# CRITICAL ZONE SCIENCE
## Current Advances & Future Opportunities

June 4-6, 2017 • Arlington Virginia

*Hosted by*
Critical Zone Observatories
U.S. NSF National Program

**CZO**

## Location

All events are at the Hilton Arlington Hotel, adjacent to the Ballston Metro station.

## Main goals

At this NSF-sponsored workshop, we will assess the current state of Critical Zone science and consider how the next iteration of a Critical Zone science program can address key scientific, societal and educational questions about the Critical Zone.

## Signing in

We ask that all participants sign in for each day of the conference. We are required to obtain a daily signature in order to provide confirmation of attendance. This will ensure that we can substantiate our travel and subsistence costs to our federal sponsors.

Those who have requested participant stipends to help offset travel costs will receive an email from Cornell Financial Affairs with a link to an online form that you will need to complete in order to receive funds. The funds will be transferred electronically, and treated as taxable income for tax purposes.

## NSF Support
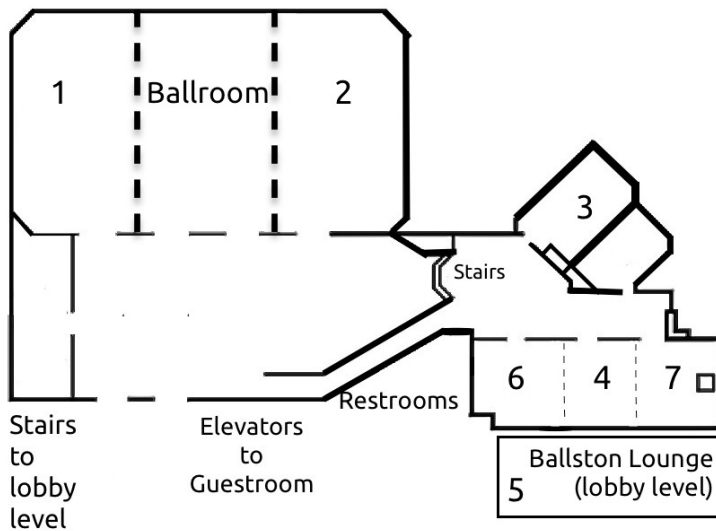
## Meeting Map

Most activities take place in and near the Gallery Ballroom on the second floor, although some are in the Ballston Lounge on the lobby level.

The hotel also uses the following room names:
3. Renoir
4. Da Vinci
5. Ballston Lounge
6. Picasso
7. Matisse

## Breakout Group leaders

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Diana Karwan | Asmeret Berhe | Wendy Yang | Steven Hall | Allison Goodwell |
| Adam Ward | Ashlee Dere | Beth Herndon | Nikki West | Lin Ma |

## Agenda Committee

**Bill McDowell** - Luquillo CZO and Univ. of New Hampshire (Chair)
**Pam Sullivan**, Univ. of Kansas
**Adam Wymore**, Univ. of New Hampshire
**Praveen Kumar**, IML CZO and Univ. of Illinois
**Jon Chorover**, Jemez-Catalina CZO and Univ. of Arizona
**Louis Derry**, CZO National Office and Cornell University

## Technical Committee

**Sarah Sharkey**, CZO National Office and Penn State University
**David Lubinski**, CZO National Office and Univ. of Colorado, Boulder
**Mary Reinthal**, CZO National Office and Cornell University
**Alexandra Moore**, CZO National Office and Paleontological Research Institution

# OVERVIEW AGENDA

| PM Sunday June 4 | | |
|---|---|---|
| 3:00 | Participant check in at the Hilton Arlington (Ends at 7:00pm, Pick up badge etc, Dinner *not* provided) | Ballston Lounge (early) Gallery Ballroom (later) |
| **7:00** | **Introduction to CZ Science and CZOs** – The NSF perspective | Richard Yuretich |
| **7:15** | **Plenary address** - Perspectives on CZ science | Sue Brantley |
| 8:00 | Icebreaker (ends at 9:30pm) | Ballston Lounge |

| Monday June 5 | | |
|---|---|---|
| 7:00 | Check in and breakfast buffet (provided) | Outside Gallery Ballroom |
| **8:00** | **Welcome and introductions** | G. Grant & W. McDowell |
| **8:20** | **Scientific talks I** | 7 talks |
| 9:45 | Coffee break | |
| **10:15** | **POSTER SESSION I** | 5 themed rooms |
| 12:00 | Working lunch (provided) | Discussion |
| **1:00** | **Scientific talks II** & intro to breakout groups | 7 talks |
| 2:30 | Coffee break | |
| **2:40** | **Breakout groups I** | 5 meeting rooms |
| **4:00** | **Plenary discussion I** | Incl group reports |
| **5:15** | **POSTER SESSION II** (ends 7:00) | 5 themed rooms |
| 5:30 | Cash bar | |
| 7:00 | Dinner (provided, ends 9:00pm) | Incl discussion w/ NSF+ |

