Inter-annual variation in precipitation affects the spatial heterogeneity of soil CO_2 efflux in a West Virginia watershed

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INTRODUCTION

Soil respiration and the hydrologic cycle are tightly coupled. Variation in precipitation affects soil respiration through the alteration of soil moisture regimes. Landscape position within heterogeneous terrain can also alter soil moisture regimes through the effects of elevation and the lateral redistribution of soil water. Understanding how inter-annual variation in precipitation affects carbon cycling in humid, complex watersheds will fill a crucial knowledge gap and will allow for more accurate accounting and model parameterization. To examine the interactive effects of precipitation with elevation and vegetation cover on carbon and water cycling at the watershed scale, we compared data from the Weimer Run watershed near Davis, West Virginia for a dry year—2010 (precipitation = 1137 mm)—and a wet year—2011 (precipitation = 1848 mm).

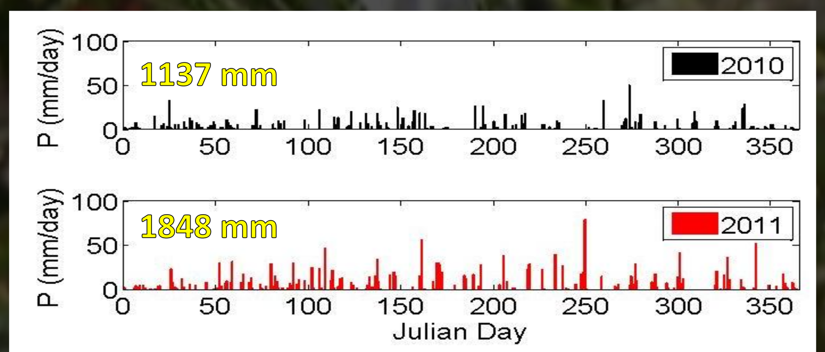

Figure 1. Left, hyetographs show the distribution of precipitation throughout the year for 2010 and 2011. Note the lack of seasonality. The large spike in 2011 at the end of August is Hurricane Irene. Precipitation data courtesy US Forest Service, collected at the Beardon Knob Meteorological station located in the research watershed.

RESEARCH QUESTIONS

1) How does precipitation variability affect the spatial heterogeneity of soil CO_2 efflux in a humid, temperate watershed?

2) Is the effect on carbon cycling uniform, or dependent upon landscape position, vegetation cover type, or the interaction of these variables?

STUDY SITE

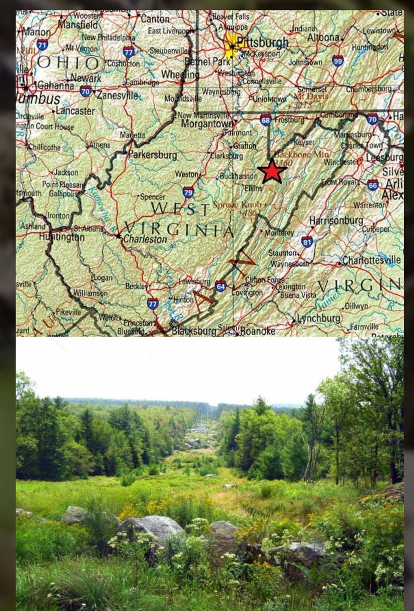

Figure 2. Above, Weimer Run (indicated by the red star), below, looking up into the watershed.

The Weimer Run watershed is a 373 ha watershed located near Canaan Valley, West Virginia. It has an elevation range of 950 – 1175 m (figure 3), a mean summer temperature of 17.1° C and a mean winter temperature of -3.5 ° C (NCDC). Mean annual precipitation is 1439 mm (1970-2010, PRISM). The soils are heavily acidic (3.5 – 4.1 pH), and the vegetation is secondary-growth, mixed-hardwood (red maple, yellow birch, red spruce, etc.) with a prominent shrub layer understory (rhododendron and mountain laurel).

METHODS

Soil CO_2 efflux, soil temperature at 12 cm, and volumetric water content were measured weekly during the growing season for 2010 and 2011 at three elevation levels (LOW, MID, HIGH) and under three vegetation cover types (CANOPY, SHRUB, OPEN)—a 3X3 factorial design with 3 replicates for 27 total plots. Soil chemical and physical properties were also evaluated.

