Modelling the Response of Surface Water Cycle to Rising Atmospheric CO_2: Implications for Impact Assessment on Groundwater Recharge

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Abstract

Atmospheric CO_2 has increased by over 100 ppm since the beginning of the Industrial Revolution. Rising CO_2 concentration affects land surface water cycle through a number of mechanisms. First, it results in climate change as a greenhouse gas, which affects the atmospheric demand for evapotranspiration (ET). ET plays important roles in surface water cycle. Worldwide, ET returns about 64% of land-based precipitation to the atmosphere. Second, it has impact on plant physiology such as the opening of leaf stomata, through which water vapour transpires in an amount of more than the annual flow of all rivers on earth. Third, it affects plant growing conditions and alternates the land surface energy balance, which has ecohydrological consequences.

The changes in land surface ET can strongly affect recharge to subsurface aquifers and stream flow. Rising CO_2 suggests two contrasting water resource scenarios. On one hand, it decreases stomatal conductance and thereafter ET, thus increases recharge and streamflow when scaled to landscapes. On the other hand, changes and feedbacks in vegetation and climate are likely to increase ET. While many field experiments of CO_2 enrichment have tested and supported the first hypothesis, experimentally manipulate climate and atmospheric CO_2 at sufficient spatial and temporal scales to directly test the second hypotheses is infeasible. As such, the development of mechanistic models is imperative to study the impact of rising atmospheric CO_2 on surface water cycles and groundwater recharge.

This presentation introduces the ET scheme developed for the EALCO model (Ecological Assimilation of Land and Climate Observations). This scheme dynamically integrates the three mechanisms of rising CO_2 impact on ET through solving the coupled canopy energy-water-CO_2 transfer equations. The model was first tested using eddy correlation flux measurement at a boreal aspen forest in Canada. Results showed that the correlation coefficient (r) between modeled and measured daily ET was higher than 0.96. The average absolute error was approximately 0.3 mm day^{-1}. The modelled groundwater recharge was found to correspond to the water table observations reasonably well. The model was then applied in the Free-Air CO_2 Enrichment (FACE) study in the Duke Forest of Loblolly Pine and in the Oak Ridge Experiment of Sweetgum, USA. We found the magnitude of ET response to rising atmospheric CO_2 was dependent on interacting variables such as radiation, vapour pressure deficit, and soil water potential. Long-term (e.g., annual) ecosystem ET showed smaller reduction due to atmospheric CO_2 enrichment than at short-term leaf level, implying the role of scales in estimating the response of groundwater recharge to rising atmospheric CO_2.