| Tuesday June 6 | | |
|---|---|---|
| 7:00 | Check in and breakfast buffet (provided) | Outside Gallery Ballroom |
| **8:00** | **Scientific talks III - Invited session** | 4 talks |
| **9:20** | **Scientific talks IV** | 4 talks |
| 10:00 | Coffee break | |
| **10:30** | **Plenary discussion II** | Panel |
| **11:30** | **Scientific talks V** | 5 talks |
| 12:30 | Working Lunch (provided) | Speaker/Activity TBD |
| **2:00** | **Breakout groups II** | 5 rooms |
| **3:30** | **Breakout reports II** | |
| **4:00** | **Writing teams (meeting ends at 5:00)** | |

# DETAILED AGENDA

| | PM - Sunday June 4, 2017 | |
|---|---|---|
| 3:00 to 7:00 | Participant check in at the Hilton Arlington (Pick up badge etc, Dinner *not* provided) | Ballston Lounge (early) Gallery Ballroom (later) |
| **7:00** | **Introduction to CZ Science and CZOs** – the NSF perspective | Richard Yuretich *NSF EAR Program Officer* |
| **7:15** | **Plenary address -** Perspectives on CZ science | Sue Brantley *Penn State University* |
| 8:00 | ⍦ Icebreaker Reception | Ballston Lounge |
| 9:30 | End of day | |

## AM - Monday June 5, 2017

| | | |
|---|---|---|
| 7:00 | 🍴 Check in and breakfast buffet (provided) | Outside Gallery Ballroom |
| **8:00** | **Welcome & Introductions** | |
| 8:00 | Welcome and introduction to conference | Gordon Grant<br>*USDA Forest Service* |
| 8:10 | Meeting structure and objectives | Bill McDowell<br>*Univ. of New Hampshire* |
| **8:20** | **Scientific talks I** | |
| 8:20 | Opportunities for integrating and leveraging LTER, NEON, and CZO Networks. [Invited] | Peter Groffman<br>*Cary Institute of Ecosystem Studies* |
| 8:40 | Critical zone structure controls concentration-discharge relationships and solute generation in forested tropical montane watersheds. | Adam Wymore<br>*Univ. of New Hampshire* |
| 8:50 | Describing Microbial Community of the Critical Zone with CZIMEA: Critical Zone Integrative Microbial Ecology Activity. | Emma Aronson<br>*Univ. of California, Riverside* |
| 9:00 | Leveraging critical zone observation networks to inform and improve the NOAA National Water Model prediction system. | Aubrey Dugger<br>*NCAR* |
| 9:10 | The Hakai Critical Zone Observatory: exploring critical zone connections from land to sea in the Pacific rainforest of Canada. | Ian Giesbrecht<br>*Hakai Institute* |
| 9:20 | Predictive spatial geochemical modelling of the Australian Critical Zone from local to continental scales. | Elisabeth Bui<br>*CSIRO* |
| 9:30 | Integrated science in AGU journals. | Hari Rajaram<br>*Univ. of Colorado, Boulder* |
| 9:35 | Overview of poster sessions | Bill McDowell<br>*Univ. of New Hampshire* |
| 9:45 | ☕ Coffee Break | Presenters to posters |
| **10:15 to 12:00** | **POSTER SESSION I**<br><br>1. Evolution of the Critical Zone *(Rm. 6)*<br>2. Process Dynamics, Stores, and Fluxes in the CZ *(Rm. 5)*<br>3. Ecosystems and the Critical Zone *(Rm. 7)*<br>4. Response of CZ and CZ Processes to Land Use and Climate Change *(Rm. 3)*<br>5. New Approaches to Advancing CZ Science at Regional-to -Continental Scales *(Rm. 4)* | Five rooms.<br>See room assignments and map on back of your name badge. |

| | | |
|---|---|---|
| 12:00 | 🍴 Working lunch (provided)<br><br>Discussion at each table: *What are the most important fundamental and societally relevant Critical Zone science challenges?* | Each table should take informal notes of the most compelling ideas |

