BRIEF AGENDA

Monday, 22 September 2014

Theme 1 - What controls CZ properties and processes?

a. How does critical zone development depend on lithology and geologic legacy?
b. How does critical zone development vary with climate?
c. How does biota influence critical zone development?
d. How does hillslope aspect, as it influences local climate, affect critical zone evolution and structure?

Theme 2 – What is response of CZ structure, stores, and fluxes to climate?

a. What is the relationship between concentration & discharge?
b. What factors moderate soil-organic carbon relationships in shallow and deep soil?
c. How do material & energy fluxes across boundaries relate to climate?
d. Especially on shorter time scales, what controls biogeochemical stores and fluxes within the CZ?
e. How do microbial communities (activity, composition) influence biogeochemical stores and fluxes?

Theme 3 – What is response of CZ structure, stores and fluxes to land use change?

a. How does the CZ respond to climate change & land-use/management effects?
b. How does regolith affect vegetation?
c. How do (bi-directional) vegetation-regolith dynamics influence CZ structure, stores & fluxes, including water & C??
d. How do material and energy fluxes across boundaries relate to land use change?

Tuesday, 23 September 2014

Field Trips

Wednesday, 24 September 2014

Theme 4 – How can CZ understanding be used to enhance resilience and sustainability, and restore ecosystem function?

How can we apply understanding of the Critical Zone to enhance ecosystem services and patterns such as: water resources, disturbance, ecological indicators, sustainability?

The CZO network emphasizes interdisciplinary research. Furthermore this meeting aims to promote current cross-CZO research and foster new collaboration. Under that premise, abstracts are tagged with multiple themes, but listed under their primary theme.

Posters for all Themes will be displayed on Monday during two poster-viewing sessions. A few research presentations, selected by each group of session conveners, will have a brief period to highlight their research during the time allotted for each Theme.

CONTENTS

INVITED TALK

Changes in the global value of ecosystem services

Paul Sutton

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In 1997, the global value of ecosystem services was estimated to average $33 trillion/yr in 1995 $US ($46 trillion/yr in 2007 $US). In this paper, we provide an updated estimate based on updated unit ecosystem service values and land use change estimates between 1997 and 2011. We also address some of the critiques of the 1997 paper. Using the same methods as in the 1997 paper but with updated data, the estimate for the total global ecosystem services in 2011 is $125 trillion/yr (assuming updated unit values and changes to biome areas) and $145 trillion/yr (assuming only unit values changed), both in 2007 $US. From this we estimated the loss of eco-services from 1997 to 2011 due to land use change at $4.3–20.2 trillion/yr, depending on which unit values are used. Global estimates expressed in monetary accounting units, such as this, are useful to highlight the magnitude of eco-services, but have no specific decision-making context. However, the underlying data and models can be applied at multiple scales to assess changes resulting from various scenarios and policies. We emphasize that valuation of ecoservices (in whatever units) is not the same as commodification or privatization. Many eco-services are best considered public goods or common pool resources, so conventional markets are often not the best institutional frameworks to manage them. However, these services must be (and are being) valued, and we need new, common asset institutions to better take these values into account.

INTRODUCTORY POSTERS

Boulder Creek CZO: Conceptual Model

Suzanne Anderson, Robert Anderson, Noah Molotch, Harihar Rajaram, Greg Tucker and the BcCZO team

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The central aim of BcCZO is to develop a deeper understanding of the structure, functioning, and evolution of the critical zone in a mountainous landscape. This understanding is required to answer fundamental questions in earth and environmental science, such as: How does rock turn to sediment? How do landscapes evolve? What controls hydrologic and biogeochemical fluxes and ecosystem services? The Colorado Front Range provides an ideal natural laboratory for exploring these questions, as the results from BcCZO-I have shown; it typifies mountainous landscapes of the American West that support large human populations. Mountain CZs have been shaped by a complex climatic history, leaving a long legacy. The juxtaposition of hard crystalline rock of the mountains against soft shale of the Plains, each with a different biota, forces acknowledgement of the roles of rock type and of both biogeomorphic and biogeochemical feedbacks in the evolution of the CZ.

The transformative nature of the program lies in its integrative and interdisciplinary approach. The BcCZO-II project brings together a diverse team of ecologists, hydrologists, geomorphologists and geochemists from CU, USGS, and Colorado School of Mines, knit by major threads that include snowmelt, subsurface flow, multiple roles of biota, emergence of long-term climate legacies, and numerical models that cross disciplinary boundaries. Weather and fire events have driven perturbations in water, sediment, and solute export from the mountains that are being monitored, and that stimulate modeling efforts that include projection into a warming climate. Research on snow, the geobiology of deep weathering, the roles of slope aspect, and the use of cosmogenic radionuclides connects BcCZO to other CZOs

Boulder Creek CZO Field Facilities

Suzanne Anderson, Robert Anderson, Noah Molotch, Harihar Rajaram, Greg Tucker and the BcCZO team

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Infrastructure has been built in Betasso and Gordon Gulch catchments within Boulder Creek watershed, and augmented in Green Lakes Valley, the headwaters of Boulder Creek and part of the Niwot Ridge LTER. BcCZO researchers also exploit sites maintained by others, including USGS and Colorado DWR Boulder Creek gages, Niwot LTER, Ameriflux tower at Niwot Ridge, National Atmospheric Deposition Program (NADP) sites, precipitation gages of Urban Drainage and Flood Control District, and the NEON test site on Table Mountain. Field infrastructure built and maintained by BcCZO includes:

Betasso Meteorological tower, stream gauge, soil moisture and water potential (3 sites, 8 sensors), snow depth (5 sensors), sapflow sensors (24 in 3 sites) weekly stream and precipitation sampling. Well (124 m deep; screened below 60 m)

Gordon Gulch Two weather stations (rain gauge, air temp, radiation, wind speed and direction, relative humidity, air pressure), snow depth (20 manual, 16 automated, 3 time-lapse cameras), 2 stream gauges (stage, water temperature, electrical conductivity sensors and automated water samplers), 6 wells (3 with automated water level sensors), sapflow sensors (48 in 6 sites) soil moisture (44 in 16 sites), temperature (84 in 23 sites), water potential (12 in 6 sites), frost heave (4 sites), and soil water sampling with fused quartz, ceramic, and zero tension lysimeters (75 samplers total). Weekly surface water sampling at stream gauges, 2 springs, precipitation and snow, along with monthly sampling of wells, and intermittent sampling of additional locations.

Fourmile Creek Stream discharge (4 sites, two USGS, two CZO), water quality (5 sites; samples collected monthly during base flow, weekly during snowmelt, and 20 min to 4 hr during convective storms). Sites are located upstream, within, and downstream of burned area. Rainfall amount and intensity available from Urban Drainage and Flood Control District gages.

Green Lakes Valley Soil moisture and temperature in 5 profiles, 1 time-lapse camera to document snow and ice conditions across the valley. Weather monitoring, water sampling, stream gages, and snow survey are accomplished by Niwot LTER.

Boulder Creek Weekly water sampling at 4 locations, two at Colorado DWR gage sites.

The Calhoun CZO: A time machine laboratory

Daniel Richter, Amilcare Porporato

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CZOs: Calhoun

Fifteen scientists and humanities scholars seek to understand how Earth's Critical Zones respond to and recover from land degradation and severe erosion. Re-instrumented experimental catchments quantify the evolution in hydrologic and biogeochemical cycles of humid zone farmland that was historically subject to severe upland erosional losses and floodplain deposition. Given that the Critical Zone is an integrated system from the atmosphere and upper plant-canopies through soils, surface and subsurface waters, and deep mineral weathering, research focuses on how land-use stresses structures and processes that network the CZ's surface and subsurface subsystems. Researchers are using historic and contemporary data of vegetation, soil, catchments, and sensor networks to help hindcast and forecast Critical Zone dynamics and evolution across temporal and spatial scales.

The Catalina-Jemez CZO: Transformative behavior of energy, water and carbon in the Critical Zone II. Interactions between long and short term processes that control delivery of Critical Zone services.

Jon Chorover, Jon Pelletier, David Breshears, Jennifer McIntosh, Craig Rasmussen, Paul Brooks, Greg Barron-Gafford, Rachel Gallery, Ty Ferré, Marcy Litvak, Tom Meixner, Guo-Yue Niu, Shirley Papuga, Virginia Rich, Marcel Schaap, and Peter Troch.

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The Catalina-Jemez CZO aims to improve our understanding of the mechanisms underlying quantitative relations between climatic forcing and critical zone evolution by focusing on linkages between long time-scale climate/lithology interactions and short time-scale ecological/geological feedbacks, and how both affect CZ services. This goal motivates our central thematic questions:

1) How do the long-term drivers of CZ structure and function (EEMT and tectonics) alter parent material to control current CZ structure and response to perturbation?

2) How is long-term CZ evolution affected by ecosystem process controls, including especially localized plant and microbial activities?

3) What is the impact of CZ structure on buffering climate- and disturbance-driven variability in water, soil and vegetation resources and how does this translate into changes in CZ services?

This poster provides a concise overview of the Catalina-Jemez CZO and describes our conceptual model of CZ evolution.

The Catalina-Jemez CZO: Infastructure

Jon Chorover, Jon Pelletier, David Breshears, Jennifer McIntosh, Craig Rasmussen, Nathan Abramson, Greg Barron-Gafford, Paul Brooks, Matej Durcik, Ty Ferré, Rachel Gallery, Marcy Litvak, Mark Losleben, Tom Meixner, Guo-Yue Niu, Shirley Papuga, Virginia Rich, Marcel Schaap, and Peter Troch.

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This CZO is located in the water-limited southwestern U.S. in two locations – the Santa Catalina Mountains (AZ) and the Jemez Mountains (NM). The CZO comprises an elevation (hence climate) gradient extending from Sonoran Desert to Mixed Conifer Forest on three rock types (Granite, Schist and Rhyolite). The CZO takes a 'nested catchment' approach, wherein zero order basins (ZOBs) are instrumented at the hillslope scale, and these ZOBs are nested within catchments that are nested within watersheds. A strong focus intensive monitoring of the water cycle links observations occurring across each of these scales. This poster depicts our sensor and sampler infrastructure, which includes eddy covariance towers, instrumented pedons, groundwater monitoring wells, and instrumented flumes/weirs, with the intent of measuring fluxes across CZ boundaries as well as processes controlling internal transformations and redistributions of matter and energy.

Luquillo CZO: The role of hot spots and hot moments in tropical landscape evolution and functioning of the critical zone

and

Instrumentation and Experimental setup in the Luquillo CZO

Miguel Leon, McDowell, Bras, Wang, Silver, Willenbring, Brantley, Comas, Porder, Jerolmack, Plante, Thompson, Scholl, González, Gould, Shanley

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The overarching question guiding LCZO2 is: How do hot spots and hot moments in weathering, biogeochemical cycling, hydrologic processes, and atmospheric inputs drive landscape evolution and CZ function in a humid tropical forest? Our research is organized into four inter-related focal areas. Focal Area 1 explores the importance of knickpoints and different landscape positions as hot spots for weathering, soil development, and biogeochemical cycling. Focal Area 2 addresses the role of hot spots and hot moments in redox cycling that contributes to the dynamics of weathering, and to the retention and loss of C and nutrients in soils over a range of spatial and temporal scales. Focal Area 3 determines the role of hot moments in the transport of sediment, C, and nutrients in stream flow, and hot spots that determine the distribution of material across the landscape. Focal Area 4 scales up hot spots and hot moments in time and space using climate and hydrologic modeling, and identifies the role of key atmospheric inputs in clouds and rain. Taken together, the research proposed in LCZO2 will provide a well-integrated assessment of critical zone properties and processes that scale from microsites to catenas, watersheds, landscapes, and the region, and from minutes to hours, days, months, and years. The data collected and synthesized as part of LCZO2 will contribute to our understanding of the controls on weathering, soil development, C and nutrient storage and loss, soil and sediment transport, and ultimately landscape evolution and effects of climate change. Through collaborations with local and federal agencies and educational institutions, we will conduct workshops and outreach activities to inform policy makers and other stakeholders of our research findings and the significance of the Critical Zone in the Luquillo Mountains of Puerto Rico.

Introduction to Intensively Managed Landscapes CZO

Qina Yan[1], Laura Keefer[2], Christopher G. Wilson[3], E Arthur Bettis III[4], Thanos Papanicolaou[3], Praveen Kumar[1]

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The Critical Zone is the region between bedrock and canopy that supports all terrestrial life. In the Midwest, the region was shaped by repeated glacial events over geologic time scales followed with rapid human modifications through conversion of prairie to intensive agriculture, wetland drainage and urbanization. The Intensively Managed Landscapes-Critical Zone Observatory (IML-CZO) aims to understand soil, water, and vegetation dynamics in the low-gradient landscapes, and assess how intensive management alters a watershed's vulnerability and resilience to disturbances. The IML-CZO consists of three study sites within the glacially impacted Midwestern U.S.: 3700 sq. km Upper Sangamon River Basin

(USRB) in Illinois; 270 sq. km Clear Creek Watershed (CCW) in Iowa; and about 40,000 sq. km. Minnesota River Basin (MRB) in Minnesota. The observatory builds on extensive studies and experiments that have been conduction in these sites. In the USRB and CCW, new instrumentation supplement historic stream flow, sediment, and nutrient data. Weather stations and flux towers are being established in the field to collect precipitation, radiation, temperature, soil moisture, carbon flux, etc. Some in-site experiments are conducted to study soil, nutrients, and sediment transport. Hyperspectral and Green LiDAR have also been flown through the two sites. A well-established friendship with local farmers and landowners is vital to these data collection efforts. Here, we illustrate various aspects of the USRB and CCW including station locations, topography, glacial features, hydrologic data, and vegetation. The information on recent and future studies within the river basin will enhance our understanding of intensively managed landscapes, which will improve the support of economic and environmental sustainability.

The Reynolds Creek Carbon CZO: Conceptual Model

Reynolds Creek CZO Team

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Most of the world's terrestrial carbon is found in the critical zone, where it is predominantly stored as soil carbon. This important carbon reservoir is sensitive to climatic and land use change and may act as a source or sink for atmospheric carbon dioxide. Despite its importance, soil carbon remains a critical source of uncertainty in both carbon cycling and global climate models. That uncertainty arises due to both an incomplete understanding of the *processes* dictating soil carbon fate and the *challenge of up-scaling* often highly spatially and temporally heterogeneous soil processes to the landscape or global level.

The Reynolds Creek Carbon Critical Zone Observatory (RCC CZO) is addressing the grand challenge of improving prediction of soil carbon storage and flux from the pedon to the landscape scale. Reynolds Creek Experimental Watershed is particularly well suited for this effort because it extends over strong gradients in climate and vegetation with associated dramatic differences in both soil organic and inorganic carbon. These gradients facilitate both observation-based science and experimental investigations in which the gradients act as primary variables. This new CZO is also be supported by unique long-term, spatially- extensive, meteorological, soil monitoring, and atmospheric datasets that will both inform and constrain conceptual and numerical models of soil carbon behavior.

Research efforts are focused in the first five years along a series of intensively instrumented (eddy flux towers, soil respiration, moisture, temperature, and a suite of climatic monitoring) sites along the elevation gradient. Extensive characterization of above and below ground biomass, soil carbon amounts, distribution and characteristics is being undertaken at these sites as well as in a distributed manner across the watershed, producing a massive watershed-scale dataset that can inform soil carbon research for generations. Experimental research includes wildfire and land use change investigations. Modeling of soil physical, chemical and biological processes are going to inform our efforts on mechanistic linkages between soil carbon behavior and key environmental variables. Sophisticated climate-hydrologic models are being used to spatially distribute those controlling variables at a sufficiently high resolution (5 m) to capture the natural heterogeneity on the landscape. This data will allow application of ecosystem-soil carbon simulations that can be tested against the landscape-scale datasets and used to inform our understanding of soil carbon behavior and direct our research activities towards the areas of greatest uncertainty.

Susquehanna Shale Hills CZO: Designing a suite of models to explore Critical Zone function

Christopher Duffy, Yuning Shi, Ken Davis, Rudy Slingerland, Li Li, Pamela L. Sullivan, Yves Goddéris, Susan L. Brantley

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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, and soil atmospheres. No single model can accomplish all these objectives. We are designing a system of models or model capabilities to explore the CZ 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 and we are exploring how to incorporate important aspects of subsurface structure to simulate water, carbon, energy, and sediment fluxes. Only with a suite of modeling tools will we learn to forecast – earthcast -- the future CZ.

Assessing the Critical Zone at the Susquehanna Shale Hills CZO: Moving from "measure everything everywhere" to "measure just what we need"

Dave Eissenstat, Jason Kaye, Margot Kaye, Andy Neal, Henry Lin, Ken Davis, Tess Russo, Susan Brantley

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The expansion from 8 hectares in Shale Hills to 163 km^2 in the Shavers Creek watershed is an expansion from a zeroth-order catchment to a watershed with 3 HUC-12 watersheds. While the expansion allows us to remain in the Valley and Ridge physiographic province, the expansion will compel us to understand new lithologies (sandstone, calcareous shale, minor limestone), and the impact of multiple land uses including farming and small towns. *Our goal is to understand the interaction of WESS fluxes in a multilithologic and mixed landuse catchment by moving from our Shale Hills paradigm of "measure everything everywhere" to a new approach of "measure only what is needed*". Underlying our expansion is the approach we have pioneered to upscale data collection and modeling from 1D (boreholes, ridgetops) to 2D (hillslope transects, i.e. catenas) to 3D systems (catchments). In this regard, upscaling to Shavers Creek represents a moderately small but important step towards developing CZ expertise for the entire Susquehanna River Basin (SRB), the largest river basin in the Chesapeake Bay watershed in the mid-Atlantic region, U.S.A.

Southern Sierra CZO and Kings River Experimental Watershed (KREW)

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The Southern Sierra CZO (SSCZO) is a community platform for research on critical-zone (CZ) processes along a steep elevation transect where precipitation grades from dominantly rain to dominantly snow and ecosystems range from oak savannah biomes to subalpine forests. Spatial gradients in CZ properties and processes permit substitution of space for time, making the SSCZO an excellent natural laboratory for studying how the CZ responds to disturbance and how the water cycle drives CZ processes. The SSCZOs goals include: i) expand process-based understanding of the CZ in a sensitive, societally crucial ecosystem; ii) establish a foundation for long-term physical, biogeochemical and ecological studies; and iii) develop a framework for improving Earth System Models. KREW is a watershed-level, integrated ecosystem project for headwater streams in the Sierra Nevada. It was developed to: i) quantify the variability in characteristics of stream ecosystems and their associated watersheds in the southern Sierra Nevada; and ii) evaluate the effects of forest management (prescribed fire and uneven-aged, small group tree thinning) on the physical, chemical, and biological components of stream ecosystems. KREW is operated by the USFS, Pacific Southwest Research Station (PSW), which is part of the research and development branch of the USFS. Eight sub-watersheds and two integrating watersheds are fully instrumented to monitor ecosystem changes. The SSCZO includes 4 of the 10 nested KREW catchments. Under a long-term partnership with the Forest Service's Pacific Southwest Region, KREW has been a watershed research site since 2001. Hydrologic research at one of its catchments (Teakettle) began in the 1950's. The SSCZO infrastructure includes a 2500-m transect of flux towers and associated instrumentation, plus the well-instrumented Providence catchments at KREW. At Providence, instrumentation includes 2 meteorological stations, a 60-m flux tower, a 60-node wireless embedded sensor network, 215 EC-TM sensors for volumetric water content, over 110 MPS sensors for matric potential, 60 snow-depth sensors, meadow piezometers and wells, sap-flow sensors, stream gauges and water-quality measurements.

Eco-hydrology at the CZO: linking plants, water and geology

C. Tague, M. Goulden, and the Southern Sierra CZO team

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Eco-hydrology is a broad and growing research area that investigates interactions between vegetation (its structure and composition) and the cycling of water. The multi-disciplinary, multi-measurement CZOs are well situated to support advances in eco-hydrologic research. In particular, the strong geologic focus of the CZOs offers a unique opportunity to investigate how soil and landform development interact with eco-hydrologic processes and how these interactions influence responses to climate and landuse change. Some examples from the Southern Sierra

CZO demonstrate some important linkages soil and landform properties and eco-hydrologic processes at geologic to diurnal temporal scales and pore to watershed spatial scales.

What controls organic carbon storage in and flux from the Critical Zone?

Alain Plante and the members of the Cross-CZO Working Group on Organic Matter

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The Cross-CZO Working Group on Organic Matter seeks to develop a process for identifying current and proposed methodologies for organic matter analysis across the CZO network, and demonstrate how these can support the development of overarching questions and common measures. To this end, each CZO site has been asked to contribute their questions, hypotheses, and objectives, as well their experimental/modeling/monitoring approaches, from their original proposals to NSF-CZO in response to the following questions:

- What controls organic carbon storage in biomass above the critical zone?
- What controls organic carbon storage and fluxes in the mineral matrix (surface soils, deep soils, saprolite, bedrock)?
- What controls gaseous exports of carbon from the critical zone?
- What controls dissolved exports of carbon from the critical zone?