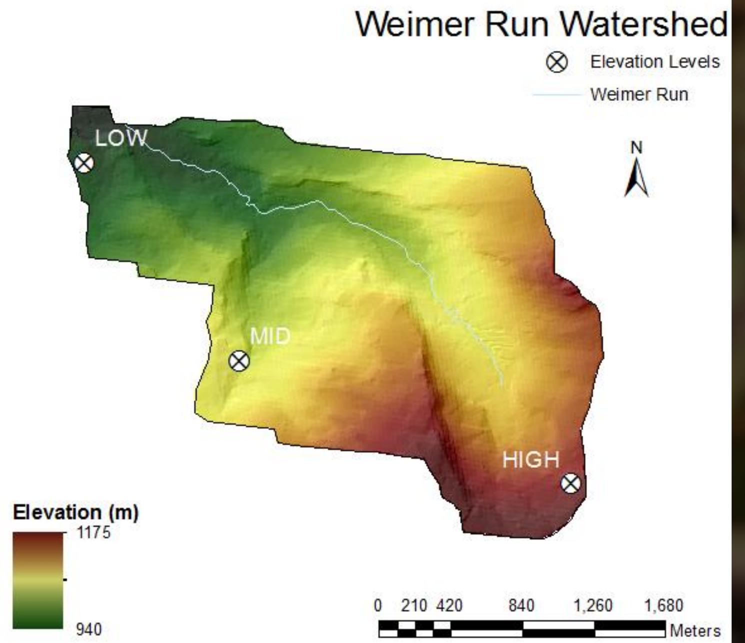

Figure 3. Weimer Run. Elevation levels indicated on map.

RESULTS

Soil CO_2 efflux measurements were statistically higher ($F = 10.15$; $p = 0.0016$) in 2010 and lower in 2011 for the entire watershed. There is a statistically significant elevation and year interaction effect ($F = 3.12$; $p = 0.0458$)—with all elevation levels registering higher measured rates of soil CO_2 efflux in 2010. Differences in soil moisture, here expressed as volumetric water content (VWC $m^3\ m^{-3}$), were highly statistically different across years ($F = 289.11$; $p = <0.0001$), while soil temperature differences among treatments were not significant. Soil moisture is strongly correlated with elevation in this system for both years.