## 1:00 Scientific talks II

| | | |
|---|---|---|
| 1:00 | Geophysical constraints on deep CZ structure and processes. [Invited] | Steve Holbrook<br>*Univ. of Wyoming* |
| 1:20 | Rock moisture dynamics in the critical zone: Direct observations from the Eel River Critical Zone Observatory. | Daniella Rempe<br>*Univ. of Texas, Austin* |
| 1:30 | Measuring full suites of trace metals in plants, soils, rocks, and water: another person's treasure. | Justin Richardson<br>*Cornell University* |
| 1:40 | Seasonality and disturbance: assessing microbial response in two adjacent high-alpine catchments in northern New Mexico. | Dawson Fairbanks<br>*Univ. of Arizona* |
| 1:50 | Reevaluating the role of dust in mountain ecosystems using tracer isotopes, microbial genomics, and global databases. | Lindsay Arvin<br>*Univ. of Wyoming* |
| 2:00 | Soil organic carbon dynamics in intensively managed landscapes. | Qina Yan<br>*Univ. of Illinois at Urbana-Champaign* |
| 2:10 | CZ science within the GEO portfolio [Invited] | William Easterling<br>*NSF Asst Director for GEO* |
| 2:25 | Introduction to breakout group questions | Praveen Kumar<br>*Univ. of Illinois* |
| 2:30 | ☕ Coffee Break | |

## 2:40 Breakout groups I

*What are the most important fundamental and societally relevant Critical Zone science challenges, and how can we address them?*

Five rooms.
See room assignments and map on back of your name badge.

## 4:00 to 5:15 Plenary discussion I

*What are the most important CZ questions, and what research framework would best address them?*

Includes five-minute report from each group leader with five minutes of discussion.

| | | |
|---|---|---|
| **5:15**<br>to<br>**7:00** | **POSTER SESSION II**<br><br>1. Evolution of the Critical Zone *(Rm. 6)*<br><br>2. Process Dynamics, Stores, and Fluxes in the CZ *(Rm. 5)*<br><br>3. Ecosystems and the Critical Zone *(Rm. 7)*<br><br>4. Response of CZ and CZ Processes to Land Use and Climate Change *(Rm. 3)*<br><br>5. New approaches to Advancing CZ Science at Regional-to-Continental Scales *(Rm. 4)* | Five rooms.<br>See room assignments and map on back of your name badge. |

| | | |
|---|---|---|
| 5:30 | ⍚ **Cash Bar** | |
| 7:00 | 🍴 Dinner (provided) | After dinner discussions with Richard Yuretich and other POs |
| 9:00 | End of day | |

## AM - Tuesday June 6, 2017

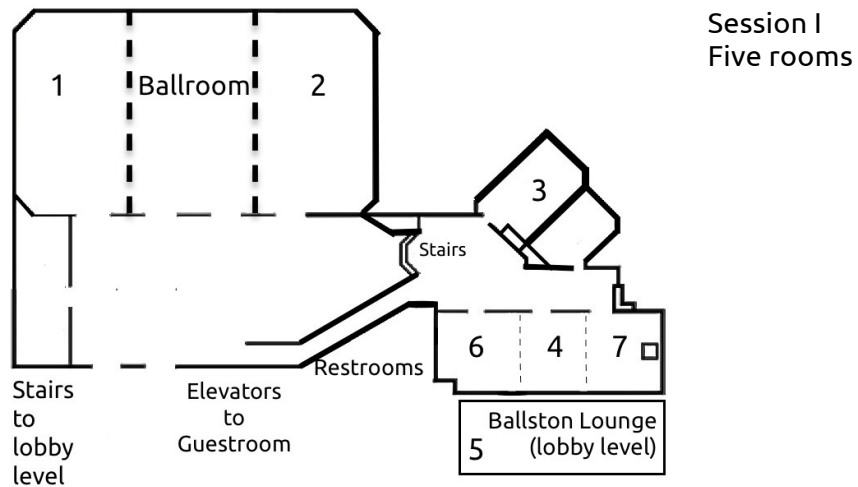| Time | Event | Location / Speaker |
|------|-------|--------------------|
| 7:00 | 🍴 Check in and breakfast buffet (provided) | Outside Gallery Ballroom |
| **8:00** | **Scientific talks III – Invited session** | |
| 8:00 | The practitioner's perspective: Value of critical zone science for environmental management and protection. [Invited] | Steve Hamburg *Environmental Defense Fund* |
| 8:20 | How can critical zone science and CZOs help to resolve landscape management and societal issues? [Invited] | Kitty Lohse *Idaho State University* |
| 8:40 | CZ science as a platform for science education reform. [Invited] | Don Duggan-Haas *Paleontological Research Institution* |
| 9:00 | A critical zone perspective on ecosystem services. [Invited] | Dave Breshears *Univ. of Arizona* |
| **9:20** | **Scientific talks IV** | |
| 9:20 | Urban ecosystems and CZOs. | Joel Moore *Towson University* |
| 9:30 | New directions in CZO biogeochemistry: Mechanisms controlling the fate and transport of nitrogen in the Colorado Front Range. | Eve-Lyn Hinckley *Institute of Arctic and Alpine Research* |
| 9:40 | The cross-scale influence of snowmelt rate, timing, and amount on runoff production across the western United States. | Theo Barnhart *Univ. of Colorado, Boulder* |
| 9:50 | Telling the story of a sediment particle:  its source & pathway. | Thanos Papanicolaou *The Univ. of Tennessee* |
| 10:00 | ☕ Coffee Break (ends 10:30) | |
| **10:30 to 11:30** | **Plenary discussion II** (panel)<br><br>CZ Futures: building cross-network observatory opportunities (CZO, LTER, LTAR, ILTER) into a robust vision for CZ Science and Education. | Gene Kelly - *NEON*<br>David Lesmes -*DOE*<br>Lindsey Rustad -*USFS*<br>Lou Kaplan – *NSF DEB*<br>John Schade -*NSF BIO*<br>Richard Yuretich -*NSF*<br>Diane McKnight -*NSF GEO*<br>Elisabeth Bui -*ILTER &ICZO* |

