Susquehanna Shale Hills Critical Zone Observatory

All Hands Meeting Agenda and Abstract Volume

The Pennsylvania State University

University Park, PA

May 2015

SSHCZO All Hands 2015 Agenda

Sunday, May 10

Arrival of out of town participants

Monday, May11 Schedule for Dorothy Merritts

7:45am – 8:45am Breakfast with Sue Brantley – meet in lobby of Atherton Hotel

9:00am – 10:00am – research group – Nikki West, Sue Brantley, Roman DiBiase, 311 Hosler

10:30am – 11:45pm – research group – Eissenstat and others, 331 Forest Resources Building

12:00pm – 3:00pm – Field Trip with Dorothy Merritts to CZO, meet in front of EES Building – box lunches will be provided for participants (RSVPs due by noon May 6th)

4:00pm – 5:00pm – Featured Seminar by Dorothy Merritts ***"*****Lidar and Field Analysis of Periglacial Landforms and their Paleoclimatic Significance, Unglaciated Pennsylvania**" in ***114 EES Building***

5:00pm – 6:00pm Poster Session Set-up

6:30pm – Dinner with Dorothy Merritts – Nicole West, Roman DiBiase, and Paul Bierman

Tuesday, May 12th

ALL HANDS MEETING - 117 EES Building

800 – 830 Brantley: ***Welcome and Introductions and Intro to SSHCZO talks are to be 10-12 minutes followed by 5-7 minute Q/A session and 1 minute speaker switchover.***

830 – 9:15 Opening Poster Session

9:15am – 9:30am – Roman DiBiase – **Preliminary morphologic analysis of the Garner Run and Shavers Creek catchments, Susquehanna Shale Hills Critical Zone Observatory, PA**

9:30am – 9:35am – Discussion of Geomorphology and Soils

9:35am – 9:50am – Team H1 – **Detecting critical zone response to perturbations by climate and base level in central Pennsylvania using *in-situ* produced 10-Be and 26-Al** (Denn et al.)

9:50am – 9:55am – Discussion of H1

9:55am – 10:10am – Team H2 – **Update: The imprint of biota on acid- and redox-weathering hypothesis** (Kaye et al.)

10:10am – 10:15 am – Discussion of H2

10:15am – 10:30am – **CZO Data Management – Current Status & Future Plans** (Dan Arthur)

10:30am – 11:00am ***Break and Posters***

11:00am – 11:15am – Team H3 – **The influence of soil lithology on root morphology, architecture and mycorrhizas** (Eissenstat et al.)

11:15am – 11:20am – Discussion of H3

11:20am – 11:35am – Team H4 – **The soil macropore hypothesis** (Lin et al.)

11:35am – 11:40am – Discussion of H4

11:40am – 11:55am – Team H5 – **Understanding the Hydrogeochemical Process at the Watershed Scale: Insights from RT-Flux-PIHM Simulation** (Bao et al.)

11:55am – 12:00pm – Discussion of H5

12:00pm – 12:15pm – Team H6 – **Evaluating groundwater - surface water interactions along a headwater, sandstone stream using a fiber-optic distributed temperature sensor and geochemical analyses** (Hoagland et al.)

12:15pm – 12:20pm – Discussions of H6

12:30pm – 1:30pm ***Lunch and Discussions and Posters – 2217 EES Building***

Poster Session Available during Breaks and Lunch:

- **Using the Shale Network to Train Future Scientists** (Jennifer Williams/students)
- **The Tree Water Isoscape of a Central Pennsylvania Catchment: Ecohydrologic Patterns and Processes** (Gaines et al.)
- **Iron mobilization and transport through the bottom of the critical zone to the stream** (Kim and Brantley)
- **Development of RT-Flux-PIHM: A Coupled Hydrological, Land Surface, and Reactive Transport Model** (Bao et al.)
- **A watershed scale estimation of regolith transport and landscape evolution in the Shale Hills CZO using a new generation landscape evolution model (LE-PIHM)** (Zhang et al.)
- **Exploring the Influence of Topography on Belowground C Processes Using a Coupled Hydrologic Biogeochemical Model** (Shi et al.)
- **Implementation of the COsmic-ray Soil Moisture Observing System (COSMOS) in SSHCZO: a Non-invasive, Landscape Scale Measurement** (Xiao et al.)

- **Data visualization and sonification** (Matt Kenney, Sue Brantley, Nikki West)
- **Nitrogen Balance of the Shale Hills Catchment** (Weitzman and Kaye)
- **Insights on deep critical zone evolution from seismic refraction surveys in the Susquehanna Shale Hills Critical Zone Observatory** (West et al.)
- **CZ-Tope: An initiative to use multiple isotopes to quantify Critical Zone processes** (Steinhoefel et al.)
- **Testing Macropore Hypothesis in the SSHCZO** (Lin et al.)

1:30am – 1:50pm – **Instrumentation at SSHCZO** (Brandon Forsythe)

1:50 pm – 2:05 pm – Team H7 – **Simulating and observing carbon stocks and fluxes at the Shale Hills catchment: Progress towards an integrated hydromet-terrestrial carbon cycle data assimilation system** (He et al.)

2:05pm – 2:10pm – Discussion of H7

2:10 pm – 2:25 pm – Team H8 – **Understanding Hydrologic & Energy Processes at Garner Run Using PIHM-MF: A Physically Based hydrologic model system** (Xiao et al.)

2:25 pm – 2:30pm – Discussion of H8

2:30pm – 2:50pm – Team H9 - **Designing a Suite of Models to Explore Critical Zone Function** (Duffy et al.)

2:50pm – 2:55pm – Discussion of H9

3:00pm – 3:30pm ***Break and Posters***

3:30pm – 5:00pm – Discussion: Intra – CZO and Inter – CZO Science Opportunity (pop-ups welcome)

Facilitator – Ken Davis

Notes – Sue Brantley

5:00pm – 5:30pm – Feedback from Dorothy Merritts – Observations of the SSHCZO

6:00pm – Happy Valley Brewing Company – for Happys

Wednesday, May 13th – travel day or additional meetings with PSU faculty/students

The 9 original hypotheses

H1 - ***Feedbacks among frost shattering, weathering reactions, and the evolution of topography have resulted in an asymmetric distribution of fractures that in turn controls the observed differences in fluid flow in the subsurface between the sun-facing and shaded sides of catchments within Shale Hills and much of the Susquehanna River Basin.*** *(Kirby, Bierman, Singha, Brantley, Lin)*

H2 – ***The distribution of weathering reactions across a landscape can be described as a function of biotic and abiotic production and consumption of acids (CO_2, DOC) and O_2.*** *(Kaye, Brantley, Eissenstat, Li)*

H3 – ***Trees with deeper roots (oaks) are associated with less frequent tree throw, slower hillslope erosion rates, fewer vertical macropores, faster weathering at depth, and deeper regolith than trees with shallower roots (maples).*** *(Eissenstat, Davis, Kaye, Brantley)*

H4 – ***Macropores are important in controlling fluid flow and chemistry in soils derived from various lithologies, but the nature and effects of these macropores differ significantly among shale, calcareous shale, and sandstone.*** *(Lin, Duffy, Eissenstat, Davis)*

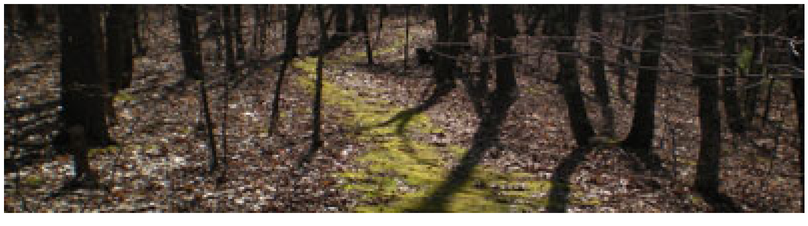
H5 – ***Greater evapotranspiration on the sunny, north side of Shale Hills means that less water recharges to the stream, explaining why Mg and other cations are less depleted in the regolith on the north compared to the south hillslopes.*** *(Li,Brantley, Kaye, Gooseff)*

H6 - ***Ions that are released quickly from ion exchange sites (Mg, Na, K) throughout the catchment demonstrate chemostatic behavior (~constant concentration in the stream), whereas Fe, Mn, and DOC concentrations vary with changes in watershed-stream connectivity.*** *(Gooseff, Brantley, Li, Kaye, Duffy)*

H7 - ***Land-atmosphere fluxes of carbon (C)and water, ground-water hydrology, and ecosystem change are coupled processes at time scales of months to decades. This coupling varies with the lithology and land use and position on the hillslope***. *(Davis, Eissenstat, Duffy, Lin, Kaye)*

H8 - ***Co-located, intensive, relocatable measurements of soil moisture, tree sap flux, sapwood area, LAI, ground water depth, temperature, ^{18}O and D/H along with a 4-component radiometer, laser precipitation monitor and landscape-level soil moisture (COSMOS) can be assimilated within a multi-scale distributed modeling framework to project physical processes from Shale Hills to Shavers Creek to YWC and Snake Creek watersheds.*** *(Duffy, Davis, Eissenstat, Lin)*

H9 - ***Increasing atmospheric CO_2 in the future will cause higher temperatures and faster weathering of clays in the catchment, increasing streamwater solute loads.*** *(Brantley, Godderis, Li, Duffy, Davis)*



Lidar and Field Analysis of Periglacial Landforms and their Paleoclimatic Significance, Unglaciated Pennsylvania