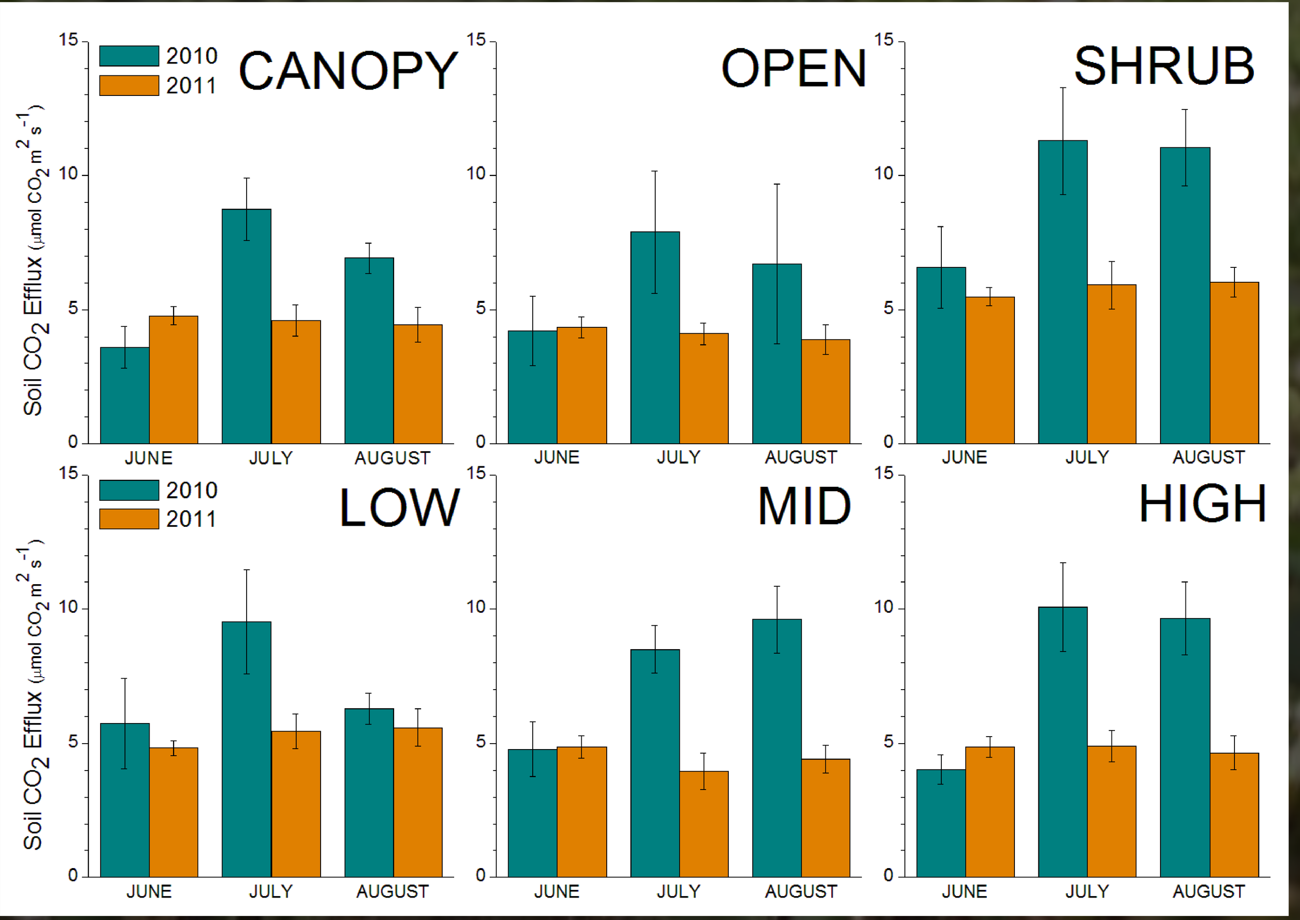

Figure 4. Soil CO_2 efflux by elevation (LOW, MID, HIGH) and by vegetation cover type (CANOPY,. OPEN, SHRUB) shown as a function of month and year for June – August, 2010 and 2011. Efflux values differ by year across vegetation types and as a function of elevation between dry and wet years. Bars indicated SE.

- Growing season soil CO_2 efflux rates were higher during the drier year (2010) and lower during the wet year (2011)—an effect more pronounced at landscape positions higher in the watershed.
- At higher soil moisture values, differences in soil CO_2 efflux rates among vegetation and elevation treatments diminish.
- Measured fluxes decreased by 42% for LOW, 44% for MID, and 42% for HIGH plots from 2010 to 2011.
- Measured fluxes decreased by 35% for OPEN, 38% for CANOPY, and 43% for SHRUB plots from 2010 to 2011.
- A strong vegetation effect is noticeable across all data—with SHRUB plots registering the highest rates of soil CO_2 efflux.

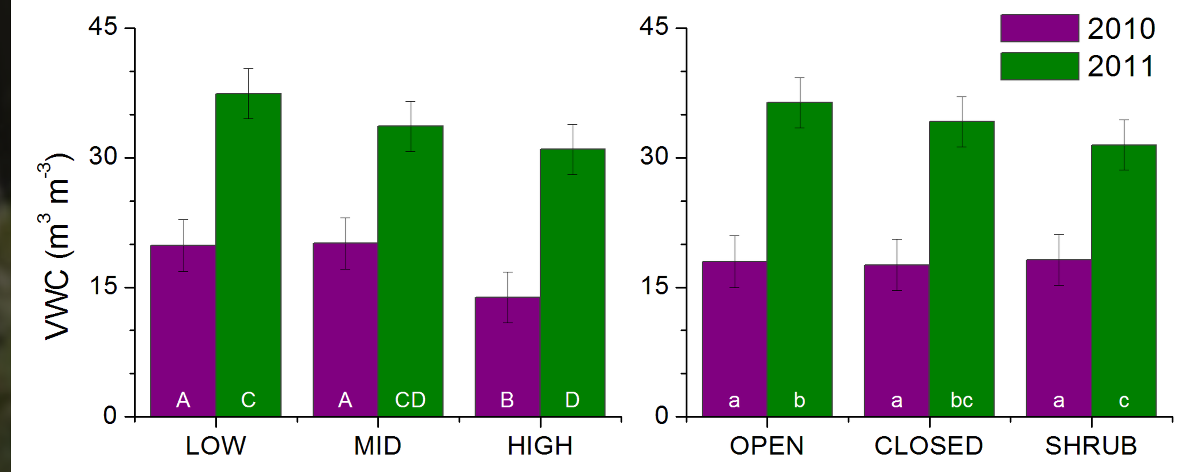

Figure 5. Volumetric water content by elevation (left) and vegetation cover type (right). Groups that do not share letters are statistically different. Note that for all treatment levels, VWC is higher for 2011. Bars indicated SE.