The task for each site is to pin a single 8.5x11 page to the poster for each of the questions that is relevant to their site. The poster will then serve as a focal point for subsequent focused discussions during the breakout sessions.

CZ-Tope: A multiple isotope approach to quantify Critical Zone processes – the Susquehanna Shale Hills CZO as an example

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As a part of the *CZ-Tope* initiative, Susquehanna Shale Critical Zone Observatory is measuring multiple isotopes to decipher how geochemical, geomorphological, hydrological and biological processes together with anthropogenic influence the evolution of the Critical Zone (CZ).

Controls of CZ properties: Meteoric ^{10}Be concentrations together with U-series show higher regolith production rates and transport efficiency on shallow south-facing slopes than that on steep north-facing slopes whereas regolith fluxes are similar. Excess ^{210}Pb and ^{137}Cs indicate soil mixing. CZ processes, stores, and fluxes: SF6, ^{3}H and CFCs give constraints on groundwater residence times providing a framework to model hydrological conditions. C isotopes reveals that especially ankerite dissolution plays a major role for CO_2 consumption. Metal isotopes are developing tools to trace weathering processes and element fluxes directly. Fe, Mg, B and Li isotopes disclose weathering, transport and redeposition mechanisms for these elements which can vary throughout the year due to changing hydrological conditions and impact of the vegetation. Isotopes of toxic metals as Pb, Cd and Zn isotopes are promising tracers to evaluate anthropogenic versus natural sources showing that former iron production had a great impact.

Vegetation-regolith dynamics influence water and nutrient fluxes: O and H isotopes describe hydrological processes showing that transpiration reduces soil water-groundwater-stream water interaction. ^{87}Sr/^{86}Sr and Ge/Si ratios but also Ca isotopes are utilized to investigate the nutrient access whereas D is used to model the rooting depth of trees.

In October 2013, we initiated a new sampling campaign to collect stream, soil and groundwater that are available for cross isotopic comparisons at Shale Hills. We are enthusiastic that this venture will serve as a platform for cross-CZO research to elucidate CZ processes across varying lithologies, tectonic settings, and climatic conditions.

CZ-Tope at the Calhoun CZO

Jason Austin, Allen Bacon, Sharon Billings, Alexander Cherkinsky, Daniel Richter, Paul Schroeder, *Contact:* austinj1@uga.edu

The focus of CZ-tope research at the Calhoun Critical Zone Observatory (CCZO) is assessing the degree to which the highly eroded post-agricultural soils have been restored to some “pristine” condition. These methods include a 40 year time-series of ^{13}C and ^{15}N depth profiles in space-for-time Loblolly Pine plots, real-time soil gas CO_2 ^{13}C measurements, ^{13}C of gibbsite-occluded CO_2, and the variation of ^{14}C concentrations of soil organic material over 50 years. Each of these will be employed in the same areas of the CCZO to improve our understanding of the evolution of the soil from highly eroded bare ground to pine forest over the past 60 years. ^{14}C, ^{13}C and ^{15}N of soil organic material will offer insight into its response to changing vegetation over time, while ^{13}C of gibbsite-occluded CO_2 will offer insight into the movement of secondary minerals above the Bt Horizon. These results will be combined to assess whether the soil is acting as a well-mixed integrated system, fully recovered from the effects of agriculture.

In order to better constrain the timing of these processes, and as a way to compare these soils to other observatories in the Critical Zone Network, meteoric ^{10}Be concentration is being employed to determine the soil residence time. A new method of accounting for ^{10}Be that is lost from the soil through leaching offers an opportunity to better understand the time frames under which soil forming processes occur. Application of this method to all CZOs across the network would allow for better comparison of the time-dependence of soil forming processes under a wide range of conditions.

THEME 1

T1A. Geophysical research and Critical Zone processes at the Reynolds Creek CZO

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CZOs: Reynolds Creek
Applicable themes: Theme 1, Theme 3

The vast majority of Critical Zone research has focused on near surface and above ground processes while the lower boundary is generally poorly characterized and associated processes poorly quantified. Recent advances in geophysics, along with a greater appreciation of potential applications of geophysical data, provide an opportunity to improve this situation and potentially lead to important scientific breakthroughs. In August of 2014, an intensive geophysical campaign was conducted at the RC CZO. Preliminary work by Boise State University was followed by extensive surveys conducted by a crew from the Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG). Work focused on experimental sites we had previously identified as potentially benefitting from additional knowledge of lower boundary conditions. We show preliminary data from four sites, a groundwater recharge zone where we use geophysical data to understand observed water table responses, two sites on contrasting geology where we used intensive surface measurements to understand landscape evolution and streamflow response to rainfall and snowmelt inputs and a desert site, where groundwater flows create springs and saline soils. We intend to follow this work with more detailed surveys and time series data.

T1B. Geophysical imaging of the depth to fresh bedrock under the steep argillite hillslopes of the the Eel River CZO

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CZOs: Eel River
Applicable themes: Theme 1, Theme 3

The bottom boundary of the of the critical zone may be defined as the three dimensional surface below which bedrock is unweathered. This boundary, which we call Z_b, the elevation of bedrock, influences geomorphic, hydrologic, geochemical, ecological and atmospheric processes yet, despite its importance, is unmapped and its controls are poorly known. Current models that describe the evolution of Z_b across a landscape emphasize top-down processes (e.g. infiltration of water and gases) and strong interactions between surface and subsurface processes. An alternative bottom-up model assumes that the chronic saturation of fresh bedrock of low permeability poses a vertical limitation to top-down weathering processes. Here, we present the results of a collaborative field campaign with the Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG) aimed at mapping Z_b within the Eel River Critical Zone Observatory to evaluate models that describe the evolution of Z_b. Mapping was accomplished via non-invasive geophysical imaging on 4 hillslopes along the South Fork Eel River or its tributary, Elder Creek. One of the sites is an intensively instrumented 4000 m^2 hillslope named Rivendell where 12 wells that penetrate Z_b have been drilled and climatic and hydrologic variables have been monitored since 2007. Direct observations of Z_b from Rivendell as well as data from geophysical surveys conducted on outcrops of fresh and weathered rock are used to aid in the interpretation of the hillslope geophysical surveys. We performed seismic refraction and electrical resistivity surveys on longitudinal profiles down hillslope axes as well as along ridge lines to determine the spatial pattern of weathering within this steep landscape. The surveyed sites are all underlain by slightly metamorphosed Franciscan marine mudstones and sandstones and vegetated by a mixed canopy of conifers and hardwoods. However, hillslope geometries and orientations vary thus allowing us to evaluate models for Z_b and the interaction between the surface and subsurface processes that controls weathering on hillslopes. Systematic mapping of the weathered rock zone underlying ridge and valley topography via drilling and geophysical imaging is expected to advance our understanding of the controls on the evolution of the critical zone.

T1C.Drilling and GPR in the Río Icacos watershed of the Luquillo CZO, Puerto Rico

Xavier Comas[1], William Wright[1], Scott Hynek[2], Joe Orlando[2], Heather Buss[3] and Susan L. Brantley[2,4]

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CZOs: Luquillo
Applicable themes: Theme 1, Theme 3

This research is part of the current efforts to characterize weathering rates and patterns in the Luquillo CZO in Puerto Rico. The Rio Icacos watershed in the Luquillo Mountains shows very unique weathering rates that result in the rapid formation of altered materials (i.e. regolith) in the critical zone. The bedrock in the Rio Icacos watershed is formed by quartz diorite with a system of heterogeneous fractures that result in the formation of corestones and associated spheroidal fracturing and rindlets. Previous studies using drilled boreholes have shown that regolith thickness increases with topography, from a meter or less in low topographic areas near the knickpoint, to 20-30 m in areas with high topography characterized by hornfels-facies ridges. In this study we used a suite of hydrogeophysical methods (mainly ground penetrating radar, GPR, and terrain conductivity measurements), to characterize regolith thickness and the lateral distribution of fracturing along km-long transects across topographic gradients. Fracturing zones were associated with areas of concentrated chaotic reflections and diffraction hyperbolas (in contrast to reflection-free areas) in the GPR and contrasts in electrical conductivity from terrain conductivity measurements. This research demonstrates the potential of hydrogeophysical measurements for understanding variability of bedrock-regolith interface in the Icacos watershed at large (i.e. km) scales.

T1D. Human impact intertwined with glacial legacy: hydro-geomorphologic exploration using LiDAR data

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CZOs: Intensively Managed Landscapes
Applicable themes: Theme 1, Theme 4

Intensively managed landscapes (IMLs) in the Midwestern United States are heavily modified by agriculture, artificial drainage, deforestation, urbanization, and wetland destruction. These landscapes have been shaped by repeated glacial events over geologic time scales followed with rapid human modifications for agriculture and drainage that are overlaid on extremely low gradient stream networks.

In this study, using LiDAR data from the Upper Sangamon River Basin in Illinois, we attempt to understand how the long-term glacial legacy has shaped the landscape and what is the impact from short-term human activities, such as channel straightening and periodic dredging. Therefore, we evaluate the present-day dynamics of landscapes by attempting to address several questions, like watershed equilibrium conditions, the degree of maturity in the river valley and the relationship between channel migration rate and spatial distributions of terraces and floodplains.

High-resolution LiDAR data is ideal for such a study as it reveals the impact of both glacial episodes and human activities. Methods used for extraction of useful information from LiDAR data include the TerEx tool, Stream Profiler, and Hec-GeoRas, among others. An integral method is built based on stream power incision model to obtain sub-basin steady state condition. These features help to reveal local and global watershed properties. A bounded relationship between terraces/floodplains, sinuosity, cross section maturity, as well as sub-basin equilibrium condition is explored. In general, we find that the glacial legacy and present-day human activity have opposed each other in regards to the sub-basin equilibrium conditions of USRB. These studies of historic and recent floodplain dynamics from high-resolution topography will enhance our understanding of intensively managed landscapes, which will strengthen the understanding of watershed dynamics under human impact.

T1E. Coevolution of topography, soils, and vegetation in upland landscapes: Using cinder cones to elucidate ecohydrogeomorphic feedbacks

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CZOs: Santa Catalina Mountains-Jemez River Basin
Applicable themes: Theme 1

In this study we expanded the range of the CZO network to include cinder cones in the western U.S. The focus of our study was on the development of slope-aspect-induced asymmetry in topography and soil development as a function of time in cinder cones that ranged in age from 1 to 1500 kyr. North-facing portions of cinder cones have steeper topographic gradients and higher mean vegetation cover (i.e. Normalized Difference Vegetation Index, or NDVI, values) under current climatic conditions compared. Drainage density is also higher on north-facing portions of cones in three of the four volcanic fields. Both and north and south aspects exhibited an increase in solum depth, increased clay and Fe-oxide content with age, and a threshold in argillic horizon formation near 200 kyr, with argillic horizons developing earlier on south facing slopes. Differences in topography and soil development between north- and south-facing sides were not present initially but developed progressively over time. The data also indicate a prominent role for Quatenary climate change and dust accumulation on early stages of pedogenesis and argillic horizon formation. To test alternative hypotheses for the slope-aspect control of topography, we developed a numerical model for cinder-cone evolution and a methodology for estimating local paleovegetation cover as a function of elevation, slope aspect, and time within the Quaternary. The numerical model results demonstrate that rates of colluvial transport were higher on south-facing slopes in at least three of the four cinder cones fields. Our paleovegetation analysis suggests that, in the two Arizona volcanic fields we studied, higher rates of colluvial transport on south-facing hillslopes were the result of greater time-averaged vegetation cover and hence higher rates of sediment transport by floral bioturbation.

T1F. Do meteoric ^{10}Be inventories underestimate Critical Zone residence times?

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CZOs: Calhoun
Applicable themes: Theme 1

Meteoric ^{10}Be inventories were coupled with with mass balance of ^{9}Be (bedrock to 18.3 meters soil-saprolite profile) to estimate the soil residence time (SRT) of a biogeomorphically stable Ultisol. We estimate RT after correcting for observed ^{9}Be losses, which indicate that more than half of the 9Be weathered from primary minerals had been leached from the soil and saprolite. Our estimates of minimum RT range between 1.3–1.4 Ma and between 2.6–3.1 Ma under high and low estimates of atmospheric ^{10}Be deposition (2.0 and 1.3 × 10^{6} atoms cm^{-2} yr^{-1}, respectively). Denudation rates of the physiographic region corroborate our residence time estimates. These estimates at minimum double to quadruple the pedogenic time constraints of interfluves on the Southern Piedmont, and demonstrate that assumptions of complete meteoric ^{10}Be retention in acidic soil systems need quantification. The results may have consequences for soil, sediment, river, and ocean research using meteoric ^{10}Be. We can propose an efficient cross-CZO project in which already sampled deep cores can be analyzed for ^{9}Be to better understand the mobility of Be in the CZ environment.

T1G. Transmisivity and storetivity of a fractured hardrock aquifer in the Sierra Nevada Foothills

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Applicable themes: Theme 1, Theme 3

This study was conducted to characterize the fractured granite aquifers in the foothill areas of SW Sierra Nevada, in Madera County of California, by evaluating the best values of Transmisivity and Storativity of the aquifer through long term pumping tests.

Theoretical feasibility studies of the aquifer-testing methods were first conducted, with the conclusion that the constant-drawdown pumping method, as compared to the constant-discharge and step-drawdown methods, was more appropriate for the

site which did not cause the wells to run dry due to limited water discharge from the local fractures. Lineaments studies were carried out using Digital Elevation Models and GIS to delineate the directions and depths of the major fractures in the region. The multiple-borehole tests were conducted and ran for up to 34 days, involving two test wells and 17 observation wells at a 540-acre study area enclosing Madera Ranch Quarry. Two hypotheses (radial or linear flow patterns) were assumed and tested using the field experimental data.

Variations in the results from different pumping tests suggested that both the flow patterns (radial or linear) and the model parameters (transmisivity and storetivity) were scale-dependent, and the "scale effect" is related to heterogeneity within the aquifer, not to the testing methods. The long-term pumping tests at two wells on the site suggested that, to characterize a large area of the fractured hardrock aquifer, at least 15 days was required to get a realistic trend line of drawdown versus time.

The long term pumping results also indicated that drawdowns at observation wells as far as 4,000 feet radius can still be influenced by linear flow intersecting the pumping well, but the influence radius (with > 0.5 ft drawdown) did not exceed 5000 feet. Models that assumed uniform aquifer properties can not be applied to the fractured rock formations, although some generalization can be made.

T1H. Soil inorganic carbon formation: Can parent material overcome climate?

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CZOs: Reynolds Creek
Applicable themes: Theme 1, Theme 2

Soil carbon is the third largest reservoir of carbon and is composed of both organic and inorganic constituents. However, the flux of soil carbon within the global cycle is not fully understood. While organic carbon is often the focus of research, the factors controlling formation of soil inorganic carbon (SIC) are complex.

Climate is largely accepted as the primary control on SIC, but the role of parent material is less clear. We hypothesize that effects of parent material are significant and that SIC accumulation will be greater in soils formed from basalts than granites due to the finer textured soils and more abundant cations.

This research is being conducted in the Reynolds Creek Watershed in southwestern Idaho. Reynolds is an ideal location because it has a range of gradients in precipitation (250-1200 mm), ecology (sagebrush steppe to juniper), and parent material (an array of igneous and sedimentary rock) over a relatively small area. Approximately 20 soil profiles will be excavated in the watershed to capture the effects of differing climate and parent material on soil characteristics. Samples at each site will be collected for analysis of SIC content and grain size distribution.

Initial field data suggests that soils formed over basalts have a higher concentration of SIC than those on granitic material. If precipitation is the only control on SIC, we would expect to see comparable amounts in soils formed on both rock types within the same precipitation zone. However, observations suggest that for all but the driest sites, soils formed over granite had no SIC detected while basalt soils with comparable precipitation had measurable amounts of SIC. Grain size distribution appears to be a large control on SIC as the sandier, granitic soils promote deeper percolation.

This ongoing research will clarify the processes involved in SIC formation and identify the situations where it is an atmospheric source or sink.

T1I. Towards improved high-resolution land surface and hydrologic reanalysis using a physically-based hydrologic model and data assimilation

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Applicable themes: Theme 1

A coupled, physically-based land surface hydrologic model, Flux-PIHM, has been developed by incorporating a land-surface scheme into the Penn State Integrated Hydrologic Model (PIHM). Flux-PIHM has been implemented and manually calibrated at the Shale Hills watershed (0.08 km2), part of the Susquehanna Shale Hills CZO. A Flux-PIHM data assimilation (DA) system has been developed by incorporating an Ensemble Kalman Filter (EnKF) for model parameter and state estimation. Sensitivity experiments isolated the model parameters that are essential for optimization, and identified interactions between subsurface and land surface processes. Synthetic DA experiment results showed that the DA system is able to provide accurate estimates of key parameters. A data requirements test showed that DA of discharge, single-point soil water content, and watershed-average land surface temperature can provide an accurate representation of watershed hydrology and land surface energy balance. Given real observations, the EnKF converged and the estimated parameters performed well. Flux-PIHM is also able to resolve the observed 101 m scale soil moisture pattern at Shale Hills when an appropriate map of soil hydraulic properties is provided.

The observational domain at Shale Hills is being expanded to include two additional catchments with different bedrock (sandstone) and land use (agriculture). These catchments will be used to study the scale and landscape dependencies of Flux-PIHM parameters and up-scale the Flux-PIHM EnKF system to the Shavers Creek (163 km^2) watershed.

Observations of key variables (e.g., MODIS surface temperature, SMAP soil moisture, and USGS gauging stations), and forcing and input data (e.g. NLDAS-2 atmospheric reanalyses, SSURGO soil databases and NLCD land cover databases) are available at national to global scales. Therefore the Flux-PIHM DA system could be expanded to provide regional scale, high resolution, land surface and hydrologic reanalyses.

T1J. Elucidating hydro-geochemical controls on chemical weathering at the Susquehanna Shale Hills CZO (SSHCZO) Using RT-Flux-PIHM: an integrated hydrological-reactive transport model at the watershed scale

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Applicable themes: Theme 1

Despite recent advances, understanding the complex hydro-geochemical interactions at the watershed scale has remained challenging. In particular, the influence of topographic and hydrological conditions on chemical weathering is poorly understood. Here we develop a finite volume based code, RT-Flux-PIHM, to mechanistically understand and quantify the coupled hydrological and geochemical processes at the Susquehanna Shale Hills Critical Zone Observatory (SSHCZO). The code solves for hydrological, land surface, and reactive transport processes in a distributed manner, which allows integrated understanding on the spatial and temporal distribution of mineral dissolution and chemical weathering. This model allows us to investigate the effects of different perturbations (climatic, hydrological, geochemical, etc.) on stream and pore water chemistry. RT-Flux-PIHM has been calibrated with field measurements for groundwater level and stream fluxes in 2009. The model can reproduce the evolution of the non-reactive tracer Cl(-I) and the weathering element Mg(II) primarily derived from chlorite dissolution. The reproduction of measured Mg(II) was contingent upon using a specific surface area for chlorite that is approximately one order of magnitude lower than laboratory-measured value.

We found that the clays weathered under far from equilibrium conditions. The weathering rates were positively correlated to the local groundwater level and soil water saturation. Across the watershed, convergent-flow depressions (swales) resulted in highest dissolution rates.

T1K. Exhumation by landslide initiated debris flows in the 2013 Colorado Front Range storm

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CZOs: Boulder Creek
Applicable themes: Theme 1

What is the role of rare events in the exhumation of steep landscapes? We use the “millennial” storm that hit the Front Range, Colorado, USA, in September 2013 to explore this question in a semi-arid landscape. More than 250 mm of rain fell over a ~100 km swath of the Front Range in a 5 day period; totals in some areas exceeded average annual precipitation. The storm triggered over 1300 landslides and debris flows in four major Front Range watersheds (Coe et al., 2014).

We created a DEM of difference in the 102 km^2 area of overlap using aerial LiDAR surveys, acquired in August 2010 by the Boulder Creek CZO and in November 2013 by FEMA. The study region covers the Boulder Creek watershed from the middle of the Rocky Mountain Surface to the western edge of the Plains, and encompasses Boulder Canyon, Fourmile Canyon, and the 26-km^2 2010 Fourmile Canyon Fire. Precambrian crystalline rocks underlie most of the area, although the eastern

margin includes sedimentary rocks in hogbacks along the mountain front. We computed site characteristics and volumes for 120 failures.

Within the crystalline terrain, most failures occurred at or near the bedrock interface at 0.5-1 m depth, often near the ridgelines downslope of bedrock outcrops. Failures occurred on slopes of 25-40°, and show no slope aspect bias. Failures evolved into debris flows that scoured chutes from the initiation site down to the master stream, traveling at up to 10 m/s. We saw little evidence of deposition; most debris was entrained in the flooding master streams and exited the mountain front. Evacuated sediment volumes represent several hundred years of exhumation within the source basins, based on published long-term erosion rates calculated from ^{10}Be concentrations. We infer that, even in this semi-arid environment, debris flows initiated by rare shallow landslides are a dominant process for evacuating sediment from steep channels and delivering it to the plains.