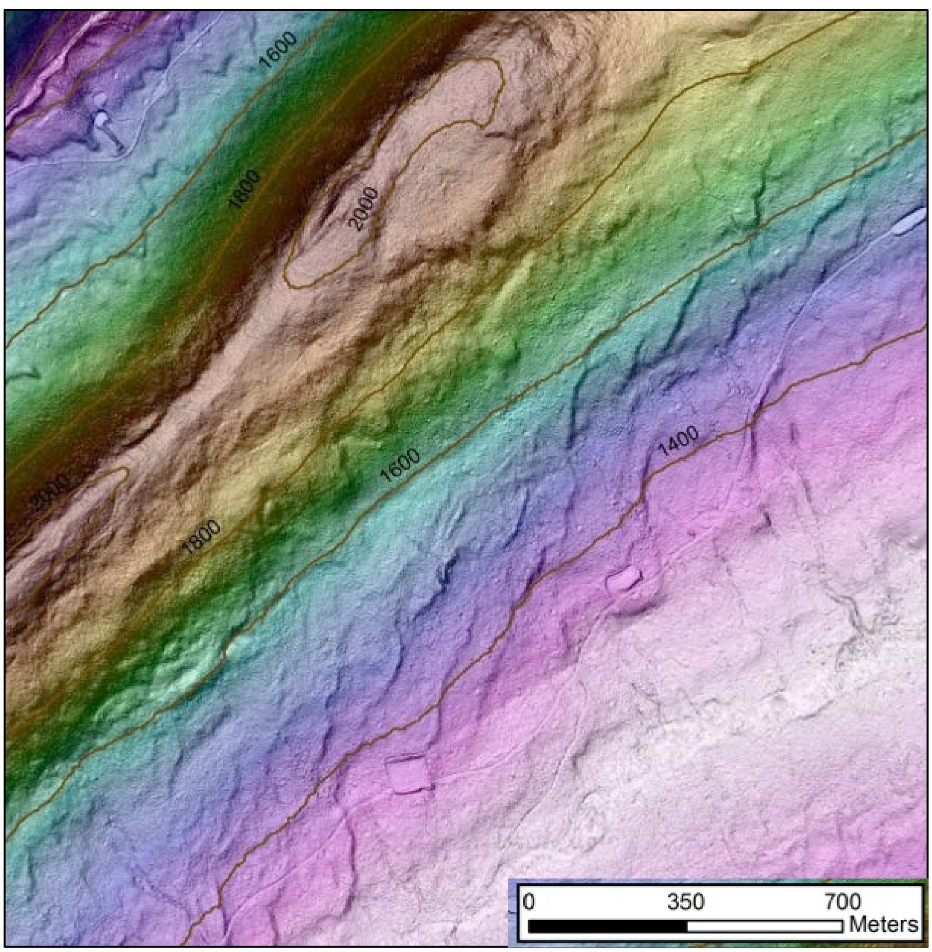
Authors: Dorothy Merritts[1], Robert Walter[1], Aaron Blair[1], Kayla Schulte[1], Noel Potter[2], Sam Alter, Erin Markey, Ben Weiserbs, and Sally Guillorn

[1] Franklin and Marshall College, Department of Earth and Environment, Lancaster, PA 17604-3003
[2]Emeritus, Dickinson College, Department of Geology, Carlisle, PA 17013

The advent of high-resolution orthoimages, topographic datasets acquired with lidar, and GPS surveying offers opportunities to map relatively fine-scale landforms, even where forested, over broad areas. Using all three technologies, we are compiling a statewide GIS database of periglacial landforms south of Pleistocene full glacial ice margins in Pennsylvania. Results from our fieldwork, which includes backhoe trenching and vibra-coring, are combined with this GIS database and previous research to evaluate the use of periglacial landforms as paleoclimatic indicators. In particular, we search for periglacial landforms that are diagnostic of the former existence and degradation of permafrost, which is ground that remains at or below the freezing point of water (0° C) for two or more consecutive years and which has an uppermost seasonally thawed active layer (typically ≤0.5 m thick). Continuous permafrost exists today in regions with mean annual air temperatures (MAAT) less than approximately -6° to -8° C, and discontinuous permafrost occurs in regions with MAAT less than approximately -0.5° C to -2° C. The boundaries of continuous and discontinuous permafrost have shifted south and north with multiple cold glacial to warm interglacial climate cycles during the Quaternary Period (~2.6 million years to present), and the last glacial maximum (LGM) extended from 26.5 to 19-20 ka.

We have identified the following evidence of permafrost throughout Pennsylvania, at all altitudes: 1) extensive networks of thermal contraction polygons on shale hills and side slopes; 2) thick, ubiquitous gelifluction sheets and lobes on quartzite, sandstone, and diabase ridges and side slopes (continuing downslope over shale benches at many locations); and 3) several pingos in valley bottoms. In addition to these landforms, we document two others—retrogressive thaw slumps and thermokarst gullies--that are common in regions of *permafrost thaw* today. Our radiocarbon dating, combined with paleoseed analysis, indicates that valley bottom wetlands became established on periglacial rubble (including extensive, low-gradient colluvial debris aprons and tributary fans) and thermokarst features after permafrost thaw during the late Pleistocene, and that in many locations these wetlands persisted throughout the Holocene until European settlement. Wetland (hydric) soils are still preserved at numerous locations where buried beneath historic sediment that was shed from hillslopes and trapped in valley bottoms as a result of land clearing, farming, and mill damming that began in the 1700s.

Figure caption: (Top): Gelifluction lobes and sheets along the slopes of the Tien Shan Mountains, Kyrgyzstan. Note that lobes widen downslope, becoming sheets, and in the valley bottom become much broader sheets with thermokarst features. Photographer and copyright: Marli Miller, University of Oregon (http://marlimillerphoto.com/). (Bottom) Lidar-derived (LAS files) slopeshade on color-shaded DEM showing solifluction lobes and sheets along the north- and south-facing slopes of Nittany Mountain, approximately 40 km south of the LGM maximum ice limit, near Madisonburg, central Pennsylvania. Lobes are better developed on the south-facing slope, and become longer and wider downslope. On the south-facing slope, lobes become sheets that trend become oriented obliquely with respect to slope. At this location, Nittany Mountain is the northern limb of a syncline. Sandstone dipping south along the ridge crest is the Silurian Tuscarora Formation; mid-slopes and valley bottom are Silurian Clinton Group (sandstone and shale). Lobes along mid-slope contain Tuscarora sandstone from the ridge crest area.



1600
1800
2000
2000
1800
1600
1400
0
350
700
Meters

Preliminary morphologic analysis of the Garner Run and Shavers Creek catchments, Susquehanna Shale Hills Critical Zone Observatory, PA

Roman A. DiBiase[1]

[1]*Department of Geosciences, Pennsylvania State University, University Park, PA 16802*

Catchment morphology exerts a first-order control on the fluxes of water, sediment, and solutes through the landscape. At the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO) in central Pennsylvania, the topography of the Shavers Creek watershed (160 km^2) reflects a complex history of lithologic, climatic, and base level controls on surface processes. Such complexities were minimized in the initial phase of the SSHCZO project, which focused on the small sub-catchment of Shale Hills (0.1 km^2). Now, as the project expands to encompass the entirety of Shavers Creek, careful attention must be paid to explicitly accounting for spatial heterogeneities in rock type, local base level control, and the imprint of Pleistocene periglacial processes. Here I present a preliminary morphologic analysis of Shavers Creek, using a 1 m resolution lidar digital elevation model (DEM) derived from airborne laser swath mapping. From this analysis emerge three important considerations for interpreting critical zone processes. First, the lidar DEM enables efficient, high resolution mapping of bedrock geology within the Shavers Creek watershed. In addition to prominent differences in drainage density and relief between different geologic units (Figure 1), the subtle topographic expression of bedding planes enables measurement of stratal geometries that would otherwise be difficult to determine in the field due to poor exposure. Second, analysis of stream longitudinal profiles reveals a prominent knickpoint on Garner Run that isolates the sub-catchment from the mainstem of Shavers Creek, and lines up with regional patterns. In contrast to Shale Hills, the hillslopes at Garner Run are less steep, despite having more resistant underlying bedrock (quartzite vs. shale). Erosion rate data from nearby analogous catchments indicate that this difference is mainly due to a 3-4 fold difference in the rate of base level fall of streams. Third, the lidar DEM shows abundant periglacial landforms that are interpreted as Pleistocene relicts, including solifluction lobes, boulder fields, and landslides. The presence of such features indicates that this landscape is decidedly not in steady-state, but the timescale and degree of this transience is unclear. Addressing the above challenges will require a combination of fieldwork, geochemical analysis, and shallow geophysical surveys to map the subsurface critical zone architecture and establish the timing of landscape evolution. In addition to informing boundary conditions for integrated critical zone flux models, the outcomes of this work will provide insight into untangling the roles of climate, tectonics and lithology on landscape evolution.

Detecting critical zone response to perturbations by climate and base level in central Pennsylvania using *in-situ* produced 10-Be and 26-Al

A. Denn, P. Bierman, N. West and E. Kirby

Studying the production and transport of regolith is essential to understanding the structure and processes operating within the critical zone. This project, will employ measurements of *in-situ* produced cosmogenic 10-Be and 26-Al to investigate the influence of glacial/interglacial climate cycles and changes in base level on regolith development rates and ages in central Pennsylvania. By widening our lens from the original 8 hectare site at the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO) to different lithologies and other areas in the Valley and Ridge province, we make progress toward understanding the critical zone processes that govern evolution of the Susquehanna River Basin as a whole. We are investigating three sites.

