Geophysical Research Abstracts
Vol. 13, EGU2011-11012, 2011
EGU General Assembly 2011

Spatial and Temporal Variability and Non-Monotonic Responses of Landscape-Scale Soil CO_2 Efflux

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Mountainous landscapes impose strong physical gradients that affect the redistribution of biophysical resources such as water, energy, and substrate. Further variability is introduced by the spatial heterogeneity of biological processes responsible for carbon (C) transformation in the soil. The juxtaposition of physical and biological processes results in high degree of heterogeneity of soil CO_2 efflux at the landscape scale, and complicates the transfer of understanding gained from point observations to entire landscapes or regions. We analyzed the role of landscape heterogeneity and structure on the distribution and flux of C to the atmosphere, based on a suite of field observations performed over three years, detailed terrain analysis, and process-based modeling. Our findings demonstrate that rates of growing season soil CO_2 efflux vary spatially by almost an order of magnitude within a small, mountainous watershed ($\sim$4 km^2), and that this variability is related to water redistribution and accumulation across the landscape. Furthermore, our results also indicate that topographically complex landscapes can respond non-monotonically to changing hydrologic regimes (e.g., 'wet' vs. 'dry' years). Non-monotonic behavior is a function of hydrologic influences on biological processes and the emergence of thresholds in the relationship between physical processes and biological responses. We suggest that the magnitude of threshold-mediated, non-monotonic landscape responses is a function of the intersection of landscape structure and biological activity. Furthermore, these observations should be transferable across different watershed morphologies (shapes), vegetation structures, and climatic conditions.