T1L. Controls on the Mg cycle in the tropics: insights from a case study at the Luquillo Critical Zone Observatory

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CZOs: Luquillo
Applicable themes: Theme 1

To better constrain the mechanisms controlling short-term Mg dynamics in the tropics, we sampled critical zone compartments of a catchment covered by thick, highly weathered regolith. Our Mg and δ^{26}Mg data indicate that rain is the main source of Mg throughout the regolith, and we do not find Mg isotope fractionation from uptake by vegetation. In addition to rain and weathering inputs, a heavy excursion in Mg isotope ratios at ~1 m depth indicates a fractionation process, likely sorption-desorption or clay dissolution. Stream water reflects mixing of rain and a heavy end-member, likely water flowing through deep fractures in the bedrock.

T1M. Fe^{2+} catalyzed iron atom exchange and re-crystallization in the Luquillo CZO soils

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Applicable themes: Theme 1

Aqueous ferrous iron (Fe^{2+}(aq)) is known to transfer electrons and exchange structural positions with solid-phase ferric (FeIII) atoms in many Fe minerals. However, this process has not been demonstrated in soils or sediments. In a 28-day sterile experiment, we reacted ^{57}Fe-enriched Fe^{2+}(aq) ($^{57/54}$Fe=5.884±0.003) with a tropical soil (natural abundance $^{57/54}$Fe=0.363±0.004) under anoxic conditions and tracked $^{57/54}$Fe in the aqueous phase and in sequential 0.5 M and 7 M HCl extractions targeting surface-adsorbed and bulk-soil Fe, respectively; we also analyzed the reacted soil with ^{57}Fe Mössbauer spectroscopy. In 28 days, the aqueous and bulk pools both moved ~7% toward the isotopic equilibrium ($^{57/54}$Fe=1.33). Using a kinetic model, we calculate final adsorption-corrected $^{57/54}$Fe ratios of 5.56±0.05 and 0.43±0.03 in the aqueous and bulk pools, respectively. The aqueous and surface/labile Fe initially exchanged atoms rapidly (10 – 80 mmol kg^{-1} d^{-1}) decreasing to a near constant rate of 1 mmol kg^{-1} d^{-1} that was close to the 0.74 mmol kg^{-1} d^{-1} exchange-rate between the surface and bulk pools. Thus, after 28-days we calculate aqueous Fe has exchanged with 20.1 mmol kg^{-1} of bulk Fe atoms (1.9% of total Fe) in addition to the 17.0 mmol kg^{-1} of surface/labile Fe atoms (1.6% of total Fe), which have likely turned over several times during our experiment. Extrapolating these rates, we calculate a hypothetical whole-soil turnover time of ~ 3.6 yrs. Furthermore, Mössbauer spectroscopy indicates the soil-incorporated ^{57}Fe label re-crystallized as short-range-ordered (SRO) FeIII-oxyhydroxides. Our work suggests Fe atom exchange can occur in soils at rates fast enough to impact ecological processes reliant on Fe minerals, but sufficiently slow that complete Fe mineral turnover is unlikely before a change (i.e., a seasonal shift) in redox conditions.

T1N. Linkages between soil Fe reduction rates and the characteristics of redox fluctuations at the Luquillo CZO

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Applicable themes: Theme 1

The biogeochemistry of iron plays an important role in soil ecosystems and can be coupled to the carbon cycle during shifts in redox. A key parameter of redox fluctuations is the frequency in which a soil shifts from oxic to anoxic conditions. We hypothesize that the rate of FeIII reduction will be truncated if soil redox fluctuates faster than the characteristic response time for an anoxic population of bacteria to thrive. To test this hypothesis, we subjected soils from the upper 10 cm of the Bisley Watershed, Luquillo CZO, PR, to a 40-day redox oscillation experiment. We kept the time exposed to anoxic vs. oxic conditions (the redox dwell ratio) at 6:1 throughout the experiment. We pre-conditioned the soil microbial community by exposing four replicated soil slurry reactors to two redox cycles at 168 h (7 day) frequencies followed by one redox cycle at a 280 h (~12 day) frequency. Then we split the treatment (2 reps each) as follows: (i) 1 redox cycle at 280 h frequency or (ii) 5 redox cycles at 60 h frequencies. Throughout the experiment, we measured 0.5 M HCl-extractable FeII every 12 h to 4 days. We found FeII concentrations increased linearly during each anoxic cycle, with rates of FeII production increasing after each oxidation event from 0.17 to 1.40 mmol kg^{-1} h^{-1} over the full course of the experiment (168 h + 280 h cycles). When we introduced shorter redox cycles (60 h) at the end of the experiment, the rate of FeII production at first decreased to 0.12 mmol kg^{-1} h^{-1}, but then remarkably increased to 1.95 mmol kg^{-1} h^{-1} by the last cycle. This suggests that redox oscillations and the frequency of those oscillations can impact rates of FeII reduction, but predicting that response is not straightforward. Our work in the coming year will vary the time soils are exposed to oxic and anoxic conditions (the dwell time ratio), and monitor organic carbon stabilization and destabilization (CO2 production).

T1O. A Mach-Zender holographic microscope for field microbiology

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Applicable themes: Theme 1, Theme 2

The development of microscopic techniques over the past two decades has revolutionized microbiology. However, there are still crucial processes whose details elude us, especially those involving motility: for example, feeding behavior of microorganisms in bodies of water, or formation of biofilms on surfaces. These types of experiments are even more challenging for prokaryotes, which range in size from several hundred nanometers to a few microns. An emerging technique to address these questions is Digital Holographic Microscopy (DHM) DHM is a well-established imaging technique that uses the interference of light to record and reproduce three-dimensional magnified images of objects; real-time DHM has been impractical for technological and computational reasons until recently. This approach has several advantages over ordinary brightfield microscopy that make it ideal for field microbiology, in particular a larger depth of field, hands-off operation, robustness regarding environmental conditions, and large sampling volumes with quantitative 3D records of motility behavior. Despite these promising features, there has so far been very limited application of DHM to biology, and most existing instruments are limited in performance by their particular (e.g. in-line, lens-less, phase-shifting) approach to holography. These limitations can be mitigated with an off-axis dual-path configuration. Here we describe the design and implementation of a design for a Mach-Zehnder-type holographic microscope with diffraction-limited lateral resolution, with intended applications in environmental microbiology. We achieve sub-micron resolution and three-dimensional tracking of three prokaryotic and two eukaryotic test strains designed to represent the different modes and speeds of microbial motility.

T1P. Investigating the influence of subsurface heterogeneity on chemical weathering in the Critical Zone using high resolution reactive transport models

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CZOs: Boulder Creek
Applicable themes: Theme 1

The critical zone (CZ) represents a major life-sustaining realm of the terrestrial surface. The processes controlling the development and transformation of the CZ are important to continued health of the planet as human influence continues to grow. The CZ encompasses the shallow subsurface, a region of reaction, unsaturated flow, and transport. Chemical weathering in the subsurface is one of the important processes involved in the formation and functioning of the CZ. We present two case studies of reactive transport modeling to investigate the influence of subsurface heterogeneity and unsaturated flow on chemical weathering processes in the CZ. The model is implemented using the reactive transport code PFLOTRAN. Heterogeneity in subsurface flow is represented using multiple realizations of conductive fracture networks in a hillslope cross-section. The first case study is motivated by observations at the Boulder Creek Critical Zone Observatory (BCCZO) including extensive hydrologic and geochemical datasets. The simulations show that fractures greatly enhance weathering as compared to a homogeneous porous medium. Simulations of north-facing slope hydrology with prolonged snowmelt pulses also increases weathering rates, showing the importance of slope aspect on weathering intensity. Recent work elucidates deteriorating water quality caused by climate change in the CZ of watersheds where acid rock drainage (ARD) occurs. The more complex reactions of ARD require a customized kinetic reaction module with PFLOTRAN. The second case study explores the mechanisms by which changes in hydrologic forcing, air and ground temperatures, and water table elevations influence ARD. For instance, unreacted pyrite exposed by a water table drop was shown to produce a 125% increase in annual pyrite oxidization rate, which provides one explanation for increased ARD.

T1Q. Ordering interfluves: a simple proposal for understanding Critical Zone evolution and function

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CZOs: Calhoun
Applicable themes: Theme 1, Theme 3, Theme 4

The Earth's critical zone (CZ) is the integrated life-supportive system between the atmosphere and the deepest bio-geoweathering front of geologic materials. When human beings are added to the natural workings of the critical zone, great uncertainty is introduced in understanding the consequences. As we begin our research at our Calhoun Critical Zone Observatory (CCZO) in the Southern Piedmont region of SC, we propose an ordering system for upland interfluves that is to an extent a reciprocal of the widely used Hortonian system that hydrophysically orders stream and river systems. At the Calhoun CZO, interfluve order and corresponding erosion and intra-critical zone regimes inform us about the evolution and functioning of hydrologic, geomorphologic, biogeochemical, and biotic systems. It also informs us to the CZ response to historic land use change and the contemporary functioning and management of the CZ. With LiDAR and DEM mapping enabling new quantitative research of landscape and critical zone structure and function, we propose that many physiographic regions will benefit from a system that orders interfluves.

T1R. Aspect as a source of heterogeneity in carbon & water fluxes in space and time

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Applicable themes: Theme 1, Theme 2, Theme 3

Current projections of climate change in the southwestern U.S. suggest increasing temperatures and reduced summer precipitation. High temperature and water deficits have major influence on ecosystem functioning by restricting plant growth and productivity. Within our Critical Zone Observatory in southern Arizona (SCM-JRB CZO), we monitor ecosystem scale carbon and water fluxes using eddy covariance. While this whole-ecosystem metric if of great use as an integrating measure of carbon and water dynamics over time and ecosystem sensitivities to abiotic stressors, details on spatial heterogeneity are not captured. We have supplemented our eddy covariance monitoring with distributed measures of carbon and water flux from the soil and overstory vegetation across aspect and soil parent material to better quantify the causes and consequences of spatial heterogeneity through time. There are limited data on how physical attributes of a landscape influences plant sensitivity to temperature and drought stress, and, thus, these dynamics are not often captured in ecosystem models. Given that (i) soil parent material influences water holding capacity of the soil; (ii) aspect influences how incoming energy drives evaporative loss of soil water, creating warmer and drier environments on south/east faces; and (iii) seasonality drives temporal patterns of soil moisture recharge, we aimed to examine the influence of these processes on carbon and water fluxes at the soil surface and from vegetation due to variation in aspect.

Conducting these spatially distributed measurements are time consuming, particularly in complex terrain over larger areas. Looking forward, we are examining the potential for low-altitude remote sensing using unmanned aerial vehicles outfitted with thermal and multi-spectral camera arrays to quantify patterns of transpiration, soil evaporation, NDVI, needle browning due to moisture stress, overall phenology due to aspect.

T1S. Aspect-related topographic asymmetry at the Susquehanna Shale Hills Critical Zone Observatory

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CZOs: Susquehanna Shale Hills
Applicable themes: Theme 1

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. We use a combination of high resolution, LiDAR-derived digital topography and the cosmogenic radionuclide meteoric ^{10}Be to measure rates of regolith transport along six hillslopes at the Susquehanna Shale Hills Critical Zone Observatory (SSHO), test transport rules, and elucidate the mechanisms acting to transport regolith materials. Topographic observations reveal a systematic asymmetry at SSHO, where north-facing hillslopes exhibit steeper gradients than south-facing hillslopes. Despite this asymmetry, our meteoric ^{10}Be results suggest that regolith is transported equally along all six hillslopes, and that the landscape is steadily lowering at ~ 20-30 m/My. Tests of frequently invoked transport rules suggest that downslope regolith transport is depth-dependent at SSHO, and that regolith transport efficiency is consistently higher on south-facing hillslopes than north-facing hillslopes by a factor of two. Our results imply that subtle differences in insolation between north- and south-facing slopes impact the frequency of dilational regolith transport processes (i.e., wetting-drying cycles, freezing-thawing cycles), which in turn affect the efficiency of downslope regolith transport. This interpretation is supported by ecologic and hydrologic observations completed at SSHO. We contend that the differences in regolith transport efficiency between north- and south-facing slopes at SSHO have conspired to drive the evolution of asymmetric topography over geologic time.

T1T. Measuring aspect-related variability in fire and erosion, and extrapolating results to larger regions

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Applicable themes: Theme 1, Theme 4

We coupled radiocarbon dating of charcoal within alluvial fan deposits with measurements of deposit volumes reconstructed from airborne LiDAR data to yield time-series of fire and erosion for small catchments incised into north and south-facing land surfaces, within the Dry Creek Experimental Watershed (DCEW) of the Reynold's Creek CZO. During the Holocene, catchments incised into north-facing slopes burned during different time periods than south-facing slopes, and more often produced debris flows rather than sheet floods. Despite these differences, and contrasting critical zone characteristics, catchment-averaged erosion rates varied substantially within aspect groupings and were not significantly different between north and south-facing catchments. North-facing slopes produce steeper, shorter catchments reminiscent of debris-chutes mantled by thicker, finer-grained, organic-rich and less dense soils that appear to retain more water for plant use, and likely reduce subsurface runoff. We hypothesize that denser vegetation, lower runoff potential, and less frequent fires and erosion on north-facing slopes allow north-facing land surfaces to remain stable at steeper slope angles and produce more developed soils, but that when burned, thicker accumulated soil and steeper gradients produce a larger erosional response, in the form of debris flows. At national scales, we have characterized and mapped remotely-measurable aspect-related variability in land forms and land cover for valley segments throughout the landscape. These maps reveal that the DCEW lies within a region of consistent aspect-related differences in landforms, suggesting that the observed differences in fire and erosion with aspect may apply to this larger area. Coupling field-scale assessments of processes with broad scale maps may facilitate the delineation of regions within which landscapes respond similarly to climate, and allow CZO results to be extrapolated to larger areas.

T1U. Role of aspect and lithology in controlling soil carbon and other Critical Zone properties

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CZOs: Reynolds Creek
Applicable themes: Theme 1, Theme 2

Semi-arid environments make up a large percentage of the world's terrestrial ecosystems, and climate is a major factor influencing soil carbon storage and release. However, the roles of local controls such as parent material, aspect and microtopography have received less attention and are important for consideration in soil carbon modeling. The purpose of this study is to understand the role that parent material, aspect and micro-topography play in storage and release of soil carbon along an elevation gradient in a semi-arid climate. Johnston Draw (JD) is a first order watershed within the Reynolds Creek Critical Zone Observatory in southwestern Idaho with underlining late cretaceous, granitic Idaho batholith bedrock. Upper Sheep Creek (USC) is a first order watershed consisting of basalt. Both watersheds were chosen for this project due to similar size, aspect, elevation, vegetation and for the contrast in parent material. Two transects, totaling approximately nine soil pits, were excavated on both the north and south facing slopes of each watershed running parallel to the water channel. Soil carbon was generally higher in basalt compared to the granite parent material in pits with similar aspect, elevation and vegetation. Preliminary data using soil organic matter (SOM) as a proxy for organic carbon (OC) and soil water dynamics showed that percent OC declines markedly with elevation in JD and soil depth at lower elevations and is more homogenous throughout the profile moving up elevation (1646 meters 4.3-9.7%; 1707 meters 6.87-3.83%). Similarly, aspect controls patterns of SOM at depth more strongly at lower elevations. Findings from our study suggest that parent material and topography may play as important roles in semi-arid ecosystems as climate factors in controlling soil carbon storage.

T1V. Three-dimensional prediction of soil physical, chemical, and hydrological properties in a forested catchment of the Santa Catalina CZO

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Applicable themes: Theme 1

Understanding critical zone evolution and function requires an accurate assessment of local soil properties and the processes that control local soil development. The utilization of mass-preserving spline functions enable the extrapolation of soil properties with depth, extending predictive functions to three-dimensions (3D). The present study was completed in a granite subcatchment of the Marshall Gulch catchment, located in the Santa Catalina Mountains, as part of the Santa Catalina-Jemez Mountains Critical Zone Observatory. Twenty-four soil pits were excavated and described following standard procedures. Mass-preserving splines were extrapolated for mass and percent carbon; percent clay, silt, and sand; sodium mass flux; pH; and metal concentrations for 24 sampled soil pits in 1-cm depth increments. The described profiles were all sampled to differing depths; to compensate for the unevenness of the profile descriptions, the soil depths were standardized from 0.0 to 1.0 and then split into five equal standard depth sections. A logit-transformation was used to normalize the target variables. Step-wise regressions were calculated using available environmental covariates to predict each variable in each depth section, and interpolated residuals added back to the predicted layers to generate the final soil maps. Logit-transformed R2 for the predictive functions varied widely, ranging from 0.20 to 0.79, with logit-transformed RMSE ranging from 0.15 to 2.77. Soil hydrological properties were

calculated from the predicted soil properties using ROSETTA and established empirical relationships. The subcatchment was further classified into clusters based on the environmental covariates, and representative depth functions for each variable in each cluster calculated. Mass-preserving splines combined with stepwise regressions are an effective tool for predicting soil physical, chemical, and hydrological properties with depth, enhancing our understanding of the critical zone.

T1W. Particle trajectories on hillslopes: implications for particle age and ^{10}Be structure

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CZOs: Boulder Creek
Applicable themes: Theme 1

Many geomorphic systems are conveyor belts onto which material is loaded at a particular rate, and is transported in one direction to a sink for that material. As the material travels, stuff happens to it: it weathers, it is comminuted, it accumulates cosmogenic radionuclides. Here I address the hillslope conveyor. As many geomorphic and geochemical problems are tied to depth into the surface, the depth history of a particle becomes important to know. I calculate soil particle trajectories in two end-member cases of slope-parallel soil transport rate profiles, one exponentially declining with depth, the other blunted by significant turbation. Vertical speeds are governed by appeal to continuity in an incompressible medium. Armed with trajectories, I calculate residence times and concentration profiles of ^{10}Be in the soil. These can be contrasted with depth-averaged values derived from hillslope models in which only the patterns of soil discharge and of depth-averaged values of these quantities are available. The results inform strategies for interpretation of nuclide concentrations from soils and streams, and for inference of transport rate profiles. They also provide the backdrop for addressing chemical evolution of soil on a catena.

T1X. Strath terraces on the western High Plains indicate variations in sediment supply from source basins in the Colorado Front Range

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Applicable themes: Theme 1, Theme 2, Theme 3, Theme 4

Outboard of the Colorado Front Range, gravel-capped strath terraces record the history of fluvial planation and vertical incision. We collected cosmogenic radionuclide (CRN) profiles (10Be) and soil profile data from three strath terraces adjacent to Lefthand Creek near Boulder, CO. 10Be profile data on the upper two terraces yield dates of 95 ka and ~91 ka. Soil development on the upper two terraces are similar, consistent with the narrow time window obtained from CRN dating of the two units. The lower terrace appears to have experienced two periods of deposition. Optically stimulated luminescence and CRN data indicate that the upper soil was deposited at ~24 ka. Additional CRN samples, as well as thermal transfer OSL, are being run to help constrain the age of the deeper soil.

CRN dates for terraces near Lefthand Canyon are much younger than the correlative mapped-units to the south and more consistent with a model of fluvial incision and aggradation driven by variations in sediment supply. 10Be inheritance in terrace profiles indicate large fluctuations in catchment-wide denudation; rates are ~5.2 cm/ka, 2.1cm/ka, and 2.6 cm/ka, from the oldest to youngest terrace. The lower soil on the youngest terrace has a much lower 10Be inheritance, with paleo-denudation rates similar to the oldest terrace (~5 cm/ka); however, additional CRN data are needed to constrain this.

High catchment-wide denudation rates increase sediment supply, leading to aggradation and lateral planation; terrace sediments are likely deposited and eroded multiple times during this process. Lower catchment-wide denudation rates generate less sediment, leading to terrace abandonment as streams rapidly incise through the soft Pierre Shale. Our data indicate: (1) strath terraces outboard of the Front Range cannot be correlated based on elevation alone, (2) exhumation of the Denver basin was both spatially and temporally variable due to variations in sediment supply from source basins.