| **11:30** | **Scientific talks V** | |
|---|---|---|
| 11:30 | Earthcasting controls of vegetation on solute fluxes and soil development in the Critical Zone. [Invited] | Pamela Sullivan *Univ. of Kansas* |
| 11:50 | Forward and backward evolution of the Calhoun CZO landscape. | Sara Bonetti *Duke University* |
| 12:00 | The control of critical zone architecture on water age and storage selection functions in hillslopes. | Ciaran Harman *Johns Hopkins University* |
| 12:10 | Considering the role of trees as Critical Zone architects. | Jill Marshall *UC Berkeley & CU Boulder* |
| 12:20 | Balancing reactivity and transport across the deep vadose zone. | Jenny Druhan *Univ. of Illinois Urbana Champaign* |
| 12:30 | 🍴 Working Lunch (provided) | Speaker or networking activity to be determined |
| **2:00** | **Breakout groups II** <br><br> Key points for a 1-page white paper from each breakout group that addresses the following: <br> 1) The Compelling Questions in CZ Science <br> 2) Observatories and Networks of the Future <br> 3) CZ Educational Initiatives of the Future | Five rooms. See room assignments and map on back of your name badge. |
| **3:30** | **Breakout reports II** | |
| **4:00** | **Writing teams** <br><br> Writing teams polish work from their breakout groups and synthesize input for final write-up to be placed on CZO website | |
| 5:00 | End of meeting | Thanks for coming! |

**10:15**
to
**12:00**

Session I
Five rooms



| | |
|---|---|
| 1. Evolution of the Critical Zone | Rm. 6 |
| 2. Process Dynamics, Stores, and Fluxes in the CZ | Rm. 5 |
| 3. Ecosystems and the Critical Zone | Rm. 7 |
| 4. Response of CZ and CZ Processes to Land Use and Climate Change | Rm. 3 |
| 5. New Approaches to Advancing CZ Science at Regional-to-Continental Scales | Rm. 4 |