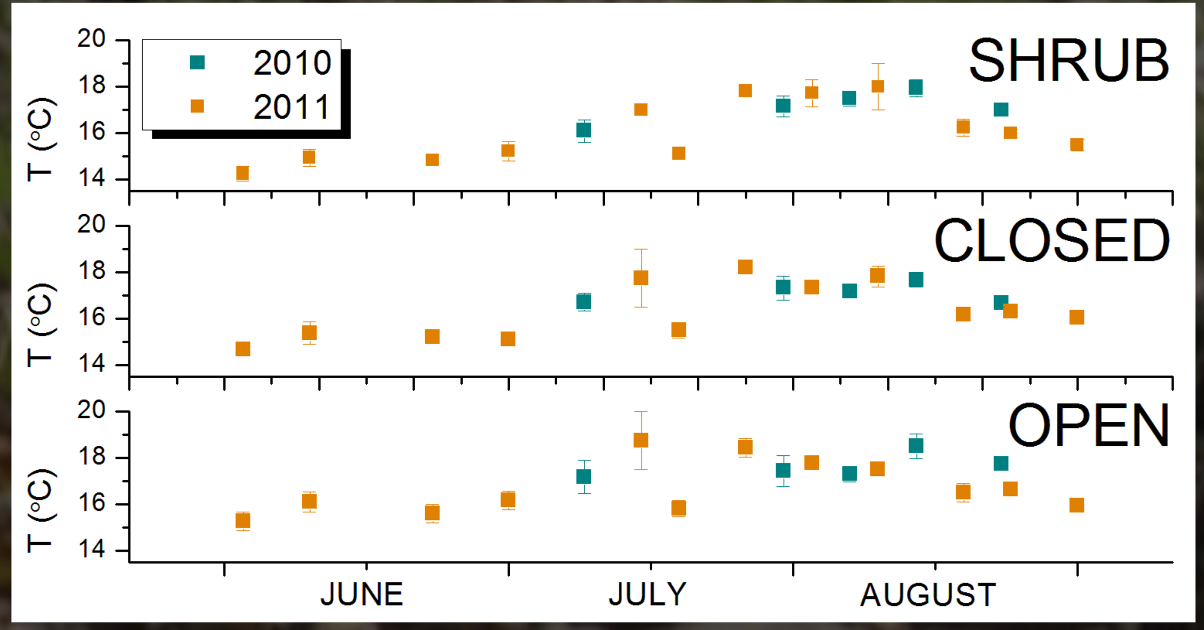

Figure 6. Soil temperature at 12 cm for growing season 2010 and 2011 data by vegetation cover type. There is no statistical significance for temperature between years. Bars indicate SE.

CONCLUSIONS

For semi-arid watersheds—where soil CO_2 efflux is often limited by available soil water—it has been shown that landscape heterogeneity results in the lateral redistribution of soil water, altering the magnitude and spatiotemporal variability of soil CO_2 efflux (Pacific et al. 2011; Riveros-Iregui et al. 2011). Our work shows that for humid watersheds:

- Soil CO_2 efflux is not limited by available soil water.
- Vegetation is the primary control on soil CO_2 efflux.
- Inter-annual precipitation variability influences carbon cycling—with wet years decreasing soil CO_2 efflux.
- During dry years, or periods of drought, the vegetation effect is more pronounced and soil CO_2 efflux rates increase differentially—SHRUB layer plots more so than other areas.
- During wet years, the vegetation effect, while still evident, is diminished and efflux rates are constrained.

