Geophysical Research Abstracts
Vol. 14, EGU2012-11461, 2012
EGU General Assembly 2012
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Modeling evapotranspiration based on plant hydraulic theory can predict spatial variability across an elevation gradient and link to biogeochemical fluxes

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In woody plant systems transpiration is often the dominant component of total evapotranspiration, and so it is key to understanding water and energy cycles. Moreover, transpiration is tightly coupled to carbon and nutrient fluxes, and so it is also vital to understanding spatial variability of biogeochemical fluxes. However, the spatial variability of transpiration and its links to biogeochemical fluxes, within- and among-ecosystems, has been a challenge to constrain because of complex feedbacks between physical and biological controls. Plant hydraulics provides an emerging theory with the rigor needed to develop testable hypotheses and build useful models for scaling these coupled fluxes from individual plants to regional scales. This theory predicts that vegetative controls over water, energy, carbon, and nutrient fluxes can be determined from the limitation of plant water transport through the soil-xylem-stomata pathway. Limits to plant water transport can be predicted from measurable plant structure and function (e.g., vulnerability to cavitation).

We present a next-generation coupled transpiration-biogeochemistry model based on this emerging theory. The model, TREEScav, is capable of predicting transpiration, along with carbon and nutrient flows, constrained by plant structure and function. The model incorporates tightly coupled mechanisms of the demand and supply of water through the soil-xylem-stomata system, with the feedbacks to photosynthesis and utilizable carbohydrates. The model is evaluated by testing it against transpiration and carbon flux data along an elevation gradient of woody plants comprising sagebrush steppe, mid-elevation lodgepole pine forests, and subalpine spruce/fir forests in the Rocky Mountains. The model accurately predicts transpiration and carbon fluxes as measured from gas exchange, sap flux, and eddy covariance towers. The results of this work demonstrate that credible spatial predictions of transpiration and related biogeochemical fluxes will be possible at regional scales using relatively easily obtained vegetation structural and functional information.