Garner Run, is a HUC-12 watershed within the SSHCZO Shavers Creek research area. The upper reaches of this drainage are dominated by talus, coarse-grained regolith of the Tuscarora Juniata Formation, likely to have been generated by processes that are no longer active in the contemporary climate regime. Investigation at this site will focus on understanding the influence of periglacial activity on the generation and movement of mass through the critical zone.

Blockfields are ubiquitous features of the Valley and Ridge province in Pennsylvania, and our second site, the blockfield at Hickory Run State Park, is the largest of its kind in the eastern United States. The field is thought to have developed from frost-induced weathering processes during the last glacial maximum, but no data exist on the age of this feature, how the field developed, or if it remains active. Ours will be the first quantitative attempt at constraining the age and dynamics of an Appalachian blockfield.

In order to understand the effect of baselevel change on the residence time of material in the critical zone, we will study Young Womans Creek, which has deeply incised its sandstone basin. Here, we will focus on the influence of base level on regolith, contrasting undissected uplands with incised valleys. By collecting sediment from the entire drainage network across a range of sub-basin slopes we aim to address the control that non-equilibrium topography exerts on the rate of regolith generation at a basin scale. Ours will be the first detailed analysis of incision rates and knickpoint distribution in a small Appalachian watershed.

Update on H2: The imprint of biota on acid- and redox-weathering hypothesis

Kaye, J., S. Brantley, D. Eissenstat, E. Hasenmueller, X. Gu, T. Adams, and L. Hill

We are ostensibly testing the hypothesis that the distribution of weathering reactions across a landscape can be described as a function of biotic and abiotic production and consumption of acids (CO_2, DOC) and O_2. Our prior work in Shale Hills documented high pCO_2 in the bottom of the soil profile of swales and the valley floor, which are the deepest and wettest soils in that landscape. More recently (fall of 2013) we excavated pits along a catena in a catchment near Shale Hills to characterize the role of roots and organic acids (dissolved organic carbon) in weathering shale that underlies augerable soil. We also sampled soil gas in intact soils adjacent to these pits. As expected, root density declined rapidly with depth, but roots were present even in the deepest, least weathered shale that we sampled. There appears to be a greater density of roots in rock fractures in the shallow, ridgetop soils. In all catena positions, roots in the rock fractures had comparable respiration rates to roots in upper portions of the profile.

The rocks near these deep roots had chemical compositions that resembled parent material, while bulk soil in A, B, and C horizons were depleted in elements (K and Mg) that reflected characteristic weathering of illite and chlorite in shale ultimately to kaolinite. Furthermore, comparing ratios of K and Mg to one element that is mobile mainly in particles (Al) and a second element that is immobile in soil (Zr) suggests that half of the K and Mg in surface soils was lost as eroding particles.

Soil was also present in rock fracture planes where roots were found. This fine material was mineralogically similar to surface soils and may have resulted from particulate movement from surface soils downward. Soil in these rock fractures was similar to B and C horizons in their concentrations of total C, total N, dissolved organic carbon, and potentially mineralizable C. Concentrations of extractable ammonium and nitrate may be higher in rock-crack soils than in surface soils.

Overall, these data suggest that soils and roots at the root-rock interface seem qualitatively similar to roots and soils in surface horizons. The main difference with depth seems to be that there are simply fewer roots and less soil. A next step is to couple root and microbial respiration estimates to model deep soil CO_2 production and O_2 consumption rates and confront these estimates with measured patterns in soil pCO_2 and O_2.

Work over the past year has focused on expanding soil pore fluid (gas and solution) monitoring to a sandstone site. By comparing shale and sandstone we will test whether patterns documented by our shale monitoring are robust in another rock type. We installed continuous sensor and manual samplers for CO_2 and O_2 in both rock types at the midslope position of the north and south facing slopes. At the ridgetop and valley floor positions we installed only the manual samplers. Comparisons of the shale and sandstone catenas will commence in summer 2015.

Dan K. Arthur
Susquehanna Shale Hills Critical Zone Observatory
CZO All-Hands Meeting
May 12, 2015

CZO Data Management – Current Status & Future Plans

Investigators in the Susquehanna Shale Hills Critical Zone Observatory collect and produce a large amount and wide variety of data. These data include observations and measurements of meteorology, hydrology, soil and water chemistry, geophysics, and biological processes. A centralized data management process has been developed that will allow researchers efficient access, control, processing, sharing, archiving, and other uses of these diverse datasets. The process described covers data management for current and future uses of the Shale Hills field area, as well as for other locations being set up in the Shavers Creek watershed (Garner Run/Sandstone Site, Shavers Creek). It also conforms to national CZO network goals including sharing of data and/or metadata with the San Diego Supercomputing Center (SDSC) Geoportal and the CUAHSI Hydrologic Information System (HIS) where appropriate.

Current status of available CZO data is also described. Datasets available on the local PSU-hosted web site are also available through the national CZO network web site at criticalzone.org: Watershed Reanalysis (1990-2010), Streamflow (2006-2012), Groundwater (2009-2012), Precipitation (hourly and daily, 2006-2013), Real-Time Hydrology (RTH) Network Soil Moisture (2009-2012), Land/Atmosphere Fluxes (2009-2014), Hydropedologic Properties (2007-2013), LPM Disdrometer (2009-2014), Sap Flow (2009-2014), Flux Tower Meteorology (2009-2013), LIDAR (leaf-off and leaf-on), LIDAR-Derived (DEM, Density, and Hillshade), Bedrock Elevation (2014), Tree Survey (2008, 2012), Geodatabase (GIS), Soil Gas (2008-2010, 2013-2014), Gamma Logs (2012), Seismic Refraction & Surface Wave Analyses (2013), Shavers Creek Discharge & Water Chemistry (2014), Shavers Creek Surface & Groundwater Chemistry (2014), Aqueous Geochemistry (ground, soil pore, and stream water; 2006-2011), Stable Isotope Hydrology (precipitation, stream, ground, and soil water; 2008-2011), Tree Tracer Study (2012), Root Length Density (2013), Tree Isotope Chemistry (2011, 2014), Model Input Soil Parameters (2014), Distributed Temperature (DTS; 2014), and Ground Penetrating Radar (2008). Metadata for these datasets have been harvested by the SDSC Geoportal except where such metadata are currently incompatible with the current Geoportal data model and database structure).

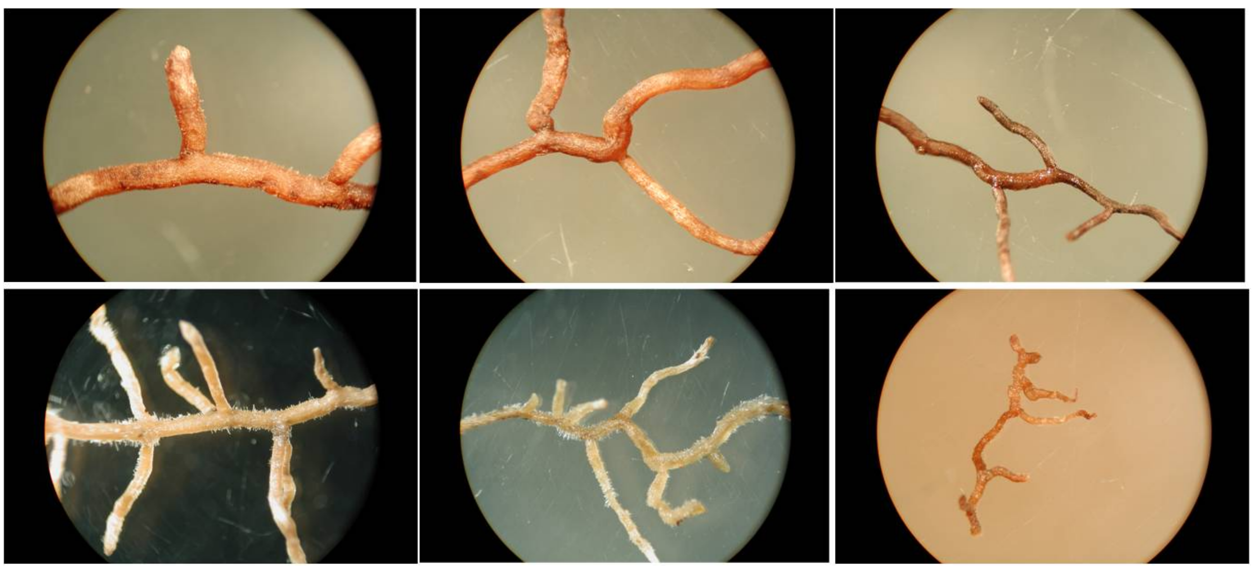
Sensor-based data from Shale Hills are transmitted in batches to a SQL Server database currently storing and archiving data: Eddy Covariance Flux Tower, Hourly and Daily Precipitation, RTH1 Soil Moisture (VWC) and Temperature. Other data currently require site visits to download due to wireless communication issues. Web pages for accessing batch sensor data, including controlled access for embargoed data and flexible queries, will be demonstrated.

The influence of soil lithology on root morphology, architecture and mycorrhizas

Eissenstat David M, Szink, Ishmaiel J., Ward, Jessie, Chen, Weile, Adams, Thomas S, Stottlemyer Aaron.

Department of Ecosystem Science, Penn State University

Tree species vary widely in root morphology and architecture, and in colonization by mycorrhizal fungi. There is great interest in identifying plant traits that can help predict ecosystem processes such as root turnover and plant nutrient acquisition. However, it is unclear to what extent environment may shape root functional traits. Roots from the O horizon, A horizon and B horizon will be collected from at least four canopy-dominant tree species that differ in their mycorrhizal type (Arbuscular, AM and ectomycorrhizal EM) at three shale sites and three sandstone sites in Pennsylvania. Root traits measured will include root diameter, specific root length, tissue density, root N concentration and mycorrhizal colonization by root branching order. Fungal species will be identified using Next Gen sequencing techniques. From these data, we will assess the degree species traits are conserved across different parent materials and soil depths.