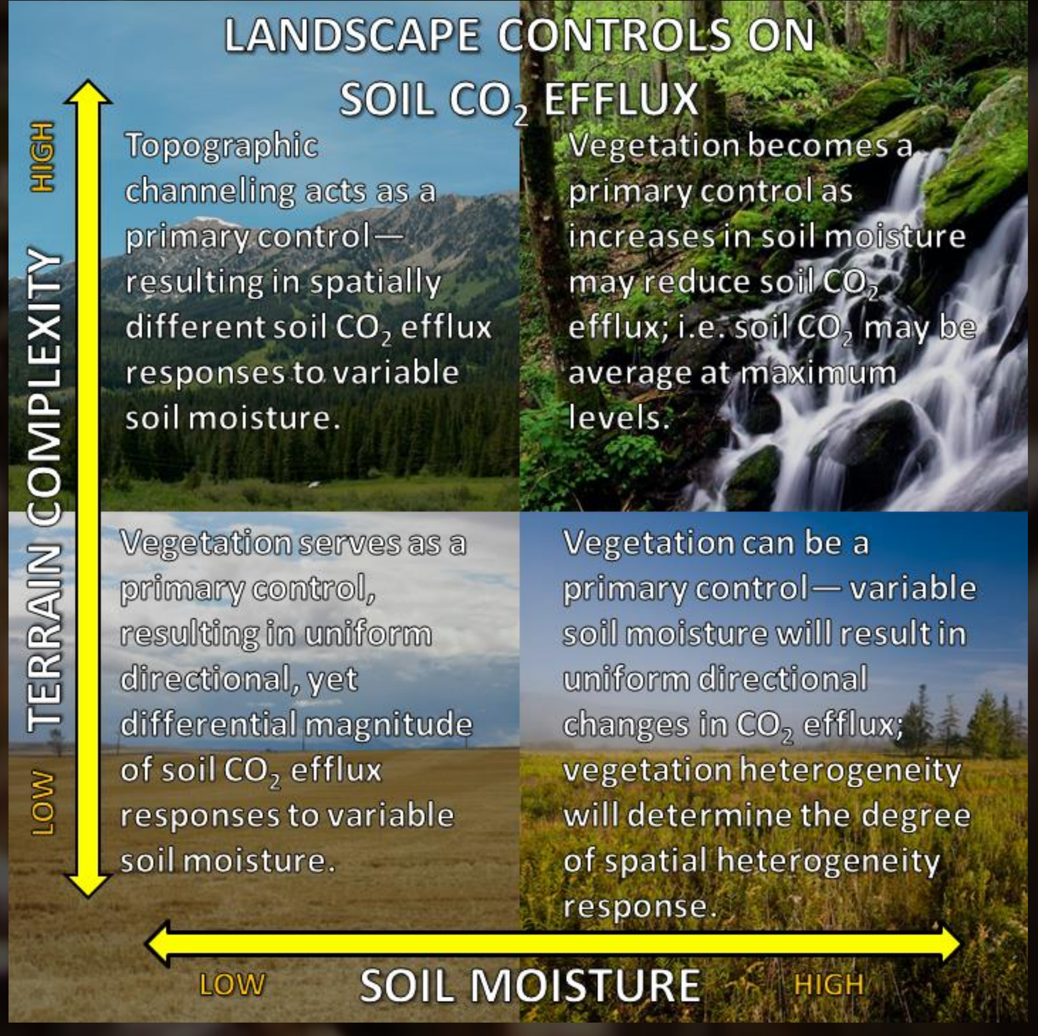

Figure 7. Impacts of variable soil moisture on soil CO_2 efflux as a function of landscape complexity.

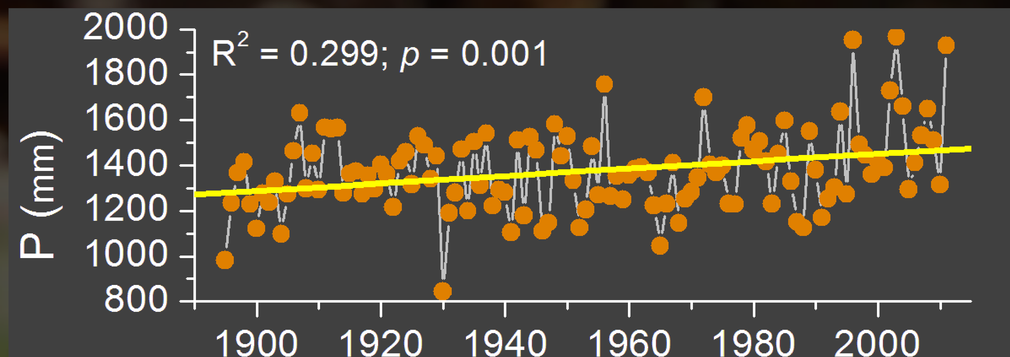

Figure 8. Long-term precipitation data (1895 – 2011; PRISM) for the Weimer Run watershed. The year-to-year variance is increasing, but not significantly.

