Technical University of Denmark

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Effects of diffuse radiation on carbon and water fluxes of a high latitude temperate deciduous forest

Sheng Wang, Andreas Ibrom, Kim Pilegaard, Peter Bauer-Gottwein, and Monica Garcia
Department of Environmental Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark
(mgarc@env.dtu.dk)

Ecosystem carbon and water fluxes are controlled by the interplay of biophysical factors such as solar radiation, temperature and soil moisture. In high latitudes, cloudy days are prevalent with a low amount of solar radiation and a higher proportion of diffuse radiation. For instance, in Denmark 90% of all days are non-clear (fraction of direct radiation < 50%). Changes in cloud cover related with climate change are considered the major source of uncertainty in our understanding of the Earth's climate sensitivity to increased atmospheric CO_2 (Brown, 2016). It is also unknown how ecosystems will respond to potential changes in the proportion of diffuse/direct radiation, which can modify the coupled photosynthesis and transpiration rates in future. This study aims to evaluate effects of diffuse radiation on the ecosystem carbon and water fluxes in a temperate deciduous forest using long term eddy covariance observations.
Eddy covariance records (Gross Primary Productivity: GPP; Evapotranspiration: ET) from 2002 to 2012, field data, Normalized Difference Vegetation Index (NDVI) from Moderate Resolution Imaging Spectroradiometer (MODIS), and sap flow data during the period of 2009-2011 at Sorø, a Danish beech forest flux site, were used for analysis. A Cloudiness Index (CI), which is based on actual and potential shortwave incoming radiation and can indicate the proportion of diffuse radiation, was used. First, multiple regression based path analysis was applied to daily and monthly observations to partition direct and indirect effects from CI to GPP and ET. Results indicate diffuse radiation increases the light use efficiency (LUE) with CI being as important as other constraints, e.g. air temperature (Tair), vapor pressure deficit (VPD) and Photosynthetically Active Radiation (PAR), on regulating LUE. An increase of the CI value of 0.1 can increase maximum LUE by about 0.286 gC•MJ-1. Following PAR and LAI, CI has the third largest effects on GPP. For ET, path analysis showed the impact of CI is limited. Further, the CI constraint was added to two physiologically based models for estimating GPP (LUE, Potter et al., 1993) and ET (Priestley–Taylor Jet Propulsion Laboratory, PT-JPL, Fisher et al., 2008) at the daily time scale to assess model improvement. When considering the effect of diffuse radiation by including the CI constraint, the RMSE of the simulated GPP decreases from 2.12 to 1.42 gC•day-1. The performance of PT-JPL improves slightly with RMSE decreasing from 17.92 to 15.51 W•m-2. The sap flow data, which indicates the transpiration, has a higher correlation with the simulated transpiration with CI (0.84) than without CI (0.81). Using these two models (LUE and PT-JPL), the Sobol global sensitivity method was applied to quantify the contribution of CI and its interactions with other forcing variables to the variability of GPP and ET. CI contributes to 23.5% of GPP variation and 4.5% of transpiration variation during summer. This study highlights how important it is to consider diffuse radiation to simulate the coupled carbon and water processes in land surface modeling schemes.