The soil macropore hypothesis***: GPR survey at the Garner Run Hillslope*** (*team personnel: Henry Lin, Jianbin Lai, Hailong Yu, Yuan Wu, Neil Xu, Jim Doolittle)*

A field investigation was completed using a ground penetrating radar (GPR) to map the depth to bedrock in the Garner Run hillslope near the three major monitoring sites. Multiple GPR traverses were completed and a distance-calibrated survey wheel with encoder was used to provide greater control of signal pulse transmission and data collection. In order to surface normalize the radar records collected, relative elevation data were collected at major slope breaks along the traverse line with an engineering level and stadia rod.

A traverse line was established that ascends Leading Ridge in essentially a west to east direction from near Garner Run to the summit, running from about 494 to 588 meters above sea level. The traverse line was cleared of debris but the ground surface remained highly irregular with numerous rock fragments and exposed tree roots. These obstacles often halted the movement and caused poor coupling of the antennas with the ground. In this study, flags were inserted in the ground at noticeable breaks in the topography along the traverse line. The elevations of these points were determined and used to "surface normalize" or "terrain correct" the radar records.

Figure 1 shows the surface-normalized plots of the data that were collected with the 400 MHz antenna as it was pulled down Leading Ridge from the summit area to near Garner Run. In these plots, the distance scale is measured from the summit area to near Garner Run. Based on a total of 14,748 soil-depth measurements from ~400 m long GPR images, the interpreted depth to bedrock averaged 1.37 m, with a range of 0.58 to 2.42 m, along this traverse line.

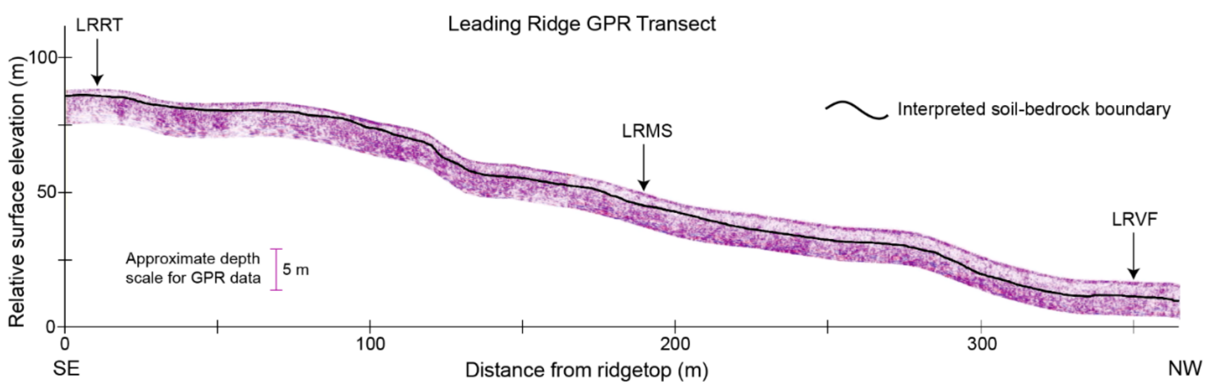


Figure 1. A continuous GPR record along the traverse line from LRRT to LRMS to LRVF. The radar records are arranged (from top to bottom) in order of decreasing elevation from the ridge top down to the valley floor. All scales are expressed in meters. The vertical scales provide only a relative measure. *Surface Normalization* was applied to the radar records to adjust the vertical scale to the general topographic form. Because of the large relief (about 94 m from ridgetop to valley floor), the elevation data were reduced (by a factor of 4) prior to running the *surface normalization* procedure. In addition, the vertical scale was set to 1:4 and compressed during *surface normalization*. These steps were necessary to view the entire "surface normalized" radar record and to prevent it from "running-off" the top and the bottom of the display window.

Understanding the Hydrogeochemical Processes at the Watershed Scale: Insights from RT-Flux-PIHM Simulation

Chen Bao[1], Li Li[1,2*], Yuning Shi[3, 2], Pamela Sullivan[4], Susan Brantley[2]

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[3] Department of Ecosystem Science and Management, The Pennsylvania State University, University Park, PA 16802

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Abstract

We developed an integrated reactive-transport-land-surface-hydrologic model to understand the complex coupling between the hydrological and geochemical at SSHCZO. The model was calibrated using the hydrological and geochemical field measurements in 2009. The model captures the temporal evolution and spatial distribution of the non-reactive chloride and the reactive magnesium, a key indicator of clay dissolution, in stream mouth and within six lysimeter nets. Simulation suggested that chloride concentration in stream mouth as well as in pore water was highly correlated to water storage, a measure of the water content in the watershed. Concentration of chloride increased when pore water was evaporated and water storage decreased in summer. Intensive rainfall events in the fall flushed high concentration chloride trapped in pore water and created a concentration spike in the stream mouth. Cation exchange reactions strongly controlled the magnesium concentration in pore water, leading to smaller spatial variations across the watershed compared to chloride. Model suggests magnesium was more enriched in cation exchanges sites in valley floor and swales than in other places, which is consistent with field measurement. Clay dissolution was primarily regulated by effective water-rock contact regulated by the water availability, which is in turn controlled by seasonality, solar radiation and topography. Our simulation suggests that in 2009 with modest precipitation, the clay dissolution rates in north and south slopes are not significantly different (less than 3.00%). However, it is still possible that over geological time scale, extended period of drier weather conditions can lead to significantly less water availability in the north slope, resulting in less clay dissolution and elemental depletion.

Evaluating groundwater - surface water interactions along a headwater, sandstone stream using a fiber-optic distributed temperature sensor and geochemical analyses

Beth Hoagland, Graduate Student, The Pennsylvania State University
Tess Russo, Assistant Professor, The Pennsylvania State University

Before determining anthropogenic changes to water chemistry, it is necessary to constrain natural influences on stream solute behavior. In areas unaffected by human disturbance, lithology and the extent of hyporheic exchange strongly influence water chemistry. Identifying zones of hyporheic exchange, which involves mixing of shallow groundwater and surface water, is often challenging in headwater environments. This study combines fiber-optic distributed temperature sensing (FO-DTS) and geochemical methods to map hyporheic exchange along a first-order, sandstone stream in the Appalachian mountains of central Pennsylvania. The objectives of this study are to (a) compare FO-DTS and geochemical methods in the context of groundwater-surface water interactions on sandstone streams, and b) determine the relative influence of groundwater discharge and hyporheic exchange on stream water chemistry. The study was conducted at Garner Run, which flows through the northeast-southwest trending Ridge and Valley Physiographic Province. We deployed a FO-DTS along 800 m of Garner Run to identify locations of groundwater inflow. FO-DTS results were then used to identify surface water sampling locations for geochemical analyses. Samples were collected and analyzed for major ions, alkalinity, and dissolved organic carbon.

Geomorphic characteristics of the stream channel create an extensive hyporheic zone, which is confirmed in geochemical and FO-DTS data. Evidence from the FO-DTS reveals discharge increases downstream along the stream reach due to groundwater inflow. A distinct geochemical signature confirms the location of groundwater inflow. Groundwater discharge has the potential to dilute stream solutes, transport ions to the stream from upslope, and drive ion exchange. Groundwater-surface water interactions result in changes to inorganic and organic water chemistry at Garner Run. Subsurface flow-paths deliver sandstone weathering products to Garner Run and affect solute export to the greater Shaver’s Creek Watershed.

Instrumentation at SSHCZO

Brandon Forsythe

Earth & Environmental Systems Institute, Penn State University

Instrumentation for SSHCZO is continuing to move forward with new sensor systems being deployed at Shale Hills, along Shavers Creek, and at Garner Run. Soil moisture and soil gas sensors are installed along a 4-location catena at Shale Hills and the new sandstone forested site. Sap-flow, dendrometer bands, leaf litter traps, and leaf area index measurements are planned at the sandstone sites. A cosmic-ray probe will be installed in Garner Run after Rothrock State Forest permit is approved. A new micrometeorological array will be installed at the sandstone site at the radio towers on Tussey Mountain. Streamflow and water chemistry sensors continue to be in operation along Shavers Creek above and below Lake Perez, Shavers Creek Outlet, and Garner Run sites. An agriculture site is being planned. These sensors and our future data collection regime will be presented.

Simulating and observing carbon stocks and fluxes at the Shale Hills catchment: Progress towards an integrated hydromet-terrestrial carbon cycle data assimilation system

Yuting He, Kenneth Davis, Yuning Shi, David Eissenstat, Jason Kaye, Margot Kaye, Henry Lin, Armen Kemanian, Lexie Orr, Lauren Smith, Yuan Wu

Groundwater hydrology and terrestrial ecosystems are part of the coupled carbon and water cycle in the Shaver's Creek watershed. Our group is working to create an integrated model-data synthesis system that can be used to understand the carbon and water cycles of the watershed and predict its responses to future climate and land use change. Towards that end we are 1) expanding carbon flux and stock observations at Shale Hills catchment, 2) building a coupled hydrologic-terrestrial carbon cycle numerical modeling system, and 3) testing the degree to which a widely-used terrestrial carbon cycle model can simulate the carbon stocks and fluxes observed within the Shale Hills catchment.