FUTURE DIRECTIONS

- Evaluate soil moisture dynamics and their effect on carbon cycling further using a high-frequency sampling approach thanks to a grant from the Appalachian Stewardship foundation.
- Calculate and model soil pore space CO_2 concentrations and diffusion through the soil.
- Further examine soil chemical and physical properties among vegetation treatments and elevation levels.
- Quantify coarse fraction organic matter in the soil and evaluate soil C throughout the soil profile.
- Quantify the vegetation effect.

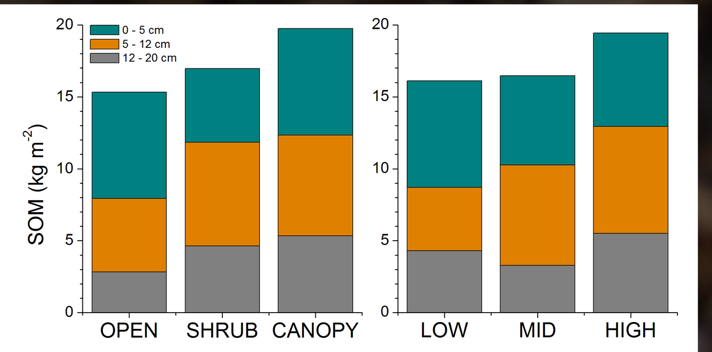

Figure 9. Soil organic matter (SOM) for the < 2mm soil fraction. for the 0 – 5, 0 – 12, and 0 – 20 cm soil depth profiles. SOM calculated using loss-on-ignition and profile specific bulk density values.

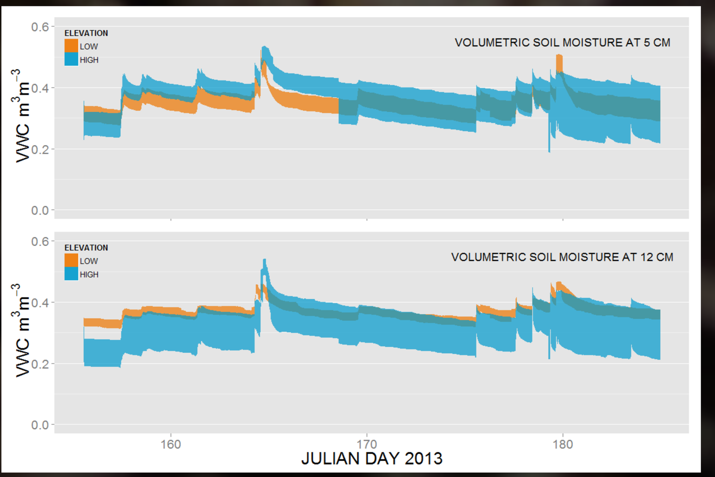

Figure 10. Volumetric water content measured every five minutes for a thirty day period in 2013 at two elevation levels (LOW and HIGH) and two soil depths (5 cm and 12 cm) using Decagon EC-5 soil moisture sensors. The range indicates the mean of 4-6 sensors plus/minus SE. Equipment funded through the Appalachian Stewardship foundation.

ACKNOWLEDGMENTS: Thanks to the Appalachian Stewardship Foundation, the Canaan Valley Institute, the University of Virginia Department of Environmental Sciences, the Shenandoah Watershed Study, WV DNR, USFS, Howard Epstein and the entire Epstein Lab Group, Jerrica Frazier, Sang Mee Ko, Trevor Klein, Stesha Dunker, Meg Miller, all others who helped with field and lab work, and my family (Annie, Gus, and Addison).

SOURCES: Pacfic, V, BL McGlynn, DA Riveros-Iregui, DL Welsch, HE Epstein. 2011. "Landscape structure , groundwater dynamics, and soil water content influence soil respiration . . . " HYDROLOGICAL PROCESSES 25, 811-827
Riveros-Iregui, DA, BL McGlynn, R Emanuel, HE Epstein. 2011. "Complex terrain leads to bidirectional responses of soil respiration . . ." GLOBAL CHANGE BIOLOGY 18, 749-756.

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