T1Y. The predominance of post-wildfire erosion in the long-term evolution of forested, mountainous landscapes

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Applicable themes: Theme 1, Theme 3

Wildfires can dramatically increase erosion over time scales on the order of years, but the relative importance of post-wildfire denudation versus non-wildfire-affected denudation over geologic time scales is unknown. Here we quantify mean erosion rates in wildfire-affected and non-wildfire-affected watersheds in the Valles Caldera, NM, over short (~10^0 yr) time scales using suspended sediment loads, terrestrial laser scanning (TLS), and airborne laser scanning (ALS), and over long (~10^3-10^6 yr) time scales using ^{10}Be cosmogenic radionuclides (CRN) and incision into a dated paleosurface. We find that following the Las Conchas fire in 2011, watersheds eroded at rates greater than 1000 micrometers yr^{-1}, ~10^3 to 10^4 times higher than nearby unburned watersheds of similar area, relief, and bedrock type. Long-term erosion rates are on the order of 10-100 micrometers yr^{-1} and incorporate both wildfire-affected and non-wildfire-affected erosion rates. These long-term erosion rates are consistent with a large pulse of wildfire-affected denudation lasting approximately 1 yr and recurring every 30 to 800 yr, with larger recurrence intervals (RI) corresponding to wildfires of greater burn severity, which agrees well with dendrochronological records. These pulses are responsible for ~99% of long-term denudation, attesting to their importance in shaping the landscape.

T1Z. Investigating the gopher dominated temporal/spatial bio-geomorphic patterns on decadal-millennial timescales on montane hillslopes of Colorado's Front Range

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Applicable themes: Theme 1, Theme 3

Within the critical zone on montane hillslopes of Colorado's Front Range (Boulder Creek Critical Zone Observatory), qualitative observations suggest that gophers prefer to forage in meadows over forests, that seedling roots are consumed by gophers, and that trees commonly occupy the rocky crests of hills overlooking open meadow hillslopes. Our observations suggest that gophers not only dominate modern geomorphic rates on decadal-millennial timescales, but that gopher intensity and location is pertinent to annual forest/meadow dynamics. Field mapping of gopher activity as the snow melts in the spring revealed that subnivean tubes ("eskers") are tightly clustered at the forest-meadow boundary while mounds generated over the remainder of the summer are concentrated strictly within the meadows. This suggests that gophers spend the winter months at the forest-meadow interface and spend the warmer seasons within the meadows. We hypothesize that variations in snow depth drive this spatial-temporal pattern of gopher activity; deeper snow near the forest-meadow boundary provides greater insulation, as near-surface ground temperatures in the wind-scoured meadow centers are colder. This motivates our initiation of monitoring of near-surface temperature across a forest-meadow pair; we will attempt to extract the meadow thermal diffusivity and effective hillslope diffusivity. Numerical modeling supports the many bio-geomorphic qualitative observations that we observe. This year's observations suggest that we must add to this mix the annual cycle of the gopher activity. Finally, probing and soil pits within the meadows reveal that on longer timescales gopher activity leads to the development of a well-mixed upper soil layer that is sharply bounded below by high concentrations of large stones ("stone lines") within the glacial till substrate of the hillslopes. In contrast, soil pits within the forest lack evidence of any bioturbation.

T1AA. Effect of forest competition on landscape development in the Luquillo CZO

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CZOs: Luquillo
Applicable themes: Theme 1, Theme 3

Forest succession theory maintains that trees drape existing landscapes as passive niche optimizers. Here, we explore the opposite view – that tree type can control the landscape morphology through canopy and soil structure differences between forest types. Using field observations, the 1 m-resolution LiDAR DEM and

cosmogenic nuclide geochemical techniques, we report links between topographic position, erosion rates, and tree distribution above 600 m in elevation in the Luquillo CZO. Flat ridges connect a subdued topographic surface and cap a relict landscape composed of 10s-of-meters-thick saprolite derived from a quartz dioritic bedrock. Erosion in the form of concave coves dissects this landscape, exposing the underlying corestones and bedrock and progressively creating a new landscape of greater local relief and higher erosion. To understand the origin of the increase in local relief we measured the contributions of ridges and coves to the stream signal by analyzing ^{10}Be in soils and stream sediments. We find that, in the coves, erosion is systematically higher than on the ridges, confirming the increase in landscape dissection. We analyzed the distribution of tree associations over the LiDAR topography by classifying high-resolution multispectral images of the forest. Vegetation in the study area is dominated by Palm and Palo Colorado forests. We found an almost systematic association of the Palm forest with the coves and of the Palo Colorado with the ridges. These forest types vary in their potential to prevent or enhance soil erosion. The Palo Colorado generates greater soil coverage and rain interception rates. Therefore, we propose that soils are more vulnerable to erosion under the Palm forest, providing a positive feedback whereby the presence of the Palm forest favors the incision of the coves while the Palo Colorado forest favors the protection of the ridges, thereby increasing local relief.

T1BB. Laser Vision: Applying LiDAR as a transformative tool to advance Critical Zone science

Adrian Harpold, Jill Marshall, Jon Pelletier, Tyson Swetnam, Nancy Glenn, Beth Wenell, Noah Molotch, Theodore Barnhart, Nicole West, and others

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CZOs: Cross-site
Applicable themes: Theme 1

Laser scanning, based on Light Detection and Ranging (LiDAR) technology, has revolutionized the spatial resolution and extent that scientists are able to make observations of the Earth surface properties and processes. As a consequence, LiDAR data have led to fundamental improvements within the individual disciplines of geomorphology, hydrology, and ecology. LiDAR datasets provide a transdisciplinary research avenue by simultaneously observing topographical, vegetation, and hydrological information that requires multiple disciplines to fully exploit. However, researchers are just beginning to utilize the transdisciplinary nature of LiDAR datasets to answer more holistic questions in Critical Zone (CZ) science, such as how landforms and soils develop in space and time as a function of the local climate, biota, and lithology. The objective of this presentation is to provide a vision for where opportunities and challenges exist for advancing CZ science using LiDAR. Achieving the full potential of LiDAR in the CZ sciences will require new, and more powerful open-source processing tools, exploiting new LiDAR acquisition technologies, and better integration with complimentary in-situ and remote-sensing observations. We provide a five-year vision using several examples of transdisciplinary research questions that would benefit from LiDAR and several recommendations for best utilizing and developing LiDAR datasets for CZ science applications.

THEME 2

T2A. Weathering and concentration-discharge relationships in granitic landscapes across CZOs

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CZOs: Southern Sierra, Boulder Creek
Applicable themes: Theme 2

Concentration-discharge relationships for silica in granitic landscapes vary throughout the critical zone network. In the Rio Icacos, Puerto Rico silica concentrations show strong dilution effects (Shanley et al., 2011). At the Boulder Creek CZO the Gordon Gulch catchment shows nearly constant dissolved silica (*DSi*) concentrations over three decades of change in discharge (*Q*) (S. Anderson). A major question is what controls the range of dilution to chemostatic behavior in catchments with similar lithology. Given that anything but perfect dilution behavior implies an increase in silica flux with increasing *Q*, we infer that different sources of *DSi* may be activated at different *Q*. Tracer data (Ge/Si) indicate that sources of *DSi* do change with *Q* in some systems (Kurtz et al., 2011; Derry et al., 2005). The CZO sites of Luquillo, Boulder, Southern Sierra and Catalina-Jemez share similar granitoid bedrock composition. We want to understand how the variation in climate, hydrology and weathering history have influenced their regolith development and reach a better understanding of the *DSi*-*Q* patterns.

We can use the geochemical tracer Ge/Si to understand silica sources and hydrologic pathways in the critical zone. During incongruent dissolution of aluminosilicates, fractionation occurs as a result of secondary mineral formation. Clay minerals are enriched in Ge/Si, while associated waters have low Ge/Si. The Ge/Si tracer can be a useful way to track silica sources with changes in concentration and discharge patterns. An objective of our research is to determine the reservoirs of dissolved silica and to understand when these reservoirs are being activated.

To date we have analyzed approximately 200 water samples from the Southern Sierra CZO for major elements and germanium concentrations. Analysis of bedrock and soil samples will be conducted in order to establish an elemental budget for the system and to learn about the concentration-discharge patterns. We recently sampled bedrock and soil samples from the Boulder CZO. We are carrying out mineral separation of primary and secondary phases for XRD and geochemistry as well as dissolved phase Ge/Si. Future work in Luquillo and Catalina-Jemez is planned in order to better understand the weathering mechanisms of granitoids across critical zone observatories.

T2B. Interpreting discharge-concentration relationships in the SCM-JRB CZO

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CZOs: Santa Catalina Mountains-Jemez River Basin
Applicable themes: Theme 1, Theme 2

The Santa Catalina Mountains and Jemez River Basin Critical Zone Observatory has developed extensive datasets on soil porewater chemistry, streamwater chemistry, and soil physical properties in zero order basins. These datasets, collected over the course of years, span hydrological events that vary in magnitude and timing (spring snowmelt, monsoons), and which therefore sample different portions of the critical zone under a variety of soil moisture conditions. By combining chemistry and physical property datasets with hydrological models, we may gain insight into the importance that the duration and timing of hydrological events have in semi-arid regions in terms of discharge-concentration relationships and elemental fluxes. Initial data showing divergent behavior for Fe and Al from chemostatic discharge trends suggests either complicated time variability among input endmembers, or dynamic pedon-specific environments.

T2C. Contrasting hydrochemistry – discharge relationships downstream of the Main Range CZO watershed divide (south-east Queensland, Australia)

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Applicable themes: Theme 2

The interaction between water and minerals within bedrock and soils through percolation and runoff generation processes determines the export of dissolved solids from catchments. By investigating the relationship between catchment discharge and hydrochemistry over an integrative catchment area, the relative influence of these processes as well as geology, vegetation, and climate on export of dissolved solids can be evaluated. The degree to which these dynamic processes are indicative of long term chemical weathering rates of catchments is also an important overarching question. Here, we investigate the relationship between discharge and hydrochemistry from historical datasets within two catchments (Emu Creek – 148km^2, and Condamine River – 92km^2) which drain from the newly established Main Range CZO in south-east Queensland, Australia (Figure 1). These catchments share similar geology (Cenozoic basalts), climate (downstream gradient from sub-tropical to semi-arid), and topography; but differ in vegetation patterns, soil types, and runoff (seasonal and annual), which may be aspect driven. Both catchments show strong logarithmic trends between increasing discharge and decreasing total dissolved solids (TDS), however Emu Ck exhibits a much stronger evapo-concentration and dilution trend with discharge (both continuous and spot measurements) than the Condamine R (Figure 2). The ~1 order of magnitude variation in TDS for Emu Ck, and half order of magnitude TDS variation for the Condamine R site are both small relative to the ~5 order of magnitude discharge variation experienced in these catchments. The flow duration curves suggest a higher baseflow contribution to the Condamine R than Emu Ck, with the former also having higher annual and seasonal runoff coefficients. This general trend of logarithmic dilution in TDS is more nuanced when separated into the major ions (Figure 3); and suggests that despite similar geology, climate, and topography, small differences in vegetation, soils, and runoff cause generally higher TDS concentrations in Emu Ck, and a higher abundance of Cl (especially at low flow), and a more buffered relationship between TDS and discharge in the Condamine R. Similarities in the general ion behaviour with discharge between the catchments suggests that the transition from Na-Ca-HCO_3 to Si-HCO_3 dominated waters most likely occurs because of the relative increase in interaction between water and Si (and K) rich soil minerals during percolation and runoff generation processes at high flow, although the contribution of bedrock weathering to hydrochemistry is still a major contributor, and dominates at more moderate to low flows.

T2D. Modeling carbon and water cycles at Shale Hills

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Applicable themes: Theme 1, Theme 2

Modeling energy, water and carbon exchanges in the atmosphere-plant-soil system requires proper representation of the physical and physiological processes of this system. Biome-BGC is a mechanistic model that is used to simulate the biogeochemical cycles of carbon, nitrogen, and water in an ecosystem. However, the simple representation of the water cycle in this model makes it difficult to reflect topographically-influenced interactions among the carbon and water cycles because of the absence of a groundwater component and no interactions among grids. Flux-PIHM is a hydrologic and land surface energy balance model that can simulate the hydrologic cycle in complex topography and the interaction between groundwater and the surface energy balance, but which lacks representation of the carbon cycle.

To address this problem, we will couple Biome-BGC (BBGC) with Flux-PIHM. As a prelude to construct this coupling system, we will improve the ability of BBGC to represent processes likely to respond to spatial variability in soil conditions, and known at our site to produce unrealistic ecosystem function. We will focus on carbon allocation and its relationship to soil moisture and soil nutrient status, and the phenology algorithm that governs leaf area index (LAI). We will drive BBGC with measured soil moisture and soil temperature to ensure accurate hydrologic forcing prior to coupling BBGC with Flux-PIHM.

The coupled Flux-PIHM-BBGC model will be tested at the Susquehanna Shale Hills Critical Zone Observatory, where multi-state observations of the water and carbon cycles are hosted. The observations in the watershed indicate strong interactions between the carbon and water cycles, with marked differences in soil and vegetation properties on different topographies. We expect the coupled model to simulate the water-carbon cycle interactions and reflect the differences in biomass and carbon fluxes caused by topography.

T2E. A case study of hillslope colluvial processes promoting carbon-mineral association within the Christina River Basin CZO

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CZOs: Christina River Basin
Applicable themes: Theme 2

Organic carbon (OC) in undisturbed soils is generated at and near the ground surface and is physically separated from fresh mineral surface area that is generated by chemical weathering and pedogenesis. An important mechanism for the persistence of OC in soil, fluvial, and marine systems is tight association of OC with mineral surface area. Understanding how and when OC overcomes physical separation and connects with mineral surface area is key to understanding the fate of OC throughout soil, fluvial, and marine systems and scales. Burial and trapping of carbon, although important storage mechanisms in erosion-driven carbon sequestration, may not indicate long-term carbon stability. We hypothesize that colluvial and erosional processes on a hillslope scale promote soil mixing that results in an increase in the fraction of mineral surface area associated with OC in depositional portions of the landscape, and therefore promotes OC stability. Here we present OC and specific surface area (SSA) measurements from a hillslope transect in a first-order, 9-hectare watershed in a mature forest in the CRB-CZO. We report OC:SSA ratios and observations of soil mineralogy throughout a transect of soil pits. Our results reveal that in the upland portions of the hillslope, the SSA and OC quantities co-vary and increase with decreasing depth. The depositional portion reveals higher SSA values and a more consistent fraction of SSA covered by OC with depth, which we interpret as increased OC-mineral associations from mixing processes during colluvial and erosional transport. Assessing OC-mineral associations in a hillslope system has enabled us to understand temporal and spatial dynamics of OC movement in a landscape evolution context. This process based approach reveals that diffusive soil mixing mechanisms promote carbon stability on first-order watershed scales, prior to sediment integration into fluvial networks.

T2F. Distribution of ^{14}C and ^{137}Cs in the profile of Ultisol in Calhoun CZO

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CZOs: Calhoun
Applicable themes: Theme 2

We have studied the soil on quite flat site under mostly loblolly pine about 100 years old. There was analyzed about 1.5m of soil for the distribution of ^{137}Cs and ^{14}C . The ^{14}C was analyzed in the different soil fraction such as the bulk soil, soil after treatment with 1N HCl himic acid extract and the residue after humic acids extraction. The detectable amount of ^{137}Cs was found only in the top horizons with relatively high organic content and below these horizons it was absent due to absorption by soil organic matter and possible clay minerals which are present in the top horizons in low concentration and almost completely absent below that. The distribution of ^{14}C has shown quite fast turnover rates of all fractions in the top 50 cm and sharply slowdown these rates below in the B horizons with increasing of concentration of clay fraction and appearing of the redox zones. We have analyzed the distribution of ^{14}C in the reduced gleish yellow zone and oxidized red zone separately and found out that turnover rates are different there.

T2G. Temperature sensitivity of soil organic carbon decomposition along an elevational gradient in a semi-arid ecosystem

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CZOs: Reynolds Creek
Applicable themes: Theme 2

Semi-arid ecosystems dominated by shrubs are an important component of the global carbon (C) cycle as they store a significant amount of soil C. Yet, changes in mean annual temperatures may alter the amount of soil organic C (SOC) currently stored in these ecosystems. Despite extensive research, a proper consensus has not emerged on the temperature sensitivity of SOC decomposition posing a major uncertainty in predicting C cycle feedback to rising temperatures. The overall objective of this study is to elucidate how litter input affects soil structure and SOC

quality along an elevational gradient in a semi-arid desert and assess impacts of these characteristics on the temperature sensitivity of SOC decomposition. The study sites are located in the Reynolds Creek Experimental Watershed situated in the Owyhee Mountains of southwestern Idaho. The sites (four) are located at an elevational gradient (1000m). The vegetation at each site is composed of sagebrush (either Artemisia tridentata subsp. vaseyana, Artemisia tridentata subsp. wyomingensis or Artemisia arbuscula) with mean annual precipitation ranging from less than 250mm/yr to greater than 1100mm/yr and mean annual temperature varying by 5°C from the lowermost to the upper. Stratified random sampling of soil up to 0-30 cm is conducted at all the elevations. Variations in soil structure and SOC quality (stability) among the elevations are assessed by fractionating the soil into silt, clay, CPOM (Coarse particulate organic matter), FPOM (Fine particulate organic matter). Litter traps are used to quantify litter inputs and assess litter quality (i.e. Lignin, C: Nitrogen). Finally, differences in the temperature sensitivity of SOC decomposition across the elevations are evaluated via exposure of the soils to a temperature gradient in controlled laboratory incubation studies. Our research will provide improved insights to the sensitivity of SOC stores to global warming in semi arid ecosystems at the landscape scale.

T2H. Changes in carbon chemistry and stability along deep tropical soil profiles at the Luquillo CZO

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CZOs: Luquillo
Applicable themes: Theme 2

Tropical forests soils contribute disproportionately to the poorly-characterized deep soil C pool. Our goal was to evaluate how C chemistry and stability change with depth in tropical forest soils formed on two contrasting parent materials. We used soils from pits excavated to 140 cm stratified across two soil types (Oxisols and Inceptisols) at the Luquillo Critical Zone Observatory. We measured soil C, N and P concentrations, and performed 90-day laboratory incubations to evaluate biological stability. ^{13}C nuclear magnetic resonance (NMR) spectroscopy and differential scanning calorimetry (DSC) coupled with evolved gas analysis (CO2-EGA) were used to characterize soil C chemistry and stability.

There were no differences in CO_2 respiration or energy density (energy released during DSC normalized to soil C concentration) across the two soil types. Peak CO_2 evolution from combustion occurred at ~300ºC in Oxisols, and 400-500ºC in Inceptisols. Soil C, N, extractable P, cumulative respiration, basal respiration rates, and energy density all declined exponentially with depth. We observed a strong positive relationship between energy density and basal respiration rates. Preliminary 13C NMR results indicate higher alkyl : O-alkyl ratios and an enrichment of aliphatic and proteinaceous C with depth, compared with greater aromatic and carbohydrate signals in surface soils.

Taken together, our findings suggest that microbial activity is driven primarily by energy availability along deep tropical soil profiles. NMR and DSC data suggest soil C is composed of energy-rich, plant biomolecules in surface soils and becomes increasingly microbial with depth. Overall, energy scarcity and poorer substrate quality may explain the long-term stability of deep C in highly weathered tropical soils.

T2I. The depth distribution of N_2O, O_2, and CO_2 along topographic gradients at the Shale Hills CZO

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CZOs: Susquehanna Shale Hills
Applicable themes: Theme 1, Theme 2

Soils are the main source of N_2O to the atmosphere but despite substantial research, models of soil-atmosphere N_2O exchange still fail to capture temporal and spatial variability. It is possible that our models of N_2O efflux suffer from an emphasis on surface soil processes. N_2O that reaches the surface may diffuse from deeper soil where lower O_2 concentrations lead to greater anaerobic microbial activity. Furthermore, topography may be a good indicator of subsurface N_2O if wetter swale and valley floor landscape positions have more persistent wet and anaerobic conditions. We tested this possibility by linking measurements of surface N_2O efflux with soil N_2O, CO_2, and O_2 concentrations along vertical profiles (0-160 cm soil depth) on two contrasting hillslopes (swale versus planar) and three landscape positions (ridgetop, midslope, and valley floor) in the Susquehanna Shale Hills Critical Zone Observatory in central Pennsylvania. All three landscape positions of the swale hillslope had higher subsoil N_2O concentrations than the corresponding

landscape positions of the planar hillslope. The highest overall N_2O concentrations were in the mid-slope swale position (>3,000 ppbv), with the lowest peak concentrations in the mid-slope planar position (~800 ppbv). Soil CO_2 and O_2 concentrations were negatively correlated with each other and appeared to reach maximum (CO_2) or minimum (O_2) values earlier in the growing season but at approximately the same depth as maximum N_2O concentrations. Though N_2O concentrations at depth were highly variable, concentrations near the soil surface for all landscape and hillslope positions remained close to atmospheric levels (~320 ppbv). On many measurement dates surface N_2O efflux was negligible even when subsoil N_2O concentrations were high. The next phase of our research why high subsoil N_2O concentrations do not correlate with high surface effluxes by examining potential N_2O production and diffusion rates through the soil profile.