Observations of above ground carbon stocks and productivity, soil carbon stocks, leaf area index and catchment-wide net ecosystem-atmosphere carbon fluxes have been collected at the site. Observations are being expanded to include root growth, soil carbon dioxide, and soil and leaf chemistry. Biomass measurements show moderate sensitivity to position on the landscape. Tree height is particularly sensitive to topographic position. Net ecosystem productivity is fairly high in this watershed. Discrepancies between dendrometer and eddy covariance data may be due in part to drainage flows biasing nocturnal respiration measurements.

A process-based biogeochemical model, Biome-BGC, is being merged with the Flux-PIHM hydrometeorological model. The coupled modeling system will include groundwater hydrology, soil hydrology, and surface energy balance from Flux-PIHM and ecosystem carbon stocks and fluxes, ecosystem nitrogen cycling, and plant transpiration from Biome-BGC. The coupled system simulates mechanistically detailed interactions among carbon, nitrogen, and water cycles of the watershed.

Biome-BGC must be calibrated and adapted to simulate the terrestrial carbon cycle at high spatial resolution. Biome-BGC, driven with observed soil and atmospheric conditions, has been used to simulate carbon pool sizes and fluxes and evaluated with the multivariate observations available at the Shale Hills. Whole-plant mortality rate was found to be most important for simulating the vegetation carbon pool, and the decomposition rate of the recalcitrant soil carbon pool has the greatest impact on the soil carbon pool size. Sensitivities of Biome-BGC to soil moisture and soil temperature were also analyzed to test the model's ability to reflect the spatial pattern of carbon budget at the Shale Hills. Soil moisture dominates the sensitivity of the system. When soils are relatively dry, litter carbon pool and soil carbon pool sizes increase with soil moisture; but when soils become wetter, litter and soil carbon pools won't increase further with increasing soil moisture.

Understanding Hydrologic & Energy Processes at Garner Run Using PIHM-MF: A Physically Based hydrologic model system

Dacheng Xiao[1], Yuning Shi[2], Chen Bao[1], Yu Zhang[3], Li Li[1]

The Penn State Integrated Hydrologic Model with Multi-Functions (PIHM-MF), the latest upgrade of PIHM, is a physically based hydrologic modeling system with multiple optional modules, including land surface module (Flux-PIHM), reactive transport module (RT-Flux-PIHM), ecosystem biogeochemistry module (Flux-PIHM-BGC), and landscape evolution module (LE-PIHM). Including multiple modules into one integrated model, PIHM-MF is capable of reproducing the water, energy, sediment, and solute (WESS) processes at watershed scale. As a representative sub-catchment with sandstone lithology in Shaver's Creek catchment, the Garner Run watershed is an appropriate experimental site to test the modeling system and compare with what we have learnt from Shale Hills. Based on available *in situ* data and national database, the domain of Garner Run was decomposed into 537 triangular grids and 18 river segments. Numerical experiments have been conducted to figure out the optimal spin-up time for PIHM in Garner Run. The simulated discharge, water table depth, soil water content, evapotranspiration, and surface heat fluxes are affected by soil type, topography, and forcing data. For instance, the water table depth and soil moisture patterns (Figure 1) show impact from soil type and topography. The model will be calibrated using outlet discharge and COsmic-ray Soil Moisture Observing System (COSMOS) measurements. The calibration coefficients, especially the macropore parameters, will be compared with those at Shale Hills. Synthetic data assimilation experiments will be performed to determine "what needs to be measured", i.e., the minimum requirement of calibration data at Garner Run.

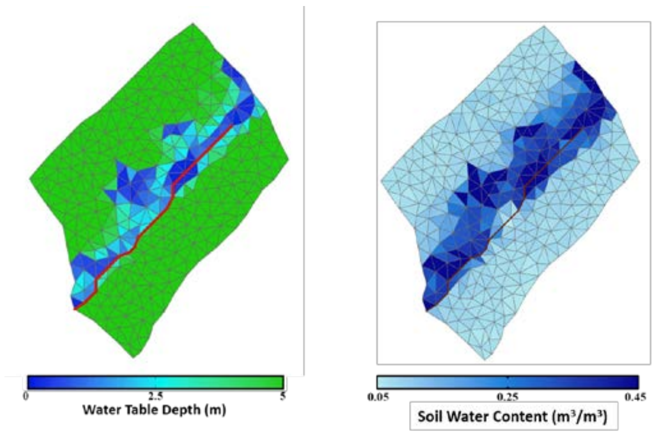

Figure 1 Simulated annual averaged pattern of water table depth and soil water content in 2009 using PIHM.

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Designing a Suite of Models to Explore Critical Zone Function

Christopher Duffy[a], Yuning Shi[b], Ken Davis[b,c], Rudy Slingerland[b,d], Li Li[e], Pamela L. Sullivan[b], Yves Goddéris[f], Susan L. Brantley[b,d*]

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The Critical Zone (CZ) incorporates all aspects of the earth's environment from the vegetation canopy to the bottom of groundwater. CZ researchers target processes that cross timescales from that of water fluxes (milliseconds to decades) to that of the evolution of landforms (thousands to tens of millions of years). Conceptual and numerical models are used to investigate the important fluxes: water, energy, solutes, carbon, nitrogen, and sediments. Depending upon the questions addressed, these models must calculate the distribution of landforms, regolith structure and chemistry, biota, and the chemistry of water, solutes, sediments, and soil atmospheres. No single model can accomplish all these objectives. We are designing a group of models or model capabilities to explore the CZ and testing them at the Susquehanna Shale Hills CZ Observatory. To examine processes over different timescales, we establish the core hydrologic fluxes using the Penn State Integrated Hydrologic Model (PIHM) – and then augment PIHM with simulation modules. For example, most land-atmosphere models currently do not incorporate an accurate representation of the geologic subsurface. We are exploring what aspects of subsurface structure must be accurately modelled to simulate water, carbon, energy, and sediment fluxes accurately. Only with a suite of modeling tools will we learn to forecast – earthcast -- the future CZ.

Using the Shale Network to Train Future Scientists

Authors: STUDENTS: Kristen Miller, Maria Rebecca Duiker, Lachlan Campbell, Hannah Yoder, Catherine Curtin, Samuel Woytowich, Jason Keller, Lauren Deardorff, Elena Gomez, Hannah Good, Connor Simons, Laura Brownstead, Meghan Petrine, Greta Miller, Chloe Spencer, Cole Klima, Andrea Kling, Kacy Mann, Sarah McClintic, Emily Lieb, Han Strouse, Valeria Soler Pelaez, Oliver Rose, Lena Nyblade, Noah Miller, Maria Rodriguez-Hertz, Aaron Li, Emily Redmond, Alison Weiss, Hannah Cropper TEACHERS: Eugene Ruocchio, Philip Gipe, John Donoughe, Yvonne Pickering, William Lukens PENN STATE: Jennifer Z Williams, Andrew Neal, Brandon Forsythe, David Yoxtheimer, Susan Brantley

This project was put into place to monitor the quality of water in the waterways of Centre County, specifically the Black Moshannon Creek, where fracking sites are in close proximity. Using the water quality monitoring as a base, the project provides young adults with field research opportunities to help develop their interests in scientific based careers. The purpose of this presentation is to connect with other scientists and professionals involved with the Shale Network to display what has been learned by the students and to show the growth and development of these students due to their involvement in this project. This collaboration between the Earth and Environmental Systems Institute at Penn State University and students from State College Area High School started last year with ninth graders who were trained by their Earth Science teachers and Penn State experts. The high school students have now become trainers in their own right working with current students enrolled in the Earth Science courses. The Teen Shale Network has grown from a small group of untrained students to a larger group of more experienced students, who have learned to use various instruments to test different aspects of water quality. The students have been guided by their teachers and the scientists from Penn State with a shared goal of collecting, accessing, analyzing, and presenting data. This year the students are involved in a deeper analysis and understanding of the data and its relevance to the Shale Network's monitoring of fracking activities.

The Tree Water Isoscape of a Central Pennsylvania Catchment: Ecohydrologic Patterns and Processes

Katie P. Gaines[1,3], Chris J. Duffy[2,3], David M. Eissenstat[1,3]
[1]Dept. of Ecosystem Science & Management; [2]Dept. of Civil & Environmental Engineering
[3]Penn State University

The connections between vegetation and catchment hydrology are important for tree physiology, species distributions, stream flow, and contaminant transport within a watershed. Stable isotopes of plant water are instrumental in determining water sources of plants, including depth and seasonality of water extraction from soil layers and ground water. While water isotopes from tree stems have been studied extensively to examine source water differences at a small scale, there has been little emphasis on modeling of plant stem water isotopes at larger scales. We characterized a tree stem water isotopic landscape (isoscape) of a first order catchment in central Pennsylvania in order to address the following questions: 1) How does tree water isotopic composition relate to catchment topography and tree characteristics? 2) What are the underlying hydrologic processes that are revealed by tree water isotopes?

We used observations of tree xylem water $\delta^{18}O$ to build a statistical model with variables related to topography, soils, and tree characteristics. We then applied the final model to predict the tree xylem water $\delta^{18}O$ composition during the growing season of the remaining trees over 18 cm diameter in the catchment. The final model included tree canopy height and degree of slope as predictors, and explained about 56% of variance in tree water $\delta^{18}O$ composition (Fig. 1). Tree canopy height and degree of slope were both negatively related to tree water $\delta^{18}O$ suggesting the tallest trees and trees on the steepest slopes had tree water isotopic compositions most depleted in heavy isotopes. These depleted compositions indicated the use of water with longer residence times, as opposed to recent precipitation in these areas of the catchment. On the valley floor, depleted values may indicate use of ground water from early in the growing season, and on steep hill slopes may indicate the use of tightly-bound soil water. The model highlighted the feedbacks between catchment topography and vegetation that may relate to contrasting hydrologic drivers. As the variables included in this model were derived from LiDAR datasets, this model can be validated and readily applied to other ecosystems.