## 1. Evolution of the Critical Zone   Rm. 6 (Session I)

| | | |
|---|---|---|
| 24 | Imaging subsurface properties along and across soil-mantled ridges | Mong-Han Huang<br>*Jet Propulsion Laboratory* |
| 25 | Shallow critical zone architecture of a headwater sandstone catchment quantified using near-surface geophysics | Roman DiBiase<br>*Penn State University* |
| 26 | Understanding the architecture of the deep critical zone and its relation to knickpoint evolution in the Rio Icacos watershed (Luquillo Critical Zone Observatory, Puerto Rico) using hydrogeophysical methods | Xavier Comas<br>*Florida Atlantic University* |
| 27 | Implications of topographically induced variations in solar radiation for water balance, vegetation and soil development. | Mark Seyfried<br>*USDA-ARS* |
| 28 | Using the Landlab modeling toolkit to understand earth surface dynamics in CZOs | Nicole Gasparini<br>*Tulane University* |
| 29 | Weathering the hillscape: Water, rock, and soil on the move | Bob Anderson<br>*Univ. of Colorado, Boulder* |
| 30 | Bedrock controls on mountain ecosystems evaluated using geophysics, geochemistry, and remote-sensing | Russell Callahan<br>*University of Wyoming* |
| 31 | A service-oriented architecture for coupling web service models using the basic model interfaces (bmi) | Peishi Jiang<br>*University of Illinois* |
| 32 | Impact of stochastic bioturbation and transport on the formation of argillic horizons at the Calhoun Critical Zone | Salvatore Calabrese<br>*Duke University* |
| 33 | A probabilistic approach to quantifying soil physical properties using time-integrated effective energy and mass transfer (EEMT) | Christopher Shepard<br>*University of Arizona* |
| 34 | Scaling magnesite dissolution rates versus time in heterogeneous porous media | Hang Wen<br>*Penn State University* |

## 2. Process Dynamics, Stores, & Fluxes in the CZ Rm. 5 (Session I)

| | | |
|---|---|---|
| 47 | More rain and less snow at the Reynolds Creek CZO | Patrick Kormos <br> *ARS-USDA* |
| 48 | Insights into chemical weathering patterns from hydrologic data in Gordon Gulch: Boulder Creek CZO | Alexis Navarre-Sitchler <br> *Colorado School of Mines* |
| 49 | Short term fallout radionuclides track mixing and transport in the Critical Zone | Diana Karwan <br> *University of Minnesota* |
| 50 | Concentration-flux relations in the vadose zone | Jon Chorover <br> *University of Arizona* |
| 51 | Modeling the influence of preferential flow on the spatial variability and time-dependence of weathering rates | Hari Rajaram <br> *Univ. of Colorado, Boulder* |
| 52 | Deep Soil Carbon in the Critical Zone: amount and nature of Carbon in weathered bedrock, and its implication for soil Carbon inventory | Asmeret Asefaw Berhe <br> *University of California, Merced* |
| 53 | The potential for Iron reduction in upland soils in Calhoun CZO | Aaron Thompson <br> *University of Georgia* |
| 54 | Toward a Global Network of Critical Zone Observatories | Henry Lin <br> *Penn State University* |
| 55 | Fe and C cycling is modulated by O2 levels in redox-fluctuating environments | Christof Meile <br> *University of Georgia* |
| 56 | Investigating the porosity development of shale to understand hydrologic controls on hillslope scale weathering | Xin Gu <br> *Penn State University* |
| 57 | Extreme basalt weathering results from high soil CO2, unsaturated conditions and organic acids | Alida Perez Fodich <br> *Cornell University* |
| 58 | Hot spots and hot moments for redox, Iron and Carbon cycling in soils across Luquillo and Calhoun CZOs | Diego Barcellos <br> *University of Georgia* |
| 59 | Uranium and Strontium isotope tracers of water rock interactions and biogeochemical processes in the critical zone | Alissa White <br> *University of Arizona* |

## 3. Ecosystems and the Critical Zone   Rm. 7 **(Session I)**

| 14 | Local and non-local information flow along an elevation gradient | Allison Goodwell *University of Illinois* |
|----|------------------------------------------------------------------|--------------------------------------------|
| 15 | Stable microbial biomass and soil hydrolytic enzyme potential despite dynamic Carbon exchange during summer in a Chihuahuan desert shrubland | Anthony Darrouzet-Nardi *Univ. of Texas at El Paso* |
| 16 | Using LiDAR to reveal patterns of above-ground biomass from deciduous trees and shrubs in the Critical Zone | Kristen Brubaker *Hobart & William Smith Colleges* |
| 17 | Phosphorus biogeochemical transformation and effects of aeolian dust deposition during long-term soil development in semi-arid ecosystems | Mike Zhu *University of Wyoming* |
| 18 | Parameterization of nitrogen limitation for a dynamic ecohydrological model: a case study from the Luquillo Critical Zone Observatory | Satish Bastola *Georgia Institute of Technology* |
| 19 | Forest thinning in Sierra Nevada mixed-conifer headwater forests: evapotranspiration, runoff and drought resiliency | Martha Conklin *Univ. of California, Merced* |
| 20 | Observing and simulating spatial variations of forest Carbon fluxes and stocks in complex terrain | Yuting He *Penn State University* |
| 21 | Over half of potential soil extracellular enzyme activity occurs below 20 cm | Nicholas Dove *Univ. of California, Merced* |
| 22 | Soil organic matter stabilization by Fe-C interactions in temperate and tropical soils: A cross-CZO comparison | Liz Coward *University of Pennsylvania* |
| 23 | Estimating the rate of release of base cations via chemical weathering in soils in the Catskills Region | Sara Alesi *Syracuse University* |