T2J. Modeling how different climate regimes interact with and constrain landscape evolution and soil formation

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CZOs: Reynolds Creek
Applicable themes: Theme 1, Theme 2

Though multifunctional, one of the most prominent features of soils on Earth is their responsibility for regulating the climate by storing carbon sequestered by terrestrial vegetation through photosynthesis. Due to its influence on vegetation, water is a major limiting factor on weathering and erosion in semiarid landscapes. The goal of our study is to promote fundamental understanding of the sensitivity of soil thickness to changes in precipitation in these water-limited environments. To accomplish this, we have quantified denudation rates in a semi-arid ecosystem through field work and used these data to inform a variety of climate change simulations in a landscape evolution model.

We chose three hillslope transects located in the Dry Creek Experimental Watershed to calculate denudation. Each of the transects contained four sites, enabling us to represent a variety of elevations, slopes, and aspects. During the summer of 2014, varying lengths of rebar were pounded vertically into the ground and their locations measured using a GPS with sub-centimeter accuracy. The locations of these rebar will be resampled in late fall and again in early spring. We expect to see that as the soil moves cohesively, the rebar will move with it, and thus the shorter rebar (located closest to the surface) will move a greater distance than the longer rebar. In this way, we will be able to measure the movement of soil packages as holistic unit over a given period.

Landlab is a new framework for landscape evolution models that is was created in a modular fashion to allow for flexibility within a given model. With Landlab, we have begun to create a model to test the effect of these denudation rates on landscape evolution. By changing the variables used, such as vegetation type, land use, and weather patterns, we can use the model to quantify the link between climate, local soil evolution, and landscape evolution to understand better the critical zone in semi-arid environments.

T2K. Controls on significant seasonal and diel variation of soil respiration in a subtropical moist forest in Puerto Rico

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CZOs: Luquillo
Applicable themes: Theme 2

Tropical forest soils are the largest natural source of carbon dioxide (CO2) to the atmosphere and have the highest soil respiration rates, globally. Identifying climatic controls and natural variability of soil respiration (Rs) in these ecosystems could improve our ability to predict feedbacks to future climate change. We measured hourly Rs in a secondary, subtropical moist forest in Puerto Rico for a 3-year period using an automated soil respiration system (LI-COR 8100) to determine at what time-scale Rs varies and whether this variability can be explained by abiotic factors such as temperature and moisture. Soil respiration varied significantly at both seasonal and diel time-scales. Mean monthly Rs ranged from 4 to 12 µmol CO_2 m^{-2} s^{-1} and the seasonal variation was positively correlated with air temperature (p<0.0001, R2=0.69). Soil respiration also demonstrated significant diel variation, changing from ~1 to 7 µmol CO_2 m^{-2} s^{-1} throughout the day. As with seasonal variation, Rs was positively correlated to soil temperature (p<0.0001, R2=0.61) on a diel time-scale. However, diel Rs was decoupled with soil temperature at midday possibly responding to a depression in photosynthesis, which may pause the transport of photosynthate to the roots. The significant positive effect of temperature on Rs in this forest, despite low intra-annual variability (<4°C), suggests that soil C loss from moist subtropical forests could increase as global

temperatures rise. Diel hysteresis effects of Rs suggest that temperature has both linear and non-linear effects on Rs in this forest (i.e., via effects on photosynthesis). Overall, the strong temporal variability in Rs observed at multiple time-scales in this study highlights the sensitivity of Rs in this system to relatively small changes in temperature.

T2L. Influence of climate and aspect on energy, water and solute fluxes through semi-arid critical zone

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Applicable themes: Theme 1, Theme 2

In high latitudes, the predominant aspect of a hillslope can regulate surface and subsurface hydrogeochemical processes, affecting in the short-term not only the partitioning of energy and precipitation, but also the long-term development (i.e. soil properties, vegetation, groundwater storage, solute fluxes) of the Critical Zone (CZ). In this study, we investigate how topographically-controlled microclimate and landscape characteristics (e.g. soil thickness, catchment contributing area) influence mass and energy fluxes through the CZ.

Three study catchments that share similar physical characteristics, but drain different aspects of Redondo Peak, a resurgent rhyolitic dome in the Jemez River Basin CZO, were investigated over 4 years that span relative extremes in precipitation with marked wet and historically dry years. Catchment aspect is related to the amount of distributed energy and mass transfer (EEMT) (calculations described in Chorover et al., 2011, *Vadose Zone Journal*), with the highest maximum and greatest range of EEMT observed in more north-facing hillslopes. Hydrological partitioning analysis at the catchment scale shows that the predominantly north facing catchment has the largest and least variable baseflow and discharge. Springs in the north facing catchment also have the longest water transit times, highest base cation and dissolved inorganic carbon concentrations, and greatest mineral weathering fluxes. Solute concentrations and transit times are also correlated to catchment contributing area and flowpath length. Surface discharge is primarily derived from infiltration of winter snowmelt, as indicated by water stable isotopes. These results are consistent with previous solute endmember mixing analysis highlighting the importance of relatively deep groundwater contributions to streamflow and recent seismic data showing thicker soils (likely supporting greater groundwater storage) on north facing hillslopes. These results demonstrate how variable energy and mass inputs into the CZ, controlled by catchment aspect, drive long-term development of the CZ and capacity for groundwater storage, which in turn regulates surface water quantity and quality (via fluxes of dissipative products from the CZ) and modulates the sensitivity of stream flow to climate and landuse change.

T2M. Streamflow sensitivity to climate change projections in the Southern Sierra watersheds

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Applicable themes: Theme 2

Stream flow sensitivity to the IPCC projected climate change scenarios in the Upper San Joaquin River Watersheds (USJRW) were hypothetically simulated using the Hydrological Simulation Program-Fortran (HSPF) model. A pre-specified set of climate change scenarios (CCS) by IPCC include temperature increases between 1.5 and 4.5 Co and precipitation variation between 80% and 120% of the baseline conditions.

Historical meteorological data from a nearby NOAA station at CA049855 and the daily discharge data from the USGS gauging station No.11226500 immediately below the watersheds were used for model calibration and validation. Statistical analyses show that there is a strong and continuous temperature increase during the past few decades from 1970 to 2005. The 5-year running mean temperature increased from 10 Co to 12 Co.

The calibrated and validated HSPF model was then used to simulate the stream flow response to a combination of the projected CCS. Results indicate that the stream flow of USJRW is sensitive to the specified climate change scenarios. The total volume of annual flow would vary between negative 41% and positive 16% compared to the baseline years (1970–1990). Even if the precipitation remains unchanged, the total annual flow would still decrease by 8–23% due to temperature increases. A larger portion of the stream flow would occur earlier by 15–46 days due to the temperature increases, causing higher seasonal variability of stream flow.

T2N. The interplay of regolith evolution and watershed hydrodynamics on shale weathering fluxes

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CZOs: Susquehanna Shales Hills
Applicable themes: Theme 1, Theme 2

Developing quantitative models that accurately represent regolith formation is critical for understanding the long timescale controls on the groundwater (GW) table position and solute fluxes. Thus far two main hypotheses can be proposed. First, the Top-down hypothesis: Infiltrating meteoric water interacts with exposed protolith to create a series of nested reaction fronts which control the evolution of regolith permeability from the protolith and together sets the depth of the GW table. Second, the bottom-up hypothesis: The position of the GW table is dictated by the pre-existing permeability of the bedrock and the rate of channel incision, and thus the GW table controls the depth of weathering. For both the top-down and bottom-up hypotheses the GW table is an important determinant of the conversion of fresh bedrock to weathered material and the GW table mirrors surface topography.

To investigate these hypotheses, we collected data at the SSHCZO from deep and shallow boreholes. With these holes we documented the structure, mineralogy, and geochemistry of deep regolith and bedrock. We also evaluated the physical dynamics and chemical composition of GW both spatially and temporally. We observed evidence for deep reaction fronts – sulfur and ferrous iron concentrations in samples from the newly drilled boreholes document that the deepest reaction front is pyrite oxidation and is roughly coincident with the GW table. The complex geometry of carbonate content from the drill cores suggests that a dissolution front, if present, is superimposed on large variations in subsurface carbonate content arising from stratigraphic variation. A reduced topographic control was detected in the GW table position near stratigraphic changes, and supports bottom-up control on the GW table position. These observations about regolith versus depth controlled the interaction of local and regional GW flow, and the depth of weathering at the catchment's outlet.

T2O. Cross-sites analysis of snowpack depth from LiDAR in Southern Sierra Nevada

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Applicable themes: Theme 1, Theme 2

To investigate on the differences and similarities of snow depth spatial variability over different watershed areas, five sites in Southern Sierra Nevada Critical Zone Observatory were selected for creating the snow depth maps using the snow-on and snow-off LiDAR datasets. The snow-on data were collected during the snow-peak time in 2010, while the snow-off data were collected during the summer in the same year. By subtracting the digital elevation models (DEM) of the snow-off data from the snow-on point clouds, snow-depth maps for these sites were created. Also, canopy height, slope, and aspect are appended with the snow-depth for digging out the impact on the snow distribution from these topography features. From the results, the snow depth in the open area increases at 14-15 cm/100 m elevation increasing is consistent across areas in the elevation range from 1850m to 2700m, while The results under the canopy presented an increasing rate about 2 cm/100 m higher but with around 20 cm lower of snow depth compared to that in the open area. Other than elevation, aspect also has a tremendous effect on snow distribution with the result showing that the ground facing to the northeast direction always having more snow accumulated than other areas regardless of vegetation existence.

Even though the results reveal strong consistency of the vegetation impact on the snow depth across sites, only about 35% of total area is under canopy in forested areas and less than 30% of LiDAR beams could be returned from the ground under the canopy. The LiDAR might overestimate the snowpack volume but is still an important index for blending with ground data and data from remote-sensing satellites. Also, implied from the tight connection between snow depth and aspect, it is suggested that solar radiation, wind speed and direction, temperature, as well as other environmental factors are interacting with topography features and playing important roles in snow deposition and ablation.

T2P. Determination of specific yield of montane meadow soils, Sierra Nevada, CA

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Applicable themes: Theme 1, Theme 2

Utilizing diurnal fluctuations of shallow groundwater tables to estimate evapotranspiration (ET) is a well established approach. This approach is advantageous in that ET can be estimated with little infrastructure and at relatively low cost. Most studies that use this method rely on some estimation of the specific yield, Sy, of the soil. Specific yield is the volume of water drained form a soil or rock divided by the volume of soil from which it drained. Established methods for determining Sy include field and laboratory approaches that either measure the volume of water drained from a known volume of soil or measuring the change in groundwater elevation after some perturbation, such as a precipitation or pumping event, of known water volume. Most methods for determining Sy result in a single value for a given soil volume. In shallow water table environments, soil specific yield is transient by nature, varying with depth to groundwater, time allowed for drainage, and whether the soil is experiencing wetting or drying conditions. When applied in ET calculations, inadequate estimates of Sy can result in large errors in calculated ET. We utilize eddy covariance techniques, in situ soil moisture sensors, and meteorological data to constrain specific yield values for soils in ten montane meadows in the Sierra Nevada Mountains, CA. Meadows conditions range from relatively pristine meadows to degraded and restored meadow systems. Quantifying ET in these meadows is important for understanding the meadow hydrology and connection to the greater catchments. Results from our approaches highlight the transient nature of soil specific yield. Calculated values of specific yield ranged from 0.03-0.16; higher values were obtained when using meteorological data to calculate Potential ET and lower values were obtained with eddy covariance techniques. We use these new constraints on Sy to better quantify ET calculated from diurnal groundwater fluctuations in the meadows.

T2Q. Investigating aeolian inputs to the Sierra Nevada, California: Impacts of a 500-Year drought

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Applicable themes: Theme 2

Mounting evidence shows that California is currently experiencing the most severe drought since 1580, and it is likely that extreme droughts will become more common as the climate changes. Any drought – particularly one of this magnitude – can elevate dust transport, from fallow croplands and bare natural ecosystems, to sometimes distant locations. The transported dust may bring nutrients and microorganisms, with unknown, but potentially transformational, impacts on the ecosystems where dust is deposited. In this project, we are measuring the mass, provenance, chemical makeup, and microbial composition of dust transported to the Sierra Nevada mountain range.

Dust is being collected at three sites along an elevational gradient in the SSCZO, ranging from 400 m to 2000 m elevation. At each site, dust has been collected monthly in Summer 2014 from passive dust collectors and from filters on the eddy covariance tower active CO2 samplers. To complement dust collection, soil samples have been collected within the footprint of the towers. Dust fluxes were found to be highest at the 2000 m site, with a maximum of 231 mg dust collected in July 2014. The lowest dust fluxes were found at the medium elevation site, at 1100 m, with 21 mg dust. The provenance of dust samples will be determined using radiogenic strontium (Sr) and neodymium (Nd) isotopic tracers. Nutrients and microbial composition of dust and soil samples will also be analyzed. This approach will allow us to identify the effects of mega-droughts on i) dust-related contributions to the geobiology and biogeochemistry of soils and ecosystems, ii) the role of local versus distant dust sources of microorganisms, including bacteria, archaea and fungi, and of nutrients to the Sierra Nevada, and iii) the role of elevation in determining the ecological effects of mega-drought-induced dust transport. In the future, we will compare the data collected during this year of extreme drought to data collected in wetter years.

T2R. Erosion of soil carbon and nitrogen in rain vs. snow dominated forested catchments in the Sierra Nevada Mountains

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Applicable themes: Theme 1, Theme 2

A suite of factors that include precipitation intensity and timing, slope, and soil structure determine rate of water-driven soil erosion. In the southern parts of the Sierra Nevada Mountains in California, we investigated magnitude and nature of organic matter (OM) eroded in two sets of catchments that developed under different climatic conditions to determine how amount and distribution of precipitation affects erosion of soil carbon (C) and nitrogen (N). We quantified sediment and OM exported annually (for water years 2005–2011) from four low-order, snow-dominated catchments, and four low-order catchments that receive a mix of rain and snow. The magnitude of and OM composition in sediment exported from the low-order catchments was also compared to soil at three different landform positions from the source slopes to determine if there is selective transport of some soil OM components. Sediment yield and composition showed high interannual variation, with higher C and N concentrations in sediment collected in drier years. While the sediment C:N ratio was consistent across years and watersheds, absolute C and N concentrations varied more in sediments than in the soils. We found that annual sediment mass, C, and nitrogen fluxes were positively and strongly correlated with stream flows. Our results suggest that variability in climate is a primary factor controlling the magnitude of C and N eroded from upland temperature forest catchments.

T2S. Using isotopes to source eroded carbon in captured sediments of two western Southern Sierra Nevada catchments

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Applicable themes: Theme 1, Theme 2, Theme 3, Theme 4

Topsoil and associated soil organic matter is continually distributed over the landscape laterally by soil erosion. Deposition and stabilization of eroded soil organic matter in low lying terrestrial and aquatic environments can induce a sink for atmospheric carbon dioxide. However, determining the sources that make up the deposited material that can affect the amount and stability of carbon (C) stored is not well studied due to the amount of mixing that occurs in soils. We used stable isotopes of C and nitrogen (N) and radiocarbon of captured sediments from below two gauged low- order catchments (low elevation, 1800 m and high elevation, 2300 m) of the Kings River Experimental Watersheds (KREW) in the Sierra National Forest. The captured sediments were compared to possible source materials including upland forest floor and mineral soils (0- 0.6 m) from three landform positions (crest, backslope, toeslope), and stream bank soils (0- 0.6 m). We found that stable isotope analysis of the captured sediments showed a combination of upland materials present consisting of material from all landscape positions and stream banks at both elevations. Radiocarbon determined mean residence time (MRT) also indicated the sediments were modern that correlated to surface material of mineral and stream bank soils. Our isotope results show that surface erosion and channeling from established streams are likely the largest sources of sediment exported out of these catchments. Knowing the sources of the material will enable more facilitation of C storage in Sierra Nevada forests to mitigate climate change.

T2T. Determining the drivers of redox-sensitive biogeochemistry in humid tropical forests

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Applicable themes: Theme 1, Theme 2

The availability of soil oxygen (O_2) and associated redox dynamics are key drivers of carbon (C) cycling and greenhouse gas fluxes in tropical forests. Changes in climate are likely to affect soil O_2 availability in tropical forests and feedback on ecosystem biogeochemistry. Few studies have measured soil O2 availability over time and space in tropical forests, and thus this important parameter is absent or poorly represented in Earth systems models. In this study we will use field and laboratory experiments in humid tropical forests to develop a mechanistically derived redox component for the Community Land Model (CLM4) component of the Community Earth System Model (CESM). We will use our empirical and modeling efforts to improve the prediction of C, nitrogen (N), and phosphorus (P) cycling and greenhouse gas dynamics in humid tropical forests. Our research will test the following hypotheses: 1) soil O_2 concentrations vary as a function of soil texture, slope position, and rainfall in humid tropical forests; 2) the spatial and temporal dynamics of soil O_2 availability can be used to predict patterns in redox sensitive biogeochemical processes; and 3) hot spots and hot moments in greenhouse gas fluxes are derived primarily from high substrate availability and secondarily from soil O_2 availability. Research is being conducted in the Luquillo Experimental Forest (LEF), Puerto Rico. We are using controlled field and laboratory experiments to establish the relationships between soil O_2, climate, soil physical properties, and a range of redox sensitive biogeochemical processes including soil respiration, net and gross N_2O and CH_4 fluxes, and Fe redox impacts on P mobilization. We will use automated sensor and surface flux networks to test the hypotheses. We will also use fertilization experiments to determine the relative importance of substrate availability and soil O_2 concentration on gross and net greenhouse gas dynamics.

T2U. Fe-C interactions and soil organic matter stability in two tropical soils of contrasting parent materials

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Applicable themes: Theme 1, Theme 2

The long residence time of soil organic matter (SOM) is a dynamic property, reflecting the diversity of stabilization mechanisms in the soil matrix. Evidence suggests that the long-term stability of SOM is dominated by organo-mineral interactions. However, the 2:1 phyllosilicate clays that provide much of the stabilization capacity in temperate soils are typically absent in tropical soils due to extensive weathering. In contrast, these soils may contain an abundance of iron and aluminium oxides and oxyhydroxides (i.e., short-range-order (SRO) minerals). Despite their relatively small contribution to soil mass, SRO minerals may contribute substantially to SOM stabilization in tropical soils. The objective of this work was to quantify Fe-C interactions to assess their contributions to SOM stabilization.

Surface (0-10 cm) soil samples were taken from soil pits dug in the Luquillo Critical Zone Observatory. Soils were stratified across granodiorite (DYS) and volcaniclastic (OX) parent materials. Four extraction procedures were used to isolate three different forms of Fe-C interactions: sodium pyrophosphate, hydroxylamine, ammonium oxalate, and dithionite-citrate. Extracts were analysed for dissolved organic C (DOC) and Fe and Al concentrations to estimate the amount of SOM associated with each Fe mineral type. Soils were also subjected solid-phase C analyses before and after extraction. Preliminary results suggest that granodiorite-derived soils contain on average twice the Fe concentration than volcaniclastic-derived soils.

SRO minerals appear to contribute substantially to SOM stabilization compared to the bulk mineral matrix. Additional work will focus on characterization of the organo-Fe complexes using advanced analytical techniques. Replication of this work in temperate systems may also lend insight into the role of parent material mineralogy in long-term C stabilization.

T2V. Oxygen flux rate controls net rates of microbial Fe(III) reduction in a redox-dynamic tropical soil

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Applicable themes: Theme 1, Theme 2

Iron (Fe) biogeochemistry plays an important role in nutrient availability and carbon (C) cycling in terrestrial ecosystems. Humid tropical forest soils that undergo alternating oxic/anoxic redox cycling are particularly influenced by Fe solid phase transformations. We speculated that the rate of Fe(II) oxidation by O_2 during redox cycling affects aqueous and solid phase microbial Fe(III) reduction in these soils. Our hypothesis was that slower rates of Fe(II) oxidation by O_2 would lead to slower rates of subsequent Fe(III) reduction through the formation of more ordered (i.e. less reactive) Fe(III) (oxyhydr)oxides. We tested our hypothesis with soils from an upland valley of the Bisley Watershed at the Luquillo Critical Zone Observatory, PR. The soils were subjected to a range of O_2 fluxes by injecting air (21%, 2.1% and 0.21% (vol/vol)), every hr for 7 hrs, during a 24 hr oxic period following 7 days of anoxic incubation. We repeated this anoxic/oxic cycling for a total of 31 days. We found that slow Fe(II) oxidation leads to lower net rates of Fe(III) reduction over subsequent anoxic periods. The extent to which any crystalline changes in Fe(III) (oxyhydr)oxides, due to Fe(II) oxidation rate, influence microbial Fe(III) reduction is unclear. Aqueous saturation and increasing surface coverage of Fe(II) may also contribute to decreased rates of Fe(III) reduction, that could in turn be linked to Fe(II) oxidation rate during oxic periods. We suspect Fe solid phase transformations during the oxidation events affect the variation in net Fe reduction rates. To probe these solid phases more directly, we are coupling ^{57}Fe isotope additions with Mössbauer spectroscopy. Ultimately, our goal is to improve model-based descriptions of Fe mineral evolution and the subsequent biogeochemical impact of that evolution in redox-dynamic tropical ecosystems.