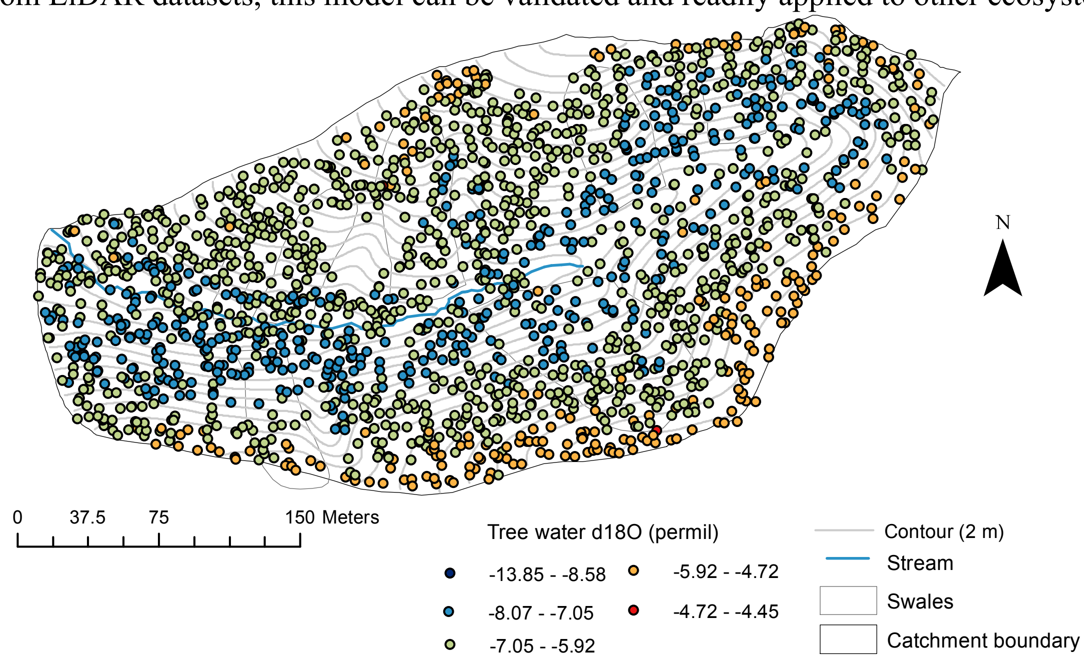

Figure 1. Predicted $\delta^{18}O$ composition (‰) of tree xylem water for the remaining trees >18 cm in the catchment based on the fixed effects of canopy height and slope in the final model. Color-coding denotes $\delta^{18}O$ composition.

Iron mobilization and transport through the bottom of the critical zone to the stream

Hyojin Kim[1] and Susan Brantley[1]

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Iron (Fe), the fourth most abundant element in the Earth's crust, is a redox-sensitive element. Fe oxidation-reduction cycles may play a central role in regolith development by opening new pore space at the bottom of the critical zone. A previous study of the Fe cycle in the Shale Hills watershed, using Fe isotopes, reported that total Fe and Fe(II) in bulk soil were depleted, but dissolved Fe (< 0.22μm) in the soil pore-water was also negligible; implying that micron-size colloid/particles may be primarily responsible for Fe transport. In addition, the authors postulated that the colloid/particle phase of Fe may provide valuable insight to the Fe isotope mass balance. However, no observations were available with adequate temporal control to assess the hypothesis. Furthermore, most research at Shale Hills has focused on Fe in the soils; its variability in groundwater and stream water is poorly understood. In this study, to understand how Fe is mobilized and transported through the critical zone to the adjacent stream, we are monitoring Fe concentrations in groundwater and stream water simultaneously at high frequency (7hr – 2 days). In April 2015, we started collecting groundwater and stream water samples using two automated water samplers – one at the stream and the other at CZMW2 (-5m) - at 1-3 days intervals. To preserve sample integrity for Fe and other reactive elements, we employed a newly-developed gravitation filtration system (GFS) in the field. This method filters (pore size 0.22 μm) a water sample (~150mL) via gravity within 30 minutes after collection and provides samples for both dissolved and colloid/particle Fe. During 3-5 rainstorms in the spring and summer, we will collect water samples at a high frequency (every ~7hrs). To quantify the Fe in each phase, we will manually collect 500mL groundwater and stream samples, and then filtered them sequentially (pore-sizes of 1.0 μm →0.45 μm →0.2 μm, →100 kDa →1 kDa). Water samples will be analyzed using an inductive coupled plasma – absorption emission spectroscopy (ICP-AES) and an inductively coupled plasma – mass spectrophotometry (ICP-MS). Selected sets of water samples will be analyzed for Fe isotopes. A subset of particle/colloid samples will be analyzed for their particle morphology, mineralogy, and chemistry. This study will provide comprehensive observations of Fe dynamics, and will improve our understanding of how, when, and in which phase of Fe is mobilized and transported through the critical zone and to the stream.

Development of RT-Flux-PIHM: A Coupled Hydrological, Land Surface, and Reactive Transport Model

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Abstract

The close coupling of hydrological and geochemical processes at the watershed scale requires an integrated approach to examine their interactions. Here we present the first model that couples hydrological, land surface, and reactive transport processes, RT-Flux-PIHM, a new addition to the PIHM (Penn State Integrated Hydrological Model) family. In RT-Flux-PIHM, Land surface (simulated by Flux) and the hydrological processes (simulated by PIHM) are tightly coupled with feedbacks between processes. Based on the water distribution and flow rate computed from Flux-PIHM, the RT module solves the advection-diffusion-reaction equation for the spatial and temporal evolution of aqueous and solid phase composition. The RT module explicitly simulates geochemical reactions in both saturated and unsaturated zone, including aqueous complexation, mineral dissolution and precipitation, redox reaction, adsorption and cation exchange. The reactive transport module was coupled to land surface and hydrological model in a sequential non-iterative manner. This coupling method enables the development of a reactive transport code that is fast, robust and adaptive to extreme flow conditions that can arise within the hydrological land surface model. Special time stepping constraints are enforced to reduce errors associated with such operator splitting. When extremely fast flow occurs, sub time step interpolations are performed to reduce chances of non-convergence. To verify this code, its solutions were compared to those of the extensively used reactive transport code CRUNCHFLOW under a variety of flow and reaction conditions. The solutions obtained from two models are close with a maximum total bias less than 10^{-8} in smooth regions. To validate RT-Flux-PIHM, it was applied at the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO) to study the controls on stream water chemistry and soil water chemistry. The temporal concentration evolution of non-reactive tracer chloride and weathering-derived magnesium in the stream water simulated in the model agreed well with measurements with a maximum total bias less than 15%. In summary, RT-Flux-PIHM provides a unique integration tool to understand the hydrogeochemical processes at the water shed scale.

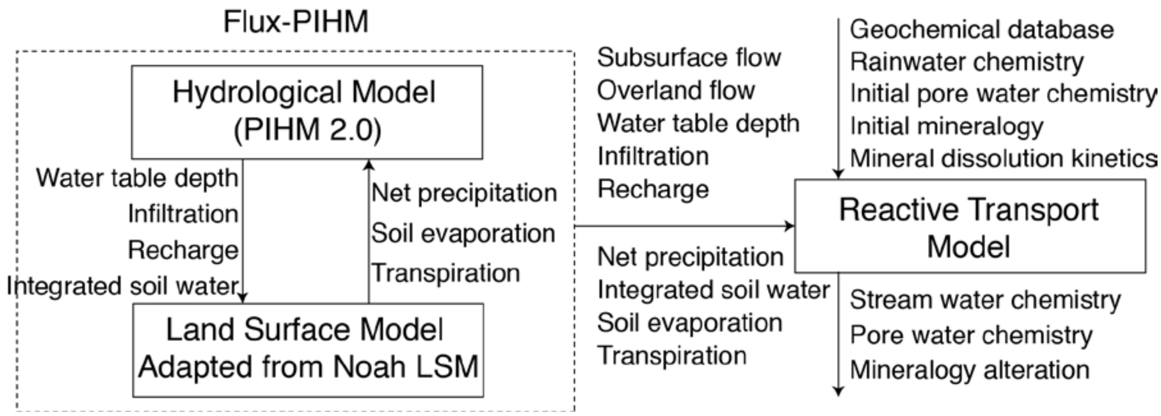

Figure 1. Data exchange and process coupling between the hydrological, land surface and reactive transport components of RT-Flux-PIHM. The RT module reads flow and water distributions from Flux-PIHM and specified initial chemistry, and outputs the spatial and temporal evolution of aqueous and solid phase composition based on the hydrological conditions and geochemical thermodynamics and kinetics.

