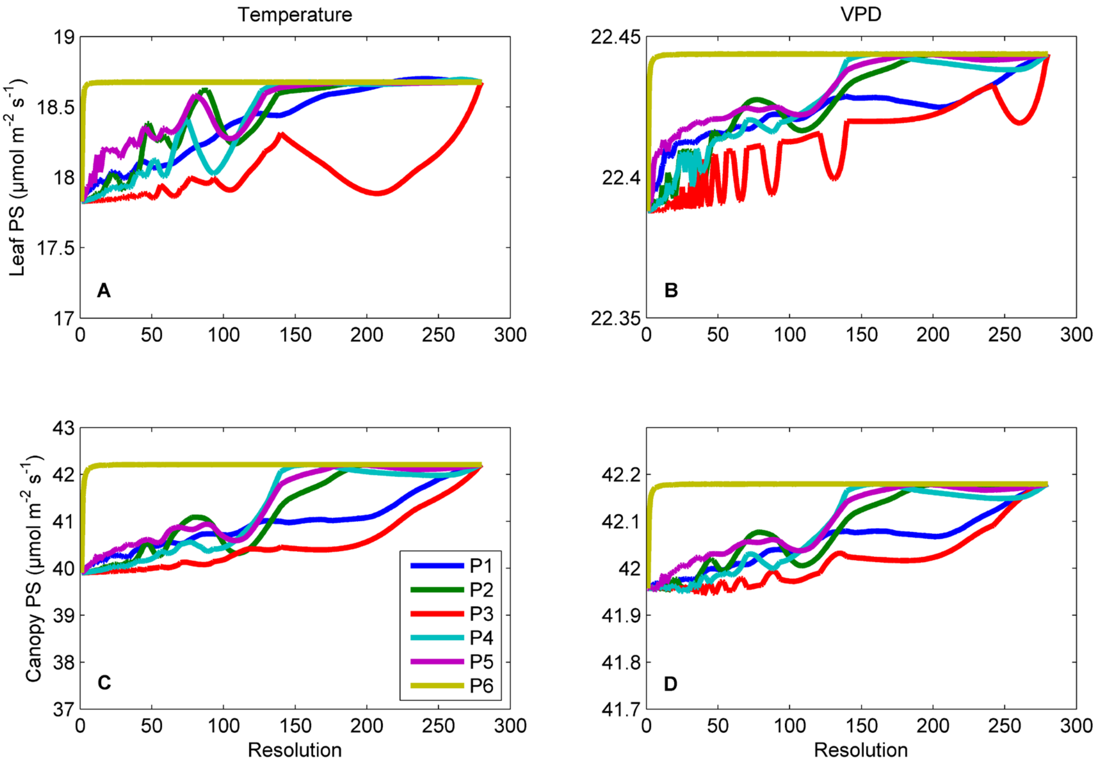

Fig. 3. Mean instanteneous leaf (A, B) and canopy photosynthesis (C, D) in dependance on the resolution of the underlying input patterns applied to temperature (A, C) and VPD (B, D).

LITERATURE CITED

Arora A, Singh VP, Mohan J. 2001. Effect of nitrogen and water stress on photosynthesis and nitrogen content in wheat. *Biologia Plantarum* **44**, 153–155.

Farquhar GD, von Caemmerer S, Berry JA. 1980. A biochemical model of photosynthetic CO_2 assimilation in leaves of C_3 species. *Planta* **149**, 78–90.

Mo X, Liu S. 2001. Simulating evapotranspiration and photosynthesis of winter wheat over the growing season. *Agricultural and Forest Meteorology* **109**, 203–222.

Monteith JL. 1973. Principles of environmental physics. *Edward Arnold, London*, 241 pp.

Monti A, Brugnoli E, Scartazza A, Amaducci MT. 2006. The effect of transient and continuous drought on yield, photosynthesis and carbon isotope discrimination in sugar beet (Beta vulgaris L.). *Journal of Experimental Botany* **57**, 1253–1262.

Reicosky DC, Brown PW, Moran MS. 1994. Diurnal trends in wheat canopy temperature, photosynthesis, and evapotranspiration. *Remote Sensing of Environment* **49**, 235–245.

Wang J, Yu Q, Li J, Li LH, Li XG, Yu GR, Sun XM. 2006. Simulation of diurnal variations of CO2, water and heat fluxes over winter wheat with a model coupled photosynthesis and transpiration. *Agricultural and Forest Meteorology* **137**, 194–219.

Yin X, van Laar HH. 2005. Crop systems dynamics. An ecophysiological simulation model for genotype-by-environment interactions. *Wageningen Academic Pub*.