T2W. Testing methods for quantifying iron reduction potential to be deployed at the Calhoun and Luquillo CZOs

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CZOs: Calhoun
Applicable themes: Theme 1, Theme 2

Iron minerals play important roles in soils that can impact nutrient availability and carbon dynamics. A key process governing the functional influence of iron in upland soils is microbially-driven iron reduction, which occurs in microsites even when soils are unsaturated. However, quantifying iron reduction in upland soils across an ecosystem is challenging. We evaluated several in situ techniques for assessing iron reduction including Fe-coated PVC pipes, rusted iron rods, Pt-electrodes and in-field anoxic incubations. Before deploying these at the Calhoun and Luquillo CZOs, which both have abundant iron and documented periods of anoxia, we tested them across a well-defined climate and redox gradient on the island of Maui. These techniques were installed at four sites along a rainfall gradient on Haleakala in Maui. We inserted uniformly rusted rods and Fe-coated PVC pipes into the soil for two weeks and quantified the disappearance of the FeIII through image analysis after 7, 11 and 14 days. Throughout the same period we monitored pH and Eh using Pt and pH electrodes. Finally, we sampled replicate mini-cores of the soil profiles along the gradient, flushed them with nitrogen gas for up to three days, and compared 0.5M HCl-extractable Fe^{2+} before and after incubation. We found that the rusted iron rods responded best to the net redox conditions of the sites: at sites with higher rainfall, a greater portion of the FeIII was removed from the rods. In addition, the iron rods allowed qualitative assessments of iron reduction potential with depth. The in situ incubations were sensitive to time of N_2 flushing and incubation time, which may need to be optimized for individual ecosystems. The Pt electrodes indicated predominately oxic conditions with some electrodes evidently influenced by reduced microsites. In summary, this suite of methods hold promise for assessing the prominence of iron reduction at the ecosystem-scale.

T2X. Short- and long-term responses of soil microbe communities to fire and mountain pine beetle disturbance

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Applicable themes: Theme 2, Theme 4

Natural disturbances such as fires and insect outbreaks are increasing in frequency and severity across the western U.S. with enormous impacts on regional carbon and water cycling. At landscape scales, tree deaths from biotic disturbances like Mountain Pine Beetle (MBP) are distinctly different from abiotic disturbances such as fire. MPB mortality skews stand size distributions towards smaller crowns, thus changing biogeochemical cycling by reducing rhizosphere exudates and litter inputs. Do these different disturbances cause contrasting successional changes in soil microbiota and how do shifts in microbial functional groups influence post-disturbance dynamics in forests? We compared responses of exoenzyme activity and microbial biomass carbon and (C) nitrogen (N) in soils of forests exposed to contrasting disturbance types. In a mixed-conifer zero order basin of the Jemez CZO, soil samples were collected across a gradient of burn severity within weeks and then one year following the June 2013 Thompson Ridge Fire. In the high elevation conifer forests of the Colorado Rocky Mountains, soil samples were collected from the 2012 High Park Fire from areas varying in fire severity and from unburned areas with and without MBP-induced tree mortality. In the short term, fire causes a reduction in total soil microbial biomass, shifts in bacterial: fungal biomass ratios, and transformations of organic compound substrate availability for microbial metabolism. Insect and fire-driven tree mortality lead to fine-scale variation in biogeochemical states and microbial population dynamics altering soil C efflux and N availability. These results suggest disturbance type causes distinctive changes to organic inputs, resulting in shifts in microbial biomass and functional structure. They provide a first step towards characterizing the response of microbial functional diversity to disturbance in this region and offer potential to inform projections of changes in critical zone services.

T2Y. Impact of fire, landscape position, aspect, and soil depth on microbial function through quantification of extracellular enzyme activity in the Jemez River Basin CZO

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Applicable themes: Theme 2, Theme 4

Fire frequency and severity are increasing across the western US, and post-fire recovery and effects on critical zone structure are not fully understood. Resident microbiota (bacteria and fungi) transform the majority of carbon in ecosystems and the function and structure of these communities influence ecosystem scale events such as seedling establishment, trajectory of vegetative recovery, and competitive advantages between plants as well as biogeochemical cycling. We surveyed changes in microbial composition and functional activity after wildfire to better understand soil microbial resilience and fire ecology. Specifically, we used potential extracellular enzyme activities (EEAs) to assess changes in functional activity in response to disturbance. We sampled eighteen days after containment of the June 2013 Thompson Ridge Fire in the Jemez River Basin Critical Zone Observatory, across a gradient of burn severities in a mixed-conifer zero order basin (ZOB). We subsampled six depths through the surface soil profile (0-2, 2-5, 5-10, 10-20, 20-30, 30-40 cm). In these samples, we measured potential activities of seven hydrolytic enzymes using established fluorometric techniques. Four of these enzymes hydrolyze C-rich substrates (β-glucosidase (BG), β-D-cellobiohydrolase (CB), xylosidase (XYL), and α-glucosidase (AG), two hydrolyze N-rich substrates (N-acetyl-β-glucosaminidase (NAG) and leucine aminopeptidase (LAP), and one hydrolyzes a P-rich substrate (acid phosphatase (PHOS). We examined the effect of landscape position and aspect on potential enzyme activity, as well as activity responses to temperature (at 5°C, 10°C, 15°C, and 25°C) in order to calculate Q10 response. Results showed decreased activities with depth for enzymes BG, CB, and LAP. Significantly higher potential enzyme activity was observed for convergent sites relative to planar or divergent sites across all depths sampled. Additionally, we looked at shifts in enzyme stoichiometry, which have been used as indicators for nutrient limitation, with higher acquisition potential often interpreted as greater resources being allocated towards nutrient acquisition. Results showed a variance

in resource acquisition potential with depth for C relative to N with greater resources being allocated towards acquiring C at shallower depth. Conversely, greater resource acquisition potential was expended towards acquiring P relative to N and C at greater depths. Collectively, these results provide a greater understanding of the microbial role in C and nutrient cycling in soil following fire disturbance and may provide insight into microbially mediated biogeochemical 'hot spots' in the landscape.

T2Z. Can chambers correctly measure soil respiration under snowpack? Laboratory and field tests of novel "forced diffusion" chambers

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Applicable themes: Theme 2

Seasonally snow covered ecosystems in mid-latitudes play a critical role in the global carbon cycle, and soil carbon dioxide (CO_2) fluxes can represent a large fraction of carbon returned to the atmosphere as ecosystem respiration, and thus are a key determinant of carbon balance. Despite this importance, technological challenges have hampered the measurement of respiration under snow and consequently, the advancement of our understanding of its temporal and spatial patterns and controls. Recently developed forced diffusion (FD) chambers may provide a solution to some of these challenges because they require no flow or flushing of atmospheric air. We plan to test FD chambers in fall 2014 using controlled flux densities of CO_2 through an artificial soil and snow diffusion system under a variety of laboratory conditions. We will then evaluate FD chamber reliability and comparability to other measurement techniques under winter field conditions in Pocatello, Idaho. This is a proof of concept study, with the ultimate aim to develop a robust method that can be integrated into a cross-site network of measurements to fill key knowledge gaps, including converting point-scale understanding to larger scales and propagation of environmental controls on subnivean CO_2 efflux.

THEME 3

T3A. Discriminating natural variation from legacies of disturbance in Western USA ecosystems

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Applicable themes: Theme 2, Theme 3 , Theme 4

Existing vegetation structure and assembly are artifacts of disturbance legacies and topographic variations on site productivity. Topographic variation has important implications for monitoring ecological succession and eco-hydrological interactions within the critical zone. Here we derive forest structure from aerial LiDAR across multiple CZOs and compare these responses to a range of climatological observations and topographic indices. Benefits of aerial LiDAR are it covers entire landscapes: all vegetation classes, topographic positions and elevations. We chose a priori undisturbed and disturbed sites that included preservation, development, logging and wildfire as exemplars. We generated two topographic indices: the topographic position index (TPI), topographic wetness index (TWI); and a spatially distributed Effective Energy to Mass Transfer (EEMT) model that uses downscaled climatological observations from a digital elevation model (DEM). Topographic EEMT is proportionate to expected gross primary productivity. We found the observed heights (H_obs) of vegetation are correlated to TPI and TWI locally, and link to broader gradients in EEMT at the landscape level. Essentially, the TPI and TWI are proportional to differences in soil depth and soil moisture. These variations strongly control the maximum height of climax vegetation (H_climax) at catchment scale. Lastly, we derive a relative disturbance index (RDI) where RDI = (H_obs – H_climax) / H_climax, that maps departure of existing vegetation from potential climax states. These techniques have promise in advancing our ability to (1) explain variation in forest structure across topographically complex landscapes, (2) identify and map previously unrecorded disturbance locations, and (3) quantify different impacts of disturbance within and upon the critical zone at ecologically relevant catchment-area scale.

T3B. Biological soil crust nitrogen fixation in semi-arid ecosystems: Climatic and grazing controls

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CZOs: Reynolds Creek
Applicable themes: Theme 3

Nitrogen, next to water, is believed to be the main limiting resource in arid and semi-arid ecosystems. Biological soil crusts (biocrusts) –a surface community of mosses, lichens and cyanobacteria-have been found to be the main influx of “new” nitrogen (N) into many dryland ecosystems. Controls on biocrust N fixation rates include climate (temperature and moisture), phosphorus availability, and disturbance factors such as trampling, yet a systematic examination of climatic and disturbance controls on biocrusts communities is lacking. Biocrust samples were collected along an elevation gradient in the Reynolds Creek Experimental Watershed near Murphy, Idaho. Four sites were selected from a sagebrush steppe ecosystem with precipitation ranging from ≤250mm yr^{-1} to ≥1100mm yr^{-1} . Each site included 5 grazed plots and one historic exclosure plot that has been free from grazing for more than 40 years. Five samples each were collected from under plants and from interplant spaces from the grazed plots and exclosures and analyzed for potential N fixation using an acetylene reduction assay. We hypothesized that N fixation rates would be the highest in the exclosures of the two middle sites along the elevation gradient, due to the lack of disturbance and optimal temperature and moisture, respectively. As predicted, results showed higher rates of potential N fixation in exclosures than non-exclosures at a mid-elevation 8.4 ± 3.1 kg N ha^{-1} yr^{-1} in the exclosures compared to 1.8 ± 1.5 kg N ha^{-1} yr^{-1} indicating that grazing may reduce N fixation activity. Interestingly, rates were 2-5 times lower under plant canopies compared to interplant spaces at all but the highest elevation site. Findings from our study suggest that biocrust N fixation may be a dominant input of N into theses dryland systems and, in line with our hypotheses, that climate, location within the landscape, and disturbance may interact to regulate the rates of this fundamental ecosystem process.

T3C. A GIS-based framework for examining the effects of water-driven erosion on soil biogeochemical cycling

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CZOs: Intensively Managed Landscapes
Applicable themes: Theme 2, Theme 3

Soil erosion has long been identified as one of the key mechanisms affecting biogeochemical processes in the soil, through the transport and delivery of carbon and nutrients adsorbed to soil particles in the soil active layer. However, most biogeochemical models treat soil erosion contributions simplistically and lack the capacity to accurately account for the mechanisms that control soil erosion and deposition on the landscape. This stems from the fact that the majority of the biogeochemical models have traditionally been employed on landscapes where lateral and downslope fluxes due to soil erosion have been less significant compared to other vertical fluxes and processes occurring at a fixed location on the landscape. In intensely managed landscapes, however, this may not be the case since land management practices such as tillage and exposed land cover can lead to copious amounts of erosion. Thus, to better understand the role of soil erosion on soil biogeochemical cycling in IMLs, we present a framework for simulating the spatiotemporal effects of soil erosion and deposition on soil biogeochemical cycling. The framework employs a geospatial approach that loosely couples a GIS-based upland water erosion model, GeoWEPP, with a soil biogeochemistry model, Century, to predict downslope and lateral fluxes of soil erosion and the resultant impacts on soil biogeochemical cycling. This approach allows us to better capture the effects of topography, soil type, land use/land cover and climate on soil erosion fluxes as well as soil biogeochemical cycling. The spatiotemporal resolution of the framework makes it particularly beneficial for identifying hotspots in fields and hot moments at scales ranging from daily to annual time scales. Preliminary results from the South Amana Subwatershed, IA, indicate that the framework is able to capture observed erosional and depositional patterns in the watershed and can provide insight into soil carbon redistribution and sequestration.

T3D. Potential Carbon Transport: Linking soil aggregate stability and sediment enrichment for updating the soil active layer of intensely managed landscapes

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Applicable themes: Theme 2, Theme 3

Currently, many biogeochemical models lack the mechanistic capacity to accurately simulate soil organic carbon (SOC) dynamics, especially within intensely managed landscapes (IMLs) such as those found in the U.S. Midwest. These modeling limitations originate by not accounting for downslope connectivity of flowpathways initiated and governed by landscape processes and hydrologic forcing, which induce dynamic updates to the soil active layer (generally top 20-30cm of soil) with various sediment size fractions and aggregates being transported and deposited along the downslope. These hydro-geomorphic processes, often amplified in IMLs by tillage events and seasonal canopy, can greatly impact biogeochemical cycles (e.g., enhanced mineralization during aggregate breakdown) and in turn, have huge implications/uncertainty when determining SOC budgets. In this study, some of these limitations were addressed through a new concept, Potential Carbon Transport (PCT), a term which quantifies a maximum amount of material available for transport at various positions of the landscape, which was used to further refine a coupled modeling framework focused on SOC redistribution through downslope/lateral connectivity. Specifically, the size fractions slaked from large and small aggregates during raindrop-induced aggregate stability tests were used in conjunction with rainfall-simulated sediment enrichment ratio (ER) experiments to quantify the PCT under various management practices, soil types and landscape positions. Field samples used in determining aggregate stability and the ER experiments were collected/performed within the historic Clear Creek Watershed, home of the IML Critical Zone Observatory, located in Southeastern Iowa.

T3E. Distinct erosion scenarios generate variable estimates of soil-atmosphere CO2 exchange: The Calhoun Critical Zone's Ultisols as a model system for historically cropped soils

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CZOs: Calhoun
Applicable themes: Theme 3, Theme 4

Soil erosion can perturb carbon (C) fluxes at diverse scales ranging from the microbe to the bio- and atmosphere systems, and thus can have a significant influence on Earth's climate. We employed an erosion model that permits the user to define profile characteristics, erosion rate, and the extent to which SOC oxidation and production at the eroding site are maintained. We estimated CO_2 source or sink strength of historical erosion at the Calhoun Critical Zone Observatory, where ~150 y of row-crop agriculture induced significant erosion prior to the re-establishment of forest vegetation. Past work suggests that historical erosion in this region may have induced significant perturbations to the regional C cycle and ultimately to atmospheric CO_2. Here, using well-constrained estimates of past erosion rates, we explore the influence of multiple erosion scenarios representing distinct SOC oxidation and production characteristics on atmospheric CO_2. Regardless of SOC oxidation and production rates at the eroding site, modeled estimates of the maximum CO_2 source after 150 y of erosion remained between 3.2 and 3.6 kg C m^{-2}. In contrast to CO_2 source strength, CO_2 sink strength varied substantially with SOC production and oxidation, revealing a maximum sink of 2.6 kg C m^{-2} when SOC production was maintained and SOC oxidation was minimized upon erosion. When model runs mimicked a decline in SOC production and maintenance of SOC oxidation at the eroding site, the minimum sink was transformed into a CO_2 source of 1.4 kg C m^{-2} after 150 y. Scaling these estimates up to the region, assuming 0.85 x 1012 ha of similar soils experiencing similar fates, suggests the Piedmont region subjected to 150 y of row-crop agriculture may have contributed up to 3.1 Pg of atmospheric CO_2, or served as a sink for up to 2.2 Pg of CO_2. Our work emphasizes the importance of incorporating historical, current, and projected future erosion into efforts to understand Critical Zone C cycling.

T3F. Structured heterogeneity of water isotopes through the Critical Zone

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CZOs: Eel River
Applicable themes: Theme 1, Theme 3

Recent studies have highlighted the use of stable isotopes of water ($d^{18}O$, dD) to measure the flux of water currencies through the hillslope and into vegetation. Although previous studies assume the conservative nature of water isotopes below the evaporative enrichment found in soil, we demonstrate that material properties within the subsurface (soil, saprolite, weathered bedrock) retain distinct isotopic compositions that result in a persistent structured heterogeneity. Through two years of intensive monitoring at the Eel River Critical Zone Observatory, we find that the mobile water transiting through the hillslope is enriched relative to the tightly held moisture found in the soil, saprolite, weathered bedrock, and fresh bedrock. These isotopically distinct subsurface reservoirs become the source water for different vegetative types growing on the hillslope. Douglas-fir rely on moisture derived from saprolite and weathered bedrock throughout the year, whereas hardwood species opportunistically use mobile soil moisture in the wet season and tightly bound moisture in the dry season. Hardwood moisture comes from soil except late in the dry season on the south facing slope, where soil water tension decreases and forces hardwoods to derive deeper moisture. Although adjacent hardwoods and Douglas-firs partition water based on matric pull on the north side, there is competition for saprolite moisture in late summer on the south side. These results show the importance of material properties and species type in controlling the isotopic composition of vegetative source water.

T3G. Non-linear dynamics in plant-soil interactions and implications for critical zone processes

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Applicable themes: Theme 3

Interaction between vegetation and soil is a prominent feature of the critical zone and influences innumerable physical, chemical, and biological processes. For example, plants stabilize soil, protect it from erosion by wind and water, and produce organic detritus that supplies nutrients to soil microbiota. In return, soil provides a reservoir for water and nutrients essential to plant growth. Together, the coupled plant-soil system filters water and chemical inputs at the surface that drive bedrock weathering at depth. Exploratory models of low and intermediate complexity can be a valuable tool for understanding the role of plants and soil in critical zone function and, in particular, to interpret empirical data and generate hypotheses regarding connections among internal processes and state variables. In this poster, we present three examples of minimalist models coupling plant and soil dynamics in the critical zone to demonstrate the utility of this approach. First, we study the role of vegetation effects on erosion, the emergence of bistability in soil formation, and soil stability under agricultural pressure. Secondly, we apply a model of the carbon-nitrogen cycle to interpret decades of observations during reforestation at the Calhoun Experimental Forest. The model suggests this forest experienced a unique under-damped regrowth trajectory related to a prior history of cultivation and fertilization. Finally, we discuss the stochastic dynamics of soil moisture and its potential role in chemical weathering and soil chemistry, offering a first step toward a more general quantitative theory of the climatic controls on soil acidity. Each of these modeling studies highlights a unique feature of critical zone dynamics that can be analyzed in detail with simple models.

T3H. Mapping soil organic carbon (SOC) content of soils in the Reynolds Creek Watershed

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Applicable themes: Theme 1, Theme 3

Quantification of soil organic carbon (SOC) is difficult in topographically and ecologically diverse landscapes. Advances in information technology and computation have, however, led to improved approaches to soil mapping, known collectively as digital soil mapping (DSM). In this research, the organic carbon content of soils in the Reynolds Creek Experimental Watershed is mapped using a coupled field and modeling approach. This study is in the Reynolds Creek Watershed (RC CZO) (239 km^2), located in the Owyhee Mountains of southwestern Idaho where a strong elevation gradient in the watershed produces a strong climatic gradient (annual precipitation: 230-1100 mm yr^{-1}). Vegetation species closely follow precipitation with generally lower biomass sagebrush-steppe in the lowlands and a higher biomass mix of conifers, junipers and some sagebrush at higher elevations. We hypothesize that vegetation species will be a primary control on SOC in the Reynolds Creek watershed and have designed our collection strategy accordingly. A preliminary map of SOC for the watershed was constructed using a random forest regression model. This preliminary mapping effort showed that, of elevation, geology, soil type, aspect, slope and annual precipitation, NDVI had the highest correlation with SOC. We hope to improve upon this model by incorporating a large field soil carbon dataset and high resolution LiDAR data and vegetation data collected in the field. At each field site, a pit is dug to 1 m and 9 cores are taken surrounding the pit to a depth of 30 cm, with 5 cores under the vegetation canopy and interspace respectively. Images will also be collected at each site to further characterize vegetation density. We will produce a map with predicted soil organic carbon content across the watershed. This map will be used to inform future sampling and help determine which processes are most important in determining SOC content at the landscape scale in semi-arid regions.