Title: A watershed scale estimation of regolith transport and landscape evolution in the Shale Hills CZO using a new generation landscape evolution model (LE-PIHM)

Yu Zhang[1], Rudy L. Slingerland[2], and Christopher J. Duffy[1]

[1]Department of Civil and Environmental Engineering, Penn State University, University Park, PA, 16802

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With relative homogeneous bedrock, regolith, and tectonic uplift, a 0.08 km^2 first order catchment (Shale Hills CZO) shows asymmetric slope and thickness of regolith on the north- and south-facing hillslopes. What are the possible factors causing these differences, and what are the differences of spatial distribution of regolith transport fluxes on both sides of hillslopes? With the support of multi-spatial and temporal scale data for model parametrization, calibration and validation, this study builds a new comprehensive model (LE-PIHM) to quantitatively understand the interaction between hydrological and morphological processes, especially the influence of subsurface flow on erosion and deposition, which is not well considered in current landscape evolution models. Three non-dimensional parameters were used to explore the competitive relationship between regolith diffusion and advection towards steady state, and helped to determine the most likely combination of parameters that fits the watershed. After simulating the landscape evolution with variable meteorological forcing, the results show obvious different spatial variations of hillslope diffusion flux. The highest diffusion rate region locates at the planar of the south-facing slope and the minimum rate comes from the planar of the north-facing slope, which indicates that the measurement of regolith transport overestimates the difference of sediment transport efficiency on the two hillslopes. The largest regolith transport rate by overland flow happens at the junction of main channel and swales. Meanwhile the rates on the two sides of hillslopes show similar magnitude. The critical transition of diffusion flux by model simulation highlights the area where additional measurement or observation should be conducted in order to support a better estimation in watershed scale.

Exploring the Influence of Topography on Belowground C Processes Using a Coupled Hydrologic Biogeochemical Model

Yuning Shi[1], Kenneth Davis[2, 3], David Eissenstat[1], Jason Kaye[1], Yuting He[2]

Belowground carbon processes are strongly affected by soil moisture and soil temperature. Current biogeochemical models, however, are 1-D and cannot resolve topographically driven hill-slope soil moisture patterns, and cannot simulate the nonlinear effects of soil moisture on carbon processes. Coupling spatially-distributed physically-based hydrologic models with biogeochemical models may yield significant improvements in the representation of topographic influence on belowground C processes.

A spatially distributed forest ecosystem model has been developed by coupling a 1-D mechanistic biogeochemistry model Biome-BGC (BBGC) with a spatially distributed land surface hydrologic model, Flux-PIHM. Flux-PIHM is a coupled physically based model, which incorporates a land-surface scheme into the Penn State Integrated Hydrologic Model (PIHM). The land surface scheme is adapted from the Noah land surface model. Because PIHM is capable of simulating lateral water flow and deep groundwater, Flux-PIHM is able to represent the link between groundwater and the surface energy balance, as well as the land surface heterogeneities caused by topography. In the coupled Flux-PIHM-BBGC model, each Flux-PIHM model grid couples a 1-D BBGC model. Flux-PIHM provides BBGC with soil moisture and soil temperature information, while BBGC provides Flux-PIHM with leaf area index. The coupled Flux-PIHM-BGC model has been implemented at the Susquehanna/Shale Hills critical zone observatory (SSHCZO). Preliminary results show that the Flux-PIHM-BBGC simulated soil carbon pool shows clear impact from topography. The simulated vegetation carbon pool is mainly affected by vegetation type.

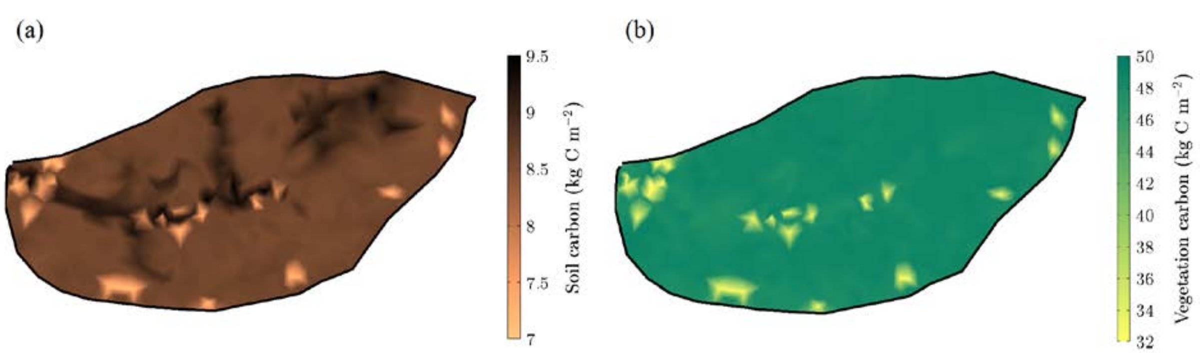

Figure 1 Flux-PIHM-BBGC simulated soil carbon pool (a) and vegetation carbon pool (b) after 6000 years of model spin-up using default BBGC ecophysiological parameters.

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Implementation of the COsmic-ray Soil Moisture Observing System (COSMOS) in SSHCZO: a Non-invasive, Landscape Scale Measurement

Dacheng Xiao[1], Yuning Shi[2], Brandon Forsythe[3], Jennifer Williams[3], Li Li[1]

Soil moisture is essential for understanding hydrological, land-surface and reactive transport processes. Point measurements of soil moisture often need to be upscaled for larger-scale models. The COsmic-ray Soil Moisture Observing System (COSMOS) offers a widely used and non-invasive measurement at the scale of hundreds of meters. By counting the number of fast neutrons present within the COSMOS footprint, a calibration function may be applied to estimate the hydrogen content of the system. By taking into account the hydrogen sources other than soil moisture, neutron intensity can be translated into soil moisture values. COSMOS has been used to validate Flux-PIHM predictions at the Shale Hills watershed (Figure 1).

COSMOS will be installed in the Garner Run watershed. For calibration, 108 soil samples will be collected at 18 different locations at six radial directions and three radial distances from the probe station using a split corer. Soil moisture of these samples will be used to calibrate COSMOS measurement. Both point and COSMOS measurements will be used to validate the Flux-PIHM model for Garner Run. The efficiency of assimilating COSMOS data for model parameter estimation will also be tested.

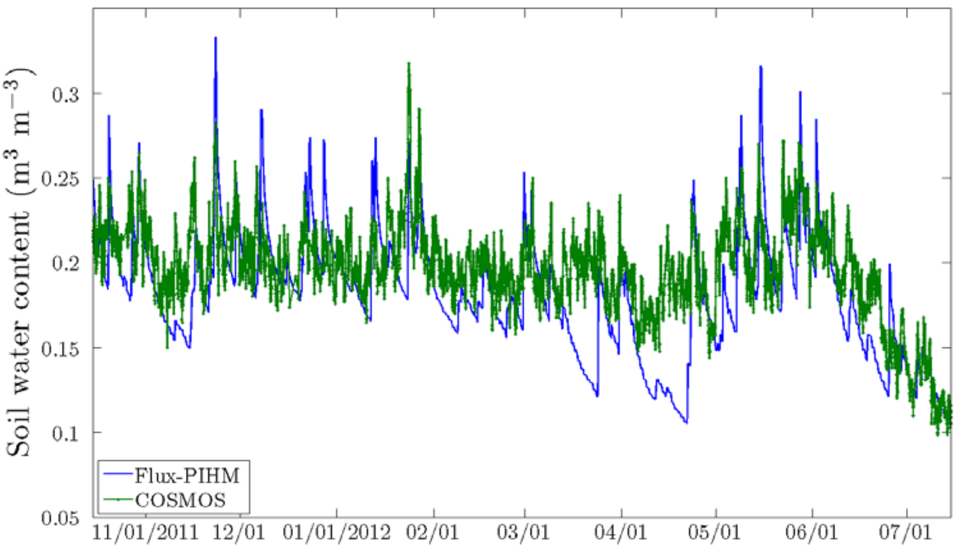

Figure 1 Comparision of soil water content between Flux-PIHM and COSMOS at the Shale Hills watershed from 15 October 2011 to 15 July 2012.

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Nitrogen Balance of the Shale Hills Catchment

Julie N. Weitzman and Jason P. Kaye
Department of Ecosystem Science and Management, The Pennsylvania State University, University Park, PA, 16802

Nitrogen (N) saturation occurs when the availability of inorganic N exceeds biological demand by plants and microbes. In forests, N saturation is predicted to occur in response to elevated inputs of anthropogenic atmospheric N. High rates of N deposition to forests can lead to a cascade of effects that ultimately reduces the capacity of the ecosystem to retain N. Some indicator symptoms of N saturation documented in forest ecosystems include: 1) high relative rates of net nitrification; 2) elevated nitrate (NO_3^-) concentrations in streamwater; 3) low seasonal variability in streamwater NO_3^- concentrations; and 4) a close balance between inputs and outputs of inorganic N (i.e. low retention of inorganic N). We assessed these four indicator symptoms in fall (September-November) versus spring (March-May) in order to characterize the N saturation status of the Susquehanna Shale Hills Critical Zone Observatory (CZO), an acidic, forested, first-order catchment in central Pennsylvania, known to receive high N depositional inputs.

N depositional data for the two seasons was obtained from a site approximately 3.2 km west of Shale Hills, which is maintained by the National Atmospheric Deposition Program (NADP site PA42). Inorganic N concentrations in streamwater, groundwater, and leachate solutions were estimated from samples collected from 2006-2010, from 2008-2010, and from 2006-2010/2013-2014, respectively. Potential net nitrification and mineralization rates for each season were estimated using samples collected at one time point (October 2014 for Fall and March 2015 for Spring), but consist of 24 samples each of mineral soil that was taken to a depth of 15 cm.