## 4. Response of CZ and CZ Processes to Land Use and Climate Change

Rm. 3 **(Session I)**

| # | | |
|---|---|---|
| 1 | Application of near surface geophysics to constrain coal bed and biogenic methane releases in an acid mine drainage wetland in Western Pennsylvania | Greg Mount *Indiana University of Pennsylvania* |
| 2 | Plant accessible water in the subsurface of mountain landscapes within Mediterranean climate-types: Insights gained from the Southern Sierra CZO | Zion Klos *UC Santa Barbara & UC Merced* |
| 3 | Clay mineral alterations in response to land-use change in the kaolinite dominated residual soil of the Calhoun CZO | Jay Austin *Duke University* |
| 4 | Dynamic assessment of current management in an intensively managed agroecosystem | Christopher G. Wilson *The Univ of Tennessee* |
| 5 | Variability in nitrate concentration-discharge relationships in forested and urban watersheds: towards a unified conceptual model of Critical Zone controls | Jon Duncan *UNC, Penn State* |
| 6 | Dynamics of the water/ soil system in an agricultural catchment of the Midwestern U.S. | Liliana Lefticariu *Southern Illinois University* |
| 7 | High-intensity rainstorm delivers water and sediment to channels in a steep semi-arid catchment | Suzanne Anderson *University of Colorado* |
| 8 | Spatial and temporal variability of nitrate loads from groundwater in nested urban watersheds | Claire Welty *University of Maryland, Baltimore County* |
| 9 | Using a paleo perspective to demonstrate climate control of critical zone processes | Nathan Schachtman *University of Oregon* |
| 10 | Modeling water and solute transport in a watershed with diverse landuses and lithologies | Callum Wayman *Penns State University* |
| 11 | Understanding controls of hydrologic processes across two monolithological catchments using model data synthesis | Dacheng Xiao *Penn State University* |
| 12 | Impact of gullying on hillslope hydrology at the Calhoun CZO | Xing Chen *Duke University* |
| 13 | Potential carbon transport: linking soil aggregate stability and sediment enrichment for updating the soil active layer of Intensely Managed Landscapes (IMLs) | Shengnan Zhou *University of Tennessee* |

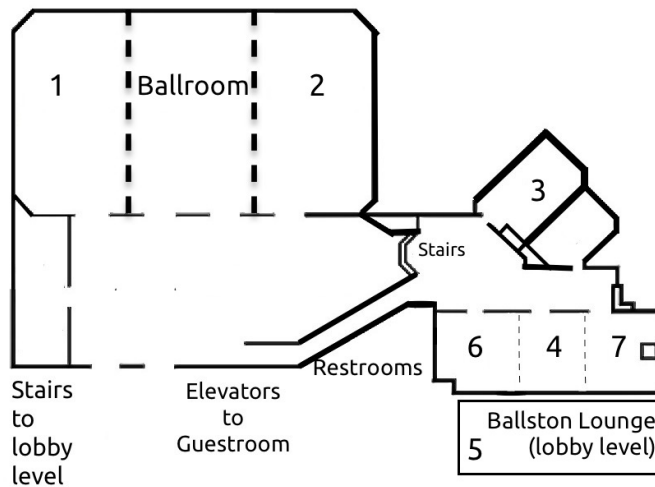## 5. New Approaches to Advancing CZ Science at Regional-to-Continental Scales — Rm. 4 **(Session I)**