T3I. Diurnal and seasonal variation in tree stem circumference using automated self-reporting dendrometer bands (TreeHuggers)

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CZOs: Reynolds Creek
Applicable themes: Theme 2, Theme 3

The Reynolds Creek Critical Zone Observatory (RC CZO) is a new CZO in southwestern Idaho whose research objectives are to quantify soil carbon storage and flux, and the factors governing these from pedon to landscape level. Aboveground carbon pools and fluxes are an important contributor to soil carbon, and quantifying variation in these is important for understanding critical-zone carbon processes. To estimate changes in aboveground carbon pools, we deployed automated, self-reporting dendrometer bands (TreeHuggers) on three tree species (Juniperus occidentalis, Populus tremuloides, Psuedotsuga menziesii). These species represent the dominant tree species in Reynolds Creek watershed, and occupy sites of varying aspect and microclimates. We installed TreeHuggers onto at least 6 trees per species, and tree-circumference-data (accurate to within 2 µm) were recorded at 15-20 minute intervals. The preliminary data suggest that the mean changes in tree circumference were 0.188+0.044 cm, 0.451+0.227 cm, and 0.522+0.123 cm for J. occidentalis, P. tremuloides, and P. menziesii, respectively, within about two months. Tree circumference-growth began on 160, 162, and 158 DOY respectively, based on dendrometer traces. Diurnal variation in tree circumference averaged about 0.012+0.003 cm, 0.070+ 0.038 cm, and 0.011+ 0.002 cm for J. occidentalis, P. tremuloides, and P. menziesii respectively. Future research includes deploying litterfall traps to measure the aboveground carbon inputs to soil and installing sap flux sensors to measure the whole tree transpiration in all three species to examine the plant physiological compared to critical zone controls on aboveground productivity and inputs.

T3J. The role of vapor flow for plant survival in dry land ecosystems

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Applicable themes: Theme 1, Theme 2, Theme 3

When the temperature of land surface is lower than that of air and deeper soils, water vapor moves toward the ground surface where dew maybe formed. Some plants are able to absorb the dew and vapor flow while the soil can readily absorb both. Certain animals such as desert beetles and ants harvest the dew or fog for daily survival. Recently, it is also realized that the dew and vapor flow can be a life-saving amount of water for plant survival at the driest seasons of the year in arid and semi-arid regions and the Mediterranean climate zones. Researches are conducted to quantify the amount of near-surface vapor flow in arid and semi-arid regions in China and USA. Quantitative leaf water absorption and desorption functions were derived based on laboratory experiments. Results show that plant leaves absorb and release water at different speeds depending on the species and varieties. The “ideal” native plants in the dry climates can quickly absorb water and slowly release it. This water-holding capacity of plant is characterized by the absorption and desorption functions derived for plant physiology and water balance studies. Field studies are conducted to measure the dynamic vapor flow movements from the atmosphere and the groundwater table to soil surface. Results show that dew is usually formed on soil and plant surfaces during the daily hours when the temperature gradients are inverted toward the soil surface. The amount of dew harvested using gravels on the soil surface was enough to support water melon agriculture on deserts in NW China. The vapor flow can be effectively intercepted by artificially seeded plants in semi-arid regions forming new forests. Recent studies are conducted to quantify the role of vapor flow for the survival of giant sequoias in the southern Sierra Nevada Mountains of California.

T3K. Critical Zone ecohydrology: Linking geological structure to water and vegetation dynamics in complex terrain

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CZOs: Catalina-Jemez, Boulder Creek
Applicable themes: Theme 1, Theme 2, Theme 3

The network of CZO sites across the country is setting the stage for rapid, transferrable advances in our understanding of critical zone response to change. A challenge for this network however is transitioning from the more familiar and traditional individual, site-based studies to research focused on developing understanding across sites and wide ranging spatial and temporal scales. The development of these broadly applicable principles is crucial for predicting and managing the effects of disturbance on the majority of the landscape where observations are limited.

Understanding how critical zone vegetation will response to widespread vegetation change, whether due to fires, insects, drought, or direct human manipulation, is one of these knowledge gaps. There is growing recognition that the connection between vegetation response and recovery to disturbance and local- to regional-scale groundwater highlights the need for a coordinated research effort linking water- and biogeochemical-dynamics across the Critical Zone, from deep subsurface to the canopy. This Critical Zone approach expands on recent advances in scaling using ecohydrological ideas by including geomorphic and geocentric approaches. By using the Critical Zone framework of "base of groundwater to canopy", we can pose two integrating questions to drive cross-CZO research:

> What are the temporal and spatial scales of hydrological, ecohydrological, hydrogeomorphic, and biogeochemical interactions between groundwater, surface water, and the atmosphere?

and

> Does the range of scales in the above interactions impart resilience, resistance, and recovery of CZ ecological structure and societal services in the face of large scale change?

This presentation will begin to address these questions using water isotopes, catchment scale hydrologic partitioning, airborne laser swath mapping (ALSM), and remote sensing of vegetation activity from multiple CZO and related sites.

T3L. Influence of trees on fluxes of water at the Susquehanna Shale Hills CZO

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CZOs: Susquehanna Shale Hills
Applicable themes: Theme 1, Theme 2

The dynamics of tree water use were investigated at the SSHCZO (Shale Hills) in order to better understand the influence of trees on water in the critical zone in a humid temperate climate. We asked the following questions: 1) How do slope position, tree species and tree size affect the depth of tree water extraction? 2) How do tree species and tree size affect sap velocity and residence time?

We focused our studies on the dominant genera: Acer (maple), Carya (hickory), Quercus (oak), and Pinus (pine). We hypothesized that most trees would use shallow water, due to the shallow soils in much of the catchment. We expected that some trees (members of the genus, Quercus, larger trees, and trees on the valley floor) would show evidence of deeper water use. We hypothesized that trees with larger vessel diameters would have faster sap velocities and larger trees would have longer tracer residence times.

We used a suite of methods to study tree water fluxes including: sap flux sensors, natural abundance stable isotopes, deuterium tracer, root length density, and soil moisture content at depth. We found that tree water use was quite shallow, with most trees using water from less than 50 cm deep. The depth of water extraction was largely independent of depth to bedrock and slope position, and modestly affected by genera and tree size. We saw evidence of Quercus using deeper roots on average than Acer and Pinus spp. The shallow water use was consistent with conceptual models of root water uptake in a humid climate.

Sap velocity was estimated at between 2 and 19 m d-1 and residence time was between 7 and 33 days. There was variation in individual trees with sap velocity and water residence time, but no clear species or size differences. The patterns in timing of tree water use were similar to other studies in tropical and arid ecosystems. These findings are necessary for modeling of hydrologic parameters that are influenced by vegetation.

T3M.Ground and airborne LiDAR measurements of shrub biomass

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CZOs: Reynolds Creek
Applicable themes: Theme 4

At the Reynolds Creek CZO, we have a complimentary study supported by NASA to improve remote sensing measurements of structure and function across the watershed for ecosystem modeling. The watershed-wide products of biomass, height, cover and biogeochemistry from LiDAR and hyperspectral data will also be used in the integrated CZO soil carbon modeling work. In this research we present work on shrub biomass estimates across Reynolds Creek Experimental Watershed (RCEW) using LiDAR. We combine multi-scale data, including field-measured biomass, terrestrial laser scanning (TLS) and airborne laser scanning (ALS) data, in a hierarchical modeling framework, with each scale validating an increasingly broader index of sagebrush (Artemisia tridentata) aboveground biomass. The model predicts biomass of sagebrush across the watershed across 5 m grid cells, with a $R^2 = 0.56$. A major advantage of this model is that the biomass estimates at the scale of 5 m is sufficient for initializing models to estimate ecosystem fluxes, and the contiguous estimates across the watershed support analyzing patterns and connectivity of these dynamics.

T3N. Sourcing organic matter input from subsurface tile drainage and overland flow in a Midwestern agricultural watershed

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Applicable themes: Theme 2, Theme 3

Installation of tile drainage systems in the US Midwest, beginning in the 1880's, dramatically altered watershed hydrology and nutrient dynamics. Tile systems are rapid conduits for dissolved and colloidal materials to ditches and streams, bypassing the riparian zone and slower in-flow biogeochemical and physical processes. This phenomenon is a critical aspect of the function of Midwestern intensively managed agricultural landscapes. Few studies assess the comparative role of tile drains and overland flow in the transport and transformations of organic carbon (OC) nor attempt to ascertain the signature/impact that these delivery paths have on overall watershed C dynamics. In a 3.6 Km2 agricultural watershed in central Indiana, we investigated the export of OC over a 16-month period. Alternating corn (C4) and soy (C3) rotations were investigated and the fate of plant carbon was tracked from the upper 0-5 cm of surface soil in a 2-hectare subplot, to colloidal (0.1-0.7 µm) and dissolved (0.1µm - 1,000 Dalton) aquatic size fractions using lignin phenol chemistry and stable carbon isotopes. Soils were fractionated into macroaggregate (>250 µm), microaggregate (53-250 µm), and silts plus clay (<53 µm) size fractions, and using a simple two-member isotope mixing model, C4-derived C was found to range from 51, 39, to 33%. Aquatic OC collected at the outlet of the watershed showed that relative contribution of C4 C varied from 0 to 85% depending upon discharge. There was a consistent trend of increasing C4 C in overland flow with discharge. Carbon mobilized from tile drains had a consistently lower contribution of C4 C with respect to overland flow. Also, an increased contribution of C4 C to aquatic OM relative to C3 material (e.g. soy, past C3 agriculture, or presettlement land cover) at the watershed outlet could only be detected when stream discharge exceeded 0.531 $m^3 sec^{-1}$.

T3O. Soil depth dependence of stable and radiogenic carbon and stable oxygen isotopes in gibbsite ($Al(OH)_3$) occluded CO2 as an indicator of recovery after anthropogenic disturbance

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CZOs: Calhoun
Applicable themes: Theme2, Theme 3

One theme of the Calhoun Critical Zone Observatory (CCZO) is the recovery of soils degraded by agricultural practices as measured by the re-establishment of macropore networks to allow nutrient transport from the surface through the clay-rich B-horizon. Depth profiles of the stable isotopic composition of CO_2 occluded in pedogenic gibbsite ($Al(OH)_3$) from two sites in the southeastern U.S. Piedmont suggest that profiles of $\delta^{13}C$ values can be diagnostic of the state of the soil disturbance and recovery. It is expected that the depth profile of $\delta^{13}C$ values of gibbsite-occluded CO_2 will follow a Fickian diffusion-controlled mixing curve between atmospheric and soil pools. The profile of a less-disturbed plot with a thick regolith (CZEN site: J. Phil Campbell Research and Education Center – JPCREC) suggests mixing or recrystallization of clay minerals formed near the surface to the top of the Bt horizon (45 cm). In a more-disturbed plot with a thin regolith (CZEN site: Panola Mountain - PM) the profile suggests that the isotopic gradient in the upper portion of the soil (the A and O horizons) has not been reformed. These two conditions are proposed as end-members on a scale of anthropogenic disturbance that can be used to assess the degree of recovery at the CCZO and perhaps also at other CZOs. Correlation between the $\delta^{18}O$ and $\delta^{13}C$ values of the undisturbed JPCREC site support the notion that these values are controlled by diffusion, and that the unexpected shape of the $\delta^{13}C$ depth profile is likely the result of transport or recrytallization after formation. Interpretation of the PM profile relative to the JPCREC profile suggests that the difference is the removal of the upper portion of the soil, which eliminates the need for unrealistically low soil respiration rates needed to explain this profile. Model C-14 ages of gibbsite-occluded CO_2 at PM show that there are distinct populations of gibbsite that tend to have younger model ages toward the surface. Combining the stable and radiogenic isotope signatures of gibbsite-occluded CO_2 and real-time pore-space CO_2 isotopic compositions will offer new insights into the timing of gibbsite formation (CO_2 occlusion) and transport in the soil. In addition, C-14 ages of the gibbsite-occluded CO_2 and associated recalcitrant organic carbon may provide insight into the turnover rates of the stable carbon pool associated with clay mineral surface complexation.

T3P. Threshold dynamics in soil carbon storage for bioenergy crops

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Applicable themes: Theme 3, Theme 4

Due to increasing demands for bioenergy, a considerable amount of land in the Midwestern United States could be devoted to the cultivation of second generation bioenergy crops, such as switchgrass and miscanthus. The foliar carbon to nitrogen ratio (C:N) in these bioenergy crops at harvest is significantly higher than the ratios in replaced crops such as corn or soybean. We show that there is a critical soil organic matter C:N ratio, where microbial biomass can be impaired as micro-organisms become dependent on net nitrogen immobilization. The simulation results show that there is a threshold effect in the amount of above-ground litter input in the soil after harvest that will reach a critical organic matter C:N ratio in the soil, triggering a reduction of the soil microbial population, with significant consequences in other microbe-related processes such as decomposition and mineralization. These thresholds are approximately 25% and 15% of above-ground biomass for switchgrass and miscanthus, respectively. These results suggest that values above these thresholds could result in a significant reduction of decomposition and mineralization, which in turn would enhance the sequestration of atmospheric carbon dioxide in the topsoil and reduce inorganic nitrogen losses when compared with a corn-corn-soybean rotation.

T3Q. Impacts of wildfire on throughfall and stemflow precipitation chemistry in the Jemez River Basin CZO of New Mexico

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CZOs: Santa Catalina Mountains-Jemez River Basin
Applicable themes: Theme 3

The occurrence of large, stand replacing wildfires is more frequent in the western United States now than ever before. The loss of canopy cover due to wildfire drastically modifies landscapes and alters ecosystems as high intensity burns replace canopies with charred branches and trunks, change soil composition and erosion processes, and affect hydrologic flow paths and water chemistry. Precipitation that is not intercepted by the forest canopy makes its way to the forest floor as throughfall or stemflow. Tracking variations in the amount and chemistry of precipitation that interacts with burned versus unburned forest stands, as well as open precipitation, will help to quantify changes in hydrologic routing and catchment water chemistry caused by wildfire. This study investigates the effects of fire on the volume and chemical composition of stemflow and throughfall by observing the effects of the June 2013 Thompson Ridge wildfire in the Jemez River Basin CZO in the Valles Caldera National Preserve of New Mexico.

Throughfall and stemflow collectors were installed beneath both burned and unburned canopies and open areas in two catchments impacted by the Thompson Ridge fire. Initial results of field parameters, including electrical conductivity, pH

and volume of precipitation collected from both burned and unburned sites, show variations across collector type (stemflow, throughfall and open precipitation), site location as the two catchments differ in aspect and gradient, and burn severity. Throughfall, stemflow and open precipitation samples were analyzed for trace metals, major cations, anions, nutrients and organic matter to determine how fire affects the chemical composition of the precipitation that interacts with burned canopies. This study is one of the first to quantify the relationship between wildfire and the chemistry and flux of stemflow and throughfall in conjunction with a full suite of pre and post fire precipitation, soil and surface water chemistry.

T3R. Potential effects of tree-to-shrub type conversion on streamflow in California's Sierra Nevada

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CZOs: Southern Sierra
Applicable themes: Theme1, Theme 3, Theme 4

Climate change may lead to vegetation change across California, which in turn can influence watershed hydrology. Yet, sensitivities of hydrologic processes to potential shifts in vegetation type are not well understood. The primary objective of our research was to generate mechanistically-based projections of how potential type conversion from forested to shrub dominated systems affect streamflow at the snow-rain transition zone in the southern Sierra Nevada. During the growing season in 2014, we measured physiological responses of two dominant tree and shrub species to changes in seasonal water availability at two sites within the southern Sierra Nevada Critical Zone Observatory. Plant physiological measurements included predawn xylem pressure potential (MPa) and maximum leaf gas exchange rates, namely transpiration (E) and photosynthesis (A). Field data was used to parameterize a process-based eco-hydrological model, RHESSys, which was then used to evaluate how vegetation type-conversion impact streamflow. We found that shrubs and trees had similar access to water through the early part of the growing season (April-early June); however, by late July, available water to shrubs was twice that of trees (shrubs, -0.55 ± 0.08 MPa; trees, -1.07 ± 0.08 MPa, $p<0.05$). Likewise, leaf gas exchange rates per unit leaf area were twice as high for shrubs then trees in July (shrubs, A= 21 ± 2.3 µmol m^{-2} s^{-1}, E=6.6 ± 1.8 mmol m^{-2} s^{-1}; trees, A=8.2 ± 1.9 µmol m^{-2} s^{-1}, E=2.4 ± 0.3 mmol m^{-2} s^{-1}). Preliminary modeled changes in streamflow following simulated vegetation conversion affected both the timing and amount of discharge. Controls on pre vs. post-conversion streamflow included changes in interception, rooting depth, energy budget, and plant transpiration. Our research demonstrates how linking strategic field data collection and mechanistic ecohydrologic models can be used as a robust tool for assessing potential impact of vegetation change on the water balance of an ecosystem.

THEME 4

T4A. Why does this place look the way it does? Virtual fieldwork experiences and CZO outreach

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CZOs: National Office
Applicable themes: Theme 1, Theme 4

Virtual Fieldwork Experiences (VFEs) are virtual representations of actual field sites that are used in classrooms and other educational settings to both serve as a proxy and catalyst for engaging learners in scientific fieldwork. Typically, VFEs take the form of a multimedia presentation including Google Earth files, photos, videos, Prezis and possibly other kinds of media. The driving question for the work is asked in this abstract's title, and it is supported by a range of other questions that can be productively investigated for any site. The Paleontological Research Institution is the outreach partner with the CZO National Office, and is working to develop VFEs for use in CZO outreach. This poster will use a VFE of Colorado's Dinosaur Ridge created in association with the 2013 GSA meeting to serve as a model for the work. See http://virtualfieldwork.org/A_VFE_Database.html. The poster will feature a graphic organizer with sets of questions related to different aspects of the environment. The graphic organizer serves as a centerpiece to templates for making VFEs that allow substitution of site-specific imagery and other data for making VFEs. CZO VFEs will be intended to serve not only as vehicles for inquiry into the science directed related to particular observatories, but also to serve as models for teachers and students to use for creating VFEs local to their schools. By authoring local VFEs, students and teachers both engage in and document actual fieldwork in a way that can be shared with other learners, and provide information in a way to facilitate comparison of different environments.

T4B. Linking human activity and CZ Processes in undergraduate educational modules at the Calhoun CZO

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CZOs: Calhoun
Applicable themes: Theme 4

Human activity both impacts and is impacted by CZ processes; quantifying and promoting public awareness of these interactions is critical to the development of more sustainable and resilient land use practices. Research at the Calhoun CZO seeks to integrate both natural and human forcing factors into our understanding of CZ dynamics. One of the primary educational initiatives at the Calhoun helps foster this integrated perspective among undergraduate students through the development of field-tested, web-based educational materials that are based on data and emerging science from the Calhoun. Lab and classroom materials will be designed as a set of inquiry-based modules that emphasize development of critical and quantitative reasoning skills and draw upon research datasets and real-time data. Maps, video interviews, case studies, and links to contemporary CZ issues will help to establish relevance and convey the sense of discovery behind the science. The first set of activities will be pilot tested at Roanoke College during the 2014-2015 academic year. In addition to outlining the framework for this initiative, this poster will detail an initial set of activities to help students quantify (1) the impacts of land use (both historical and contemporary) on soil erosion and (2) the subsequent impact of degraded soil and water quality on ecosystem services and on the human communities that depend upon them. Activities incorporate a range of collaborative learning techniques as well as lab and computer-based activities (GIS, Google Earth, STELLA) and will be updated to incorporate emerging data and science from the Calhoun CZO. These materials are intended to provide an accessible entry point to CZ science for both science majors and for the much larger population of non-science majors who may one day play a citizen's role in promoting more sustainable and resilient land management practices within their home communities.

T4C. Modeling Critical-Zone processes with Landlab

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CZOs: Boulder Creek
Applicable themes: Theme 1, Theme 4

Critical-zone science centers on understanding interactions and feedbacks in a fascinating but complex natural system. Exploratory numerical modeling can be an effective approach to studying such systems. Here we present a new software framework that helps scientists rapidly develop and explore models by drawing on a library for basic model-building tasks (such as grid creation and data ingestion) and an assortment of pre-existing process components. Landlab applications are written in Python, a high-level language with a rich set of graphical and scientific libraries. With Landlab's Gridding Engine, a model developer can create and configure a structured or unstructured grid with only a few lines of code. Relevant data fields can then be created and attached to appropriate elements of the grid. Use of the Numpy numerical libraries means that operations on grid variables can be performed as one-line operations, without the need for nested loops. Output can be visualized in real time, or written to netCDF files for import into data visualization programs. We illustrate Landlab's capabilities with several example models, which include representations of soil-moisture dynamics, rainfall-runoff, landscape evolution, and cellular automata. More information about Landlab can be found at http://landlab.readthedocs.org.

T4D. Earth's Critical Zones as Expanded Ecosystems

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CZOs: Calhoun
Applicable themes: Theme 4

The genetic models of soil, ecosystems, and critical zones are changing rapidly driven by scientific advances and accelerated human forcings. As pedologists, we argue that contemporary changes in the model of soil have significant implications for the classic ecosystem concept. Research findings demonstrate how soil and ecosystems are far deeper than previously appreciated, are polygenetic in their development and evolution, and in the Anthropocene are being transformed from natural into human-natural systems. Human forcings also transform the science of soils and ecosystems from basic, natural sciences to those that are basic and applied. In the future, we envision that soil and ecosystem science will become ever more dependent on interactions with the social sciences, humanities, and the public at large. Meanwhile, the newly conceptualized surface planetary system called the Critical Zone, is also a human-natural system that integrates solar energy, climate and the atmosphere, biota, soil, water, and the full weathering zone of the planet. Here we argue that the Earth's Critical Zone is compatible with the Tansley-Lindeman's concept of ecosystem [e.g., Tansley's (1935) "the whole system (in the sense of physics)"], and encourage all bio- and geo-scholars to get on with a overdue reconciliation and hybridization of the biogeosciences. We use ecosystem and critical zone metabolism and its effects on crustal weathering to demonstrate the conceptual identity of the ecosystem and critical zone.