Atmospheric depositional inputs of N to Shale Hills via precipitation averaged ~0.4 mg N L^{-1} in the fall and ~0.6 mg N L^{-1} in the spring. Soil inorganic N measured in leachate solution was ~0.4 mg N L^{-1} in the fall versus ~0.5 mg N L^{-1} in the spring. Measured concentrations of N in both groundwater and streamwater (<0.1 mg N L^{-1} for both seasons), however, were orders of magnitude less than atmospheric inputs or soil solutions. The difference between N inputs and outputs represents the quantity of N lost to the environment or accumulating in plants or soils. For Shale Hills, the average loss of inorganic N in stream flow was <0.5 kg N ha^{-1} yr^{-1} for both seasons, and the average input from rainfall was ~0.9 kg N ha^{-1} yr^{-1} in the fall versus ~1.6 kg N ha^{-1} yr^{-1} in the spring. Thus, ~0.4 kg N ha^{-1} yr^{-1} and ~1.1 kg N ha^{-1} yr^{-1} were retained in the forested system in the fall and spring, respectively. Internal N cycling processes were measured in order to identify possible N retention pathways in the soil. Potential net nitrification rates were near zero for both seasons at ~0.5 kg N ha^{-1} yr^{-1}, accounting for <1 % of potential net mineralization (~90 kg N ha^{-1} yr^{-1}). An index of the nitrifier populations at Shale Hills agreed with the nitrification rates, suggesting that the NH_4^+ oxidizer community is largely absent.

A crude estimate of the N budget for the site reveals that inputs of N exceed outputs of N. The low relative rates of net nitrification and low outputs of NO_3^- in groundwater and streamwater throughout the year further support this conclusion. Such a scenario indicates that demand for available N is high, and that Shale Hills is not yet N-saturated. This further suggests that N is either being retained in the forested system, likely in O-horizon soils and vegetation, or leaving via an unmeasured pathway, such as dissolved organic nitrogen, which will soon be quantified for the site.

Insights on deep critical zone evolution from seismic refraction surveys in the Susquehanna Shale Hills Critical Zone Observatory

Nicole West, Eric Kirby, Brian Clarke, Susan Brantley

Fundamental to the functioning and structure of the critical zone is the formation of regolith - the physically and chemically altered material formed from in situ parent bedrock that is available for transport. Therefore, understanding how the dynamics between regolith production and transport respond to perturbations in climate and/or tectonic forcing is a first-order problem in critical zone science. At the Susquehanna Shale Hills Critical Zone Observatory (SSHO), high resolution LiDAR-derived topographic data and hand auger depths reveal a systematic asymmetry where hillslope gradients and mobile regolith thicknesses on north-facing hillslopes. Hydrologic and geochemical studies of the SSHO subsurface are also suggestive of asymmetric fluid flow and mineral weathering with respect to aspect. We use a combination of shallow seismic surveys completed along 4 hillslopes (2 north-facing and 2-south facing) and 2 ridgetops with borehole observations to investigate the role of climatically induced fracturing in the development of the observed asymmetry. Comparisons of shallow p-wave velocities with borehole and pit observations suggest the presence of three distinct layers at SSHO. 1) A deep, high velocity layer that is consistent with unweathered shale bedrock immediately overlain by 2) an intermediate velocity layer that is consistent with fractured and chemically altered bedrock, and 3) an uppermost slow velocity layer that is consistent with mobile material or shallow soil. Initial shallow p-wave velocity profiles suggest that while augerable regolith thicknesses are different on north-and south-facing hillslopes, total regolith thicknesses (i.e., the depth to unweathered bedrock) are similar on all slopes. The observed patterns of ubiquitously increasing p-wave velocities with depth are consistent with predictive cracking intensity models related to frost action. We cannot rule out the influence of regional and topographic stress on the pattern of fractures at SSHO; however, the existing stress models alone do not appear to predict the subsurface observations at SSHO.

CZ-Tope: An initiative to use multiple isotopes to quantify Critical Zone processes

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CZ-Tope is an initiative to target the use of multiple isotope systems on the same samples in the same sites to understand Critical Zone (CZ) processes. At the Susquehanna Shale Hills Critical Zone Observatory, we demonstrate the utility of the idea in deciphering how geochemical, geomorphological, hydrological, biological, and anthropogenic processes influence the evolution of the CZ. Here we have focused on major cross-CZO themes:

(1) Controls of CZ properties: Meteoric ^{10}Be concentrations together with U-series suggest higher regolith production rates and transport efficiency on shallow, south-facing slopes than on steep, north-facing slopes despite similar downslope regolith flux. Excess ^{210}Pb and ^{137}Cs indicate soil mixing.

(2) CZ processes, stores, and fluxes: SF_6, ^{3}H and CFCs reveal groundwater residence times and provide constraints on hydrologic and geochemical models. C isotope signatures of DIC indicates that ankerite dissolution plays a major role. Fe, Mg, B and Li isotopes elucidate the influence of vegetation, hydrogeologic conditions, and climate on weathering and element fluxes. Isotopes of metals such as Pb, Cd and Zn are explored to evaluate sources of dust inputs in the Anthropocene.

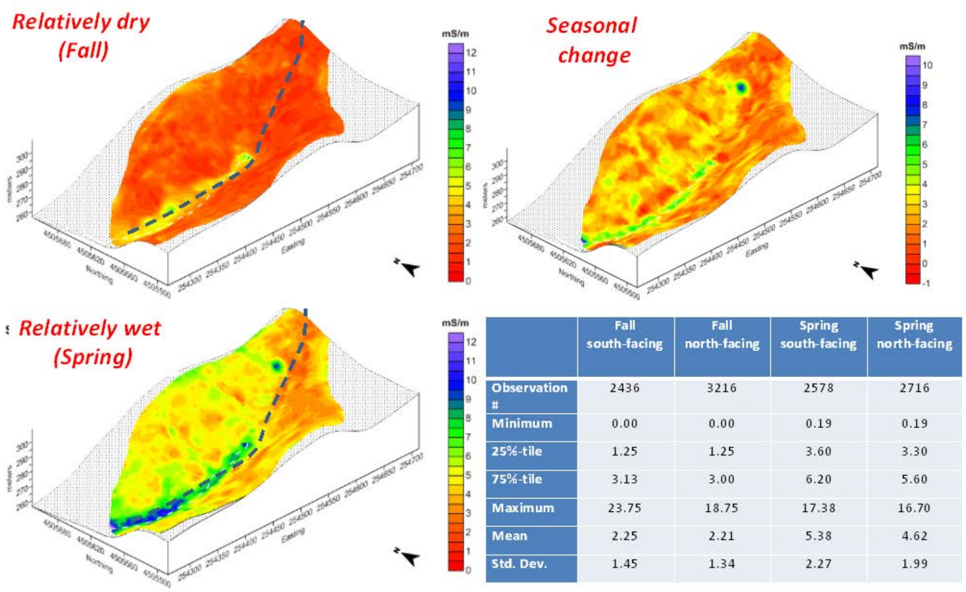
(3) Vegetation-regolith dynamics influence water and nutrient fluxes: O and H isotopes document hydrological processes including transpiration and soil water-groundwater-stream water interactions. ^{87}Sr/^{86}Sr and Ge/Si ratios as well as Ca isotopes elucidate the depth of nutrient uptake and cycling by vegetation whereas ^{2}H is used to constrain the depths from which trees access water.

In October 2013, we initiated a new sampling campaign to provide stream, soil and groundwater samples that are still available for new isotopic measurements at Shale Hills. We hope this venture will serve as a platform to promote similarly intensive isotopic measurements at other CZOs to elucidate CZ processes across varying lithologies, tectonic settings, and climatic conditions.

<u>The soil macropore hypothesis</u>*: Macropores are important in controlling fluid flow and chemistry in soils derived from various lithologies, but the nature and effects of these macropores differ significantly among shale, calcareous shale, and sandstone (* *team personnel: Henry Lin, Neil Xu, Yuan Wu, Tess Russo, Dave Eissenstat, Ken Davis)*

The following are data collections to be completed at both the Shale Hills and Garner Run, which will be synthesized in a comprehensive manner to test the macropore hypothesis:

- Repeated electromagnetic induction (EMI) surveys under various conditions (dry vs. wet seasons; before vs. after snowmelt; before vs. after rain storms), from which a possible macropore network might be identified. An example dataset from the Shale Hills is illustrated in Figure 1;
- Systematic percolation measurements using double ring infiltrometers at selected sites in the hillslopes, which can capture the degree of macropore flow in a given soil;
- Repeated surveys of ground-penetrating radar (GPR) in selected transects, which will be combined with the existing GPR database to construct a 3D soil volume that can help portrait the hillslope architecture that may be linked to macropore features;
- Exploration of the feasibility of using GPR to quantify soil moisture and subsurface flow along macropores in selected sites.
- Exploration of the feasibility of using GPR to map coarse roots of selected trees, which could play a significant role in macropore flow;
- Exploration of the feasibility of using distributed temperature sensing (DTS) to identify possible subsurface flow and related macropore flow.



	Fall south-facing	Fall north-facing	Spring south-facing	Spring north-facing
Observation #	2436	3216	2578	2716
Minimum	0.00	0.00	0.19	0.19
25%-tile	1.25	1.25	3.60	3.30
75%-tile	3.13	3.00	6.20	5.60
Maximum	23.75	18.75	17.38	16.70
Mean	2.25	2.21	5.38	4.62
Std. Dev.	1.45	1.34	2.27	1.99

Figure 1. Two EMI surveys conducted in fall (dry condition) and spring (wet condition) using EM38 with a density of about 750 measurements per ha. However, sampling was not uniform throughout the catchment because of steep terrain and trees making it challenging to traverse the landscape. On some lower-lying areas within the catchment, GPS data were either lost or degraded by multipath and masking problems caused by the steep terrain and dense vegetation canopy. The inset table shows the statistical summary of the apparent electrical conductivity (ECa) values from each survey.