| | | |
|---|---|---|
| 35 | Texas Water Observatory- utilizing advanced observing system design for understanding water resources sustainability across climatic and geologic gradients of Texas | Aline Jaimes<br>*Texas A&M University* |
| 36 | The cascading effects of hillslope aspect on the dynamics of water and energy fluxes of the Critical Zone: onto novel instrumental approaches for dryland research. | Hugo Gutierrez-Jurado<br>*University of Texas at El Paso* |
| 37 | Hydrological controls on weathering rates across Critical Zone Obervatoriess | Amilcare Porporato<br>*Duke University* |
| 38 | "Where Rock Meets Life," a film series by WSKG and CZONO | Alex Moore<br>*Paleontological Research Institution* |
| 39 | Integrating data, models, and disciplines in Critical Zone Science using process-based modeling | Li Li<br>*Penn State University* |
| 40 | Enhancing continental-scale understanding of soils: Integrating the National Ecological Observatory Network (NEON) with existing research networks to address global change | Gene Kelly<br>*Colorado State Univ. & NEON* |
| 41 | TeenShale Network: combining hands-on field experience with data-driven hydrology education tools | Jennifer Z Williams<br>*Penn State University* |
| 42 | Big Whorls have little Whorls which feed into the runoff velocity all of which affect Aggregate Stability:  The break -up of Macroaggregates to Microaggregates | Ken Wacha<br>*USDA ARS* |
| 43 | The Investigation of Thermogeology in the Critical Zone | Yu-Feng Lin<br>*University of Illinois at Urbana-Champaign* |
| 44 | Rebuilding the Critical Zone: a case for Detroit and the Great Lakes Region | Shirley Papuga<br>*University of Arizona* |
| 45 | Model-data learning to identify runoff generation mechanisms in a small forested Piedmont watershed | Shane Putnam<br>*Johns Hopkins University* |
| 46 | Using an integrated hydrologic model to assess the ecohydrologic impacts of change on a mountain headwaters Critical Zone | Caitlin Collins<br>*Colorado School of Mines* |

**END OF POSTER SESSION I**

**5:15**
to
**7:00**

Session II
Five rooms

Ballroom
1    2
3
Stairs
6    4    7
Restrooms

Stairs
to
lobby
level

Elevators
to
Guestroom

Ballston Lounge
5    (lobby level)

| | |
|---|---|
| Evolution of the Critical Zone | Rm. 6 |
| Process Dynamics, Stores, and Fluxes in the CZ | Rm. 5 |
| Ecosystems and the Critical Zone | Rm. 7 |
| Response of CZ and CZ Processes to Land Use and Climate Change | Rm. 3 |
| New Approaches to Advancing CZ Science at Regional-to-Continental Scales | Rm. 4 |

| | **1. Evolution of the Critical Zone** | Rm. 6 **(Session II)** |
|---|---|---|
| 23 | Microclimate controls on the evolution of critical zone architecture in the Susquehanna Shale Hills CZO | Nicole West<br>*Central Michigan Univ.* |
| 24 | Geophysical techniques for revealing subsurface structure and processes in the critical zone | Li Guo<br>*Penn State University* |
| 25 | Water-regolith-energy interaction in landscape evolution and its influence on forming asymmetric landscape: model development and application in the Shale Hills CZO | Yu Zhang<br>*Duke University* |
| 26 | Arborturbation rates in the Appalachian Mountains | Tim White<br>*Penn State University* |
| 27 | Life in the slow lane - Tectonic controls on soils, nutrients, and tree canopies | Jane Willenbring<br>*Univ of Calif., San Diego* |
| 28 | Biotic controls on deep Critical Zone evolution reflect persistent susceptibility to change with ecosystem disturbance at the Calhoun CZO | Sharon Billings<br>*University of Kansas* |
| 29 | Spatial variation in the development of the Critical Zone at Hubbard Brook Experimental Forest, New Hampshire | Scott Bailey<br>*USFS* |
| 30 | Comparison of soil moisture dynamics and preferential flow occurrence between two forested catchments with contrasting geology and soils | Qicheng Tang<br>*Pennsylvania State University* |
| 31 | Characterization of water sources and flowpaths and their influence on groundwater geochemical evolution and mineral weathering rates in a high elevation mountain catchment | Ravindra Dwivedi<br>*University of Arizona* |
| 32 | Ordering interfluves: landscape patterns in Critical Zone structure and evolution | Zach Brecheisen<br>*Duke University* |
| 33 | Architecture of the deep critical zone, Jemez River Basin CZO, Valles Caldera National Preserve, Northern New Mexico | Bryan Moravec<br>*University of Arizona* |

