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A New Way to Include Soil Water Stress in Terrestrial Ecosystem Models

Bin Chen
Nanjing University, International Institute for Earth System Sciences, China (chenb9@nju.edu.cn)

Drought has significant impact on the productivity of terrestrial ecosystems. However, the impact of soil water stress to photosynthesis and stomatal conductance has not been clearly described in terrestrial ecosystem models. The original Ball-Woodrow-Berry (BWB) stomatal conductance model was established from leaf-level gas exchange measurements, but it did not account for soil water stress on stomatal conductance. To account for this stress, a scalar, fw is usually introduced into the BWB equation to reduce its slope, resulting to the direct reduction of stomatal conductance. However, the extent to which m varies with soil water stress is still debated. The other option is to reduce the non-stomatal variables (i.e. mesophyll conductance and/or Vcmax) using an empirical multiplier which is related to soil moisture or soil water potential. However, it usually takes several weeks for the deterioration of leaf physiology and biochemistry such as the decrease of leaf maximum carboxylation rate (Vcmax) and/or the decomposition of the leaf chlorophyll content, which is not captured by the schemes of soil water stress in terrestrial ecosystem models so far. This study firstly quantifies the monthly and diurnal variations in canopy conductance from eddy covariance (EC) flux data at two flux tower sites (US-Var and CA-Oas) representing two plant functional types (grass and forest) by inverting the Penman-Monteith equation. Then, BWB slopes were derived and compared under contrasting water stress conditions by linear regression of canopy conductance and the carbon flux data obtained from EC measurements. Finally, the response of Vcmax to accumulated soil water deficit (ASWD) was further explored to develop a better scheme of soil water stress in the coupled photosynthesis-stomatal model. There were several results as follows: (1) The diurnal variation of canopy conductance was mostly controlled by photosynthetically active radiation (PAR), humidity and soil moisture.
(2) The response of canopy conductance to available soil water content can be described by a logistic function with parameters fitted from observational data. (3) It was found that the difference between the BWB slope during the wet period and that during the dry period was not statistically significant. Also, this difference was much smaller than the inter-annual variation of BWB slopes. It was proved that reduction of BWB slope may not be an appropriate way to describe soil water stress in terrestrial ecosystem models. Also, BWB slopes may be conservative. (4) The response of GPP to soil water stress can be divided into two stages. In the first stage (around 20 days for both of the two sites), the EC-derived GPP did not decrease obviously. During the second stage, EC-derived GPP gradually decreased with the increase of ASWD, which can be well captured by the Vmr-ASWD scheme developed in this study. This study would be helpful to improve our understanding of response of photosynthesis and stomatal conductance to the prolonged drought.