T4E. Attributing reductions in evapotranspiration in the southern Sierra Nevada to timber harvest versus drought

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CZOs: Southern Sierra
Applicable themes: Theme 3, Theme 4

Downstream water users who depend on Sierra Nevada source waters have great interest in seeing more-aggressive forest management that can enhance water

yields. We measured soil-moisture storage, evapotranspiration and streamflow in a mixed-conifer forest for four post-snowmelt seasons, 2010-2013. We used a COsmic-ray Soil Moisture Observing Systems (COSMOS) to estimate shallow soil-moisture storage and an eddy-covariance flux tower to measure evapotranspiration, covering an area of about 20 ha. Soil-moisture sensors were also strategically placed in and around the COSMOS and tower footprints. Timber harvest occurred during summer 2012, involving selective uneven-age thinning and removal of ~30% of the biomass. Annual evapotranspiration was similar for all years, averaging about 80 cm, despite 2011 being one of the wettest years on record and 2012 one of the driest. Annual precipitation amounts were about 200 and 70 cm, respectively. Soil-moisture depletion occurred immediately following snowcover depletion, dropping to about 20% of maximum values over the 3-month period following snowmelt each year. The rate of soil-water loss was about the same in all of the years. In 2012 and 2013 the dates of snow disappearance were 2-3 months earlier than in 2011. Evapotranspiration during the 3-month period following snowmelt was about half of the annual total in 2010 and 2011, and for the fall period following harvest was about 10-20% lower than the previous year. Summer precipitation for all years was only 4-6 cm. Thus soil-water storage from snowmelt and rainfall provides much of the moisture for both evapotranspiration and streamflow. This storage provides multi-year buffering for moisture stress, and some resiliency to the forest. Results also suggest that the effect of a multi-year drought on evapotranspiration and the water balance is greater than the effect of selective timber harvest.

T4F. Design, implementation and hydrologic evaluation of a snow-measurement network using wireless sensors in the American River basin of California

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Applicable themes: Theme 2, Theme 4

The American River basin is the site for the deployment of a wireless sensor network (WSN) that provides distributed estimates of water balance and a full-basin, well-instrumented research platform. The technology extends that developed at the Southern Sierra CZO to the full-basin scale, with applications to hydropower operations, water-supply forecasts, drought management and reservoir management for flood control. The WSN is a set of sensors integrated into a single instrument to make spatial measurements to capture the landscape variability, and provide both spatially distributed and representative values of snowcover and the energy that drives snowmelt across the basin. In 2012, 18 sites were selected for local clusters forming the basin-scale WSN. Each local WSN has 10 snow-depth, air-temperature and relative-humidity sensors placed in a ~1-km^2 area, and is centered on existing snow-pillow, snow-course and meteorological-station sites. A subset of the nodes is also being equipped with 15-20 soil-moisture and soil-temperature sensors. Locations of individual nodes were first randomly chosen and analyzed to determine how well the aggregate of the 10 nodes represent the landscape variability within the 1-km^2 area and full basin. To improve the distribution pattern of the randomly chosen measurement nodes across the 1-km^2 area and basin, a random stratified method was used, whereby nodes that were oversampling various physiographic parameters were removed, and relocated to locations within the 1-km^2 area, which would improve the representativeness of the landscape variability. Results indicate that the aggregate of all measurement nodes are representative of the landscape variability across the American River basin, as well as the three forks of the American River. The spatially distributed sensors distinguish temperature and humidity differences across topographic and vegetation variables, e.g. cold-air drainage associated with micro-topography, or humidity differences between dense forest versus meadows. It is planned to blend these ground-based data with remotely sensed products to provide spatial maps of snowcover, snowmelt, soil moisture and evapotranspiration.

T4G. Optimizing CZ sensor networks using information theory and machine learning methods

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CZOs: Calhoun
Applicable themes: Theme 2

Accurate observation of complex ecohydrological and biogeochemical processes is crucial to CZ research. Sensor network designs must strike a balance between accuracy or completeness of information and size or cost of the network. The optimal design of networks presents a challenge when, as is often the case in environmental sensing, the space-time field of the variable to be measured depends on distributed parameters which may also change in space and time. Starting with space-time soil moisture dynamics which result from hydrologic

forcing and topographic variability within a watershed in the Calhoun CZO, we present theoretical results regarding the optimal design of soil moisture sensor networks providing optimal compromises between obtaining representative data and physical and budget constraints that limit the location, type, and number of sensors that can be deployed. As a criterion for the optimal network we select the network design that carries the most possible information about the soil moisture field for the entire basin. We explore such arrangements based on a minimalist soil moisture model, parameterized on these inputs as well as stochastic rainfall forcing to develop a reference space-time soil moisture field. We focus on 5 parameters—slope, aspect, contributing area, vegetation type, and soil type—which can be estimated from DEM data or obtained elsewhere. We use machine learning methods to numerically estimate the soil moisture PDF for the entire basin and compare it to soil moisture PDFs for possible network configurations. We then use information theory measures to quantify the discrepancy in the hypothetical soil moisture PDFs between the overall basin and the individual network configurations. The configuration of sensors which minimizes the system information loss and meets requirements for cost and network size is chosen as the optimal configuration. This criterion is applied to a case study in the Holcomb branch of the Calhoun CZO.

T4H. Design and optimization of a wireless sensor network for monitoring spatially distributed phenomena at the Southern Sierra CZO

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CZOs: Southern Sierra
Applicable themes: Theme 1, Theme 2

We present a study on the design and optimization of a wireless sensor network at the Southern Sierra Critical Zone Observatory. The network covers a one kilometer transect of the Providence Creek observation region and consists of twenty-three observation stations that measure snow depth, temperature, relative humidity, incoming solar radiation, soil moisture, and matric potential. Data is relayed every fifteen minutes to an Internet uplink through a network of signal repeaters, which form a self-healing mesh network using low power 802.15.4e radios. In addition to the network design, we discuss optimal sensing strategies, which use LIDAR data and K-means clustering to identify representative sampling regions throughout the transect. The optimal sampling locations can then be integrated with a methodology for optimizing the wireless network topology. Our approach to network optimization evaluates millions of possible network combinations by stochastically generating configurations for signal repeaters and uses shortest path-algorithms to identify a set of placements that maximize the number of redundant paths in the network. This ensures that all sensor stations can continue relaying data, even if individual network elements fail. Finally, we present opportunities for cross-CZO research using wireless technologies and remote sensing.

T4I. Sensitivity of catchment scale hydrologic partitioning to snowpack dynamics, Como Creek, CO

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CZOs: Boulder Creek
Applicable themes: Theme 2, Theme 4

Snowmelt is the primary source of surface water in the western United States. Climate warming is forecast to change the amount of precipitation that falls as snow and therefore snowpack magnitude, the timing of snowmelt, and snowmelt rate. We ask how these perturbations may impact how snowmelt is partitioned between evapotranspiration (ET) and runoff (R) at Como Creek, a snowmelt dominated catchment on the Colorado Front Range. Como Creek is a 4.5 km^2 headwater catchment spanning 2900-3560 m and is part of the Niwot Ridge Long Term Ecological Research Station and the Boulder Creek Critical Zone Observatory. We use observations of snow water equivalent (SWE), ET, and precipitation (P) from Niwot Ridge, CO, and discharge from Como Creek to explore relationships between snowpack dynamics and snowmelt partitioning. Measurements of ET are collected nearby at the Niwot Ridge Ameriflux site and are assumed representative for Como Creek. Analyses from point data show that years with higher peak SWE/P ratios partition proportionally more snowmelt to ET (pValue: 0.045). For example, water year (WY) 2005 has a peak SWE/P ratio of 0.49 and a growing season ET normalized by WY precipitation (ET/P) ratio of 0.48 while WY 2008 has a peak SWE/P ratio of

0.83 and an ET/P ratio of 0.82. Observations also show that years that experience later peak SWE (DOY=142) partition proportionally less snowmelt into ET (ET/P=0.42) compared to years that experience earlier peak SWE (DOY=86) and partition proportionally more snowmelt to ET (ET/P=0.56). Point analyses also suggest that more rapid snowmelt results in proportionally less snowmelt partitioned to ET and more partitioned to runoff. To explore the underlying processes responsible for these relationships at the catchment scale, we use the Regional Hydro-Ecologic Simulation System (RHESSys) to model how snowmelt is partitioned between ET and R under observed conditions and under a variety of snowmelt timing, magnitude, and rate scenarios.

T4J. Interactions between climate and CZ structure control snowpack dynamics across CZO sites

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CZOs: Boulder Creek, Jemez River, Southern Sierra
Applicable themes: Theme 2, Theme 3, Theme 4

Snowpacks provide the majority of water available for ecosystem services and downstream water supplies in the Western U.S. However, differences in hydroclimate and critical zone (CZ) structure (e.g. topography, vegetation, etc.) lead to widely varying snowpack dynamics that are challenging to observe and predict. The Western U.S. CZO sites range in climate and forest structure: moderately cold and dry continental (Jemez River Basin), cold and moderately dry continental (Boulder Creek Watershed), and warmer and wetter maritime conditions (Southern Sierras). Utilizing consistent ecohydrological measurements across sites has led to insights about snow-vegetation interactions and hydrological response. Forest canopy controls on snow accumulation led to 12 to 42 cm greater peak snow depths in open versus under-canopy positions. Differences in accumulation and melt across sites resulted in earlier snow disappearance in open positions at Jemez and earlier snow disappearance in under-canopy positions at Boulder and Sierra sites. Snowpack energy budget models were developed that explicitly characterized forest canopy using high-resolution Light Detection and Ranging (LiDAR) information. The models showed that higher resolution representations of forest structure led to higher estimates of winter vapor losses from sublimation that more closely resembled observations. Finally, irrespective different snowpack processes, we found that peak annual soil moisture was nearly synchronous with the date of snow disappearance at all sites. Slightly contrasting this relationship was the Southern Sierra site, which had peak soil moisture preceding snow disappearance in many years. This interesting cross-site difference was confirmed with a larger-scale analysis of Snow Telemetry (SNOTEL) stations. The cross-site studies have demonstrated value for testing models and developing process-based hypotheses that can be verified with larger observational datasets.

T4K. Chemical signals of Critical Zone processing: Quantification of water and sediment sources during individual storm events in the Christina River CZO

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CZOs: Christina River Basin
Applicable themes: Theme 2, Theme 4

Chemical signals of water and materials in catchment exports have long been studied as proxies for within-watershed processing. In the Christina River Critical Zone Observatory, we use the chemistry of water, in particular the oxygen-18 and chloride concentrations, and hydrograph separation to evaluate the contributions of different water sources to the stream discharge during a series of five storm events in 2011 and 2012. These events varied in magnitude, from 44 to 168 mm total precipitation, and precipitation chemistry, with $\delta^{18}O$ values ranging from -5.38 to -11.06 ‰. The contribution of old water during the storm peak, determined by isotope hydrograph separation, varied from 0% in a spring storm of annual magnitude to 76% during Hurricane Sandy. Soil moisture data, available for all but one of our storms, indicates higher old water contribution at peak flow when the catchment has higher antecedent soil moisture.

Understanding differences in water sourcing to the stream during different events provides a basis on which we analyze the movement of critical zone processing with regard to erosion and the source of exported sediment. For example, sediment fingerprinting with fallout radioisotopes indicated variation in sediment source between extreme events, with more surface erosion during events in which a larger fraction of peak discharge was contributed by event or “new” water. Suspended sediment samples taken during Hurricane Irene (28 August 2011) contained between 0 and 11.4 Bq/kg cesium-137 (^{137}Cs) and 175 – 698 Bq/kg of beryllium-7 (^{7}Be), indicating some level of recent surface erosion. Suspended sediment samples taken during Hurricane Sandy (29 October 2012) did not contain measurable activities of either ^{137}Cs or ^{7}Be.

T4L. Exploring the origin and spatial extent of wetted channels during summer low flow of the Eel River system

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CZOs: Eel River
Applicable themes: Theme 1, Theme 2, Theme 4

In seasonally dry environments, wetted channels diminish in length and become shallower over summer months. This results in the heating of the atmosphere (due to lack of evaporation), and shrinking the river habitat, as well as the surface water available for both human and other biotic consumption. There appears to be no theory, however, to anticipate the contraction of wetted channels as watersheds progressively dry. With growing water demands, and increasingly severe and sustained droughts, we need to be able to predict the evolution of the extent of wetted channels, and specifically link it to climactic patterns. Because the water flow that sustains these wetted channels derives directly from the critical zone, studying flow patterns should give us an explicit link between hydrological dynamics, climate, vegetation and the critical zone. In this study, four field channel surveys (two early in the summer dry period, two at low flow near the end of the summer, over two different years; 2012 & 2014) were conducted in two adjacent watersheds (the Fox and Elder drainages, with respective sizes of 2.7 km^2 and 17 km^2) located in the Angelo Coastal Range Reserve in Northern California. These surveys were performed by walking each tributary and sub-tributary of both watersheds while mapping the presence of surface flow, and mapping the location of the origin of flow (or 'wetted channel head') in each sub-drainage area. Additionally, channel width, depth, velocity, water temperature, air temperature and humidity were recorded, and revisited at over 250 select data points in each round. For the Fox and Elder watersheds, respectively, the early summer 2012 channel surveys (June 18-July 23) translate to drainage densities of 2.06 and 1.88 km/km^2, and the late summer 2012 channel surveys (August 24-September 23) equate to drainage densities of 1.46 and 1.49 km/km^2. While both of these watershed's drainage densities' decreased significantly throughout the summer months, the wetted channel heads in almost all sub-watersheds in both Fox and Elder remained stationary, even though the amount of flow from these locations typically decreased by over 50%. These findings indicate that in watersheds with similar geology to the Eel River basin (sandstone & mudstone), subsurface fractures and preferential flow patterns dominate the spatially wetted extent of flow, leading to continually flowing, year round 'springs' that provide all biota annual sources of surface water. The similarities in these drainage densities also suggest that systematic surveys will yield characteristic drainage densities in different topographical and geological settings that can be explored using models and theory.

T4M. Vadose zone modeling in support of geochemical transport estimates in a montane first order catchment

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CZOs: Santa Catalina Mountains-Jemez River Basin
Applicable themes: Theme 4

The NSF-funded Catalina-Jemez Critical Zone Observatory (CZO) studies couplings among hydrologic, lithologic, ecological, and geochemical dynamics in the Southwest U.S. The motivation to study this region is to understand and to develop predictive models of how slow changes and abrupt disturbances affect landscape evolution and water resources for growing urban populations. One disturbance prevalent in Southwestern forested ecosystems is fire, which can dramatically alter near surface hydraulic properties and cause large changes in hydrological response in catchments. This poster will present data collected before and shortly after the June 2013 Thompson Ridge Fire near Redondo Peak in the Valles Caldera 10 miles north of Jemez Springs, NM. Pre- and post-fire data include infiltration measurements, moisture sensors, and meteorological data. Soil texture and organic matter content were taken from 53 GPS-referenced sites in 2011 and 22 infiltration sites shortly after the fire in 2013 (5 depth increments down to 50 cm). This poster will present pre-fire and post-fire dynamics modeled using meteorological data and a statistical analysis comparing the model output to measured data.

T4N. Colonial soil loss fingerprinted and quantified over multiple timescales

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CZOs: Christina River Basin
Applicable themes: Theme 2, Theme 4

Anthropogenic sediment erosion during the colonisation of Pennsylvania, USA, was investigated over different time frames (pre-colonial, colonial, and the last century) using fallout radionuclides that can trace soil residence and mobility. For our analysis, ^{210}Pb was used to characterize sediment deposits over the last century, whereas ^{10}Be was capable of tracing processes over millennial timescales. These two radionuclides served as 'fingerprinting' tools, which along with historical records have yielded insight into hillslope and fluvial response to changes in land use in this region.

This research is conducted within the catchment of the White Clay Creek (WCC), a sub-basin of the Christina River in the far south-eastern part of Pennsylvania. Floodplain and millpond deposits along with present suspended loads were analysed to investigate changes in sediment sources and processes within WCC. The colonial era experienced a drastic increase in agricultural land use and extensive deforestation. Sediment deposits from colonial times (floodplain and millpond deposits) display a very high variation in ^{10}Be concentrations, which we interpret as resulting from the substantial changes in sediment sources within the watershed. Furthermore, the ^{10}Be data suggest that our small study watersheds reflect different timing and impacts of colonial land use on soil loss, meaning that there is no generic timeline of ^{10}Be concentration in suspended loads that is applicable to all basins.

In contrast, river sediment from the last century displays high and relatively consistent ^{10}Be concentrations. The low variation in ^{10}Be is characteristic of the recovery of the watershed following the erosion stabilization provided by Best Management Plans (BMPs) in many upland areas -- stable ^{10}Be concentrations across many basins imply similar sediment sources and relatively constant sediment delivery to channels.

T4O. The use of fly ash to identify post-settlement legacy sediment

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CZOs: Intensively Managed Landscapes
Applicable themes: Theme 3, Theme 4

Human land use has transformed the landscapes, ecosystems and hydrology of the North American Midcontinent. One widespread impact of this transformation is increased runoff and accelerated soil erosion, which, along with direct human channel modifications and artificial drainage, have dramatically altered hydrologic and ecological conditions in streams and rivers with far-reaching results. A legacy of this change in streams and rivers is preserved on floodplains throughout the region in the form of flood sediment known as post-settlement alluvium (PSA). Documenting the spatial and temporal pattern of historic floodplain sedimentation in the drainage network is part of a larger effort to understand decadal and century-scale sediment routing through the drainage system and the role of floodplain sedimentation in carbon sequestration. Fly ash, a product of high-temperature coal combustion, began to accumulate on the landscape in the early historic period (c.a.1840 in Iowa and Illinois) as coal-burning technology such as steam engines came into wide use. Prior to that time no source of fly ash was present. Fly ash particles are coarse clay to silt size (3-63µ) spheroids, some of which are magnetic. By identifying the percentage of fly ash spheroids in the magnetic separate through a soil or sediment profile the pre-fly ash Historic surface can be discerned. Application of this technique in selected localities in eastern Iowa resulted in successful demarcation of the buried Historic soil/post-settlement alluvium contact in areas where the boundary was physically evident. Bolstered by this success we were able to confidently recognize the contact in other settings in Iowa and Illinois where the boundary was not as physically evident. This relatively easy to use, inexpensive tool will provide us with critical ground truth data for understanding long-term sediment movement through drainage basins and for modelling landscape evolution during the Anthropocene.

T4P. A probabilistic approach for shallow rainfall-triggered landslide modelling at basin scale: Distribution of hot spots and hot moments in the Luquillo Forest, Puerto Rico

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CZOs: Luquillo
Applicable themes: Theme 2, Theme 4

Here we study the spatiotemporal occurrence of landslides in the mountains of Puerto Rico. Geotechnical and hydrologic factors that control slope stability exhibit wide natural variability, which is often not taken into account in hydrologic - stability models. The associated uncertainty, which exerts a strong control on landslide modelling, is systematically taken into account in a probabilistic approach for the prediction of rainfall-triggered landslide occurrence at basin scale. The methodology was implemented into a distributed eco-hydrological and landslide model, tRIBS-VEGGIE -landslide (Triangulated Irregular Network (TIN)-based Real-time Integrated Basin Simulator - VEGetation Generator for Interactive Evolution). More precisely, soil cohesion and friction angle were randomized to consider the natural variability of geotechnical soil characteristics. Soil retention parameters were treated as correlated random variables to account for hydrological uncertainty on the estimation of matric suction. As a result, the Factor of Safety (FS) follows an assumed theoretical probability distribution. The temporally variant FS statistics are approximated at each cell by the First Order Second Moment (FOSM) method, as a function of parameters statistical properties. The probability of failure is then estimated, conditioned on soil moisture, at each time step.

We applied the model on the Rio Mameyes Basin, located in the Luquillo Experimental Forest in Puerto Rico, which is highly susceptible to landslides. At each time step, the model provides the probability of failure (hot spots), and the most probable depth of failure at each soil column. Moreover, the probabilistic approach is able to reveal and quantify landslide risk at slopes assessed as stable by simpler deterministic methods. Future efforts include studying the propensity of sediment transport (hot spots) and the occurrence of large sediment movements (hot moments) in the Rio Icacos Basin, focusing on the role of contrasting lithology on the basin's hydro-geomorphic response.