## 2. Process Dynamics, Stores, & Fluxes in the CZ    Rm. 5 (Session II)

| | | |
|---|---|---|
| 46 | River particulate load transport, drivers and yields in the Luquillo CZO | KC* Clark<br>*University of Pennsylvania* |
| 47 | Finding the "missing" cations: biogeochemical mechanisms that liberate occluded nutrients from highly weathered soils | Steven Hall<br>*Iowa State University* |
| 48 | Evaluation of the effects of landscape attributes on overland flow using a conceptual modeling framework that accounts for the spatiotemporal evolution of flow resistance | Dimitrios Dermisis<br>*McNeese University* |
| 49 | The impact of O2 concentrations and organic matter on Fe(II) oxidation and the resulting Fe(III) solids in the presence of Fe/Al oxide sorbents | Chunmei Chen<br>*University of Georgia* |
| 50 | Tracking water through the critical zone: models and isotope tracers at the Southern Sierra CZO | Ate Visser<br>*Lawrence Livermore* |
| 51 | Predicting soil thickness and total organic Carbon on soil mantled hillslopes | Nick Patton<br>*Idaho State University* |
| 52 | Quantifying mineral transformations in the Calhoun Critical Zone Observatory (CCZO): What is it and how much is there? | Paul Schroeder<br>*University of Georgia* |
| 53 | Gilbert's soil production paradigm and the critical zone's fractionation of particle sizes | Dan Richter<br>*Duke University* |
| 54 | Influences of kerogen-rich bedrock on the molecular and isotopic composition of soils; implications for the Carbon cycle | Bill Hockaday<br>*Baylor University* |
| 55 | Lithologic control on critical zone development and the consequences for the persistence and spatial extent of wetted channels during the summer dry season | Bill Dietrich<br>*University of California, Berkeley* |
| 56 | Iron loss promotes SOC destabilization on a Hawaiian soil gradient | Katie Grant<br>*Cornell University* |
| 57 | Metal transport Enhanced by Dissolved Organic Carbon (DOC) at the watershed scale | Wei Zhi<br>*Penn State University* |
| 58 | Quantifying the changes of soil surface microroughness due to rainfall-induced erosion on a smooth surface | Benjamin Abban<br>*University of Tennessee* |
| 59 | Modeling structural controls on sub-surface flow in a 2-D Hillslope | Cassandra Cosans<br>*Johns Hopkins University* |

## 3. Ecosystems and the Critical Zone   Rm. 7 **(Session II)**

| | | |
|---|---|---|
| 14 | Rapid recovery of gross production and respiration in a mesic mountain big sagebrush site following prescribed fire | Aaron Fellows<br>*USDA-ARS* |
| 15 | Magnesium isotopes reveal a decoupling of Mg sources to the vegetation and the stream at the Luqillo CZO | María Chapela<br>*UNH & University of Bristol* |
| 16 | Using a spatially-distributed hydrologic biogeochemistry model to study the spatial variation of Carbon processes in a Critical Zone Observatory | Yuning Shi<br>*Pennsylvania State University* |
| 17 | Critical Zone Observations in the Tropical Andes | Giova Mosquera<br>*Universidad de Cuenca* |
| 18 | The biological Si filter in temperate hardwood forest ecosystems | Chris Johnson<br>*Syracuse University* |
| 19 | Responses of $CO_2$, $CH_4$, and $N_2O$ fluxes from soils to temperature and Nitrogen availability | Jim Tang<br>*Ecosystems Center - Marine Biological Laboratory* |
| 20 | Seasonal water and carbon fluxes at ecosystem scales in sagebrush steppe ecosystems | Harmandeep Sharma<br>*Idaho State University* |
| 21 | How soil water storage moderates climate changes effects on transpiration, across the different climates of the Critical Zone Observatories | Christopher Heckman<br>*University of California, Santa Barbara* |
| 22 | Variable Critical Zone water storage capacity constrains ecosystem productivity and resilience to drought in the Northern California Coast Ranges | Jesse Hahm<br>*University of California, Berkeley* |

## 4. Response of CZ and CZ Processes to Land Use and Climate Change — Rm. 3 (Session II)

| # | Title | Presenter |
|---|-------|-----------|
| 1 | Impacts of dryland irrigation and land use changes on inorganic Carbon dynamics in southwest USA | Lin Ma *Univ. of Texas at El Paso* |
| 2 | Modeling Critical Zone controls on ecohydraulics and stream temperature in a Mediterranean watershed | David Dralle *Univ of California, Berkeley* |
| 3 | Nutrient export from intensively managed landscapes integrates human and natural forcing | Adam Ward *Indiana University* |
| 4 | Land use change in four dimensions: Groundwater as a vector for the lateral transmission of ecohydrological impacts | Sam Zipper *McGill University* |
| 5 | Investigating weathering and solute fluxes in Intensively managed critical zones | Ashlee Dere *Univ. of Nebraska - Omaha* |
| 6 | Hot spots and hot moments for redox, Iron and Carbon cycling in soils across Luquillo and Calhoun CZOs | Neal Blair *Northwestern University* |
| 7 | Luquillo loco! Insights on hot moments from in-stream optical sensors in the Puerto Rico wet forest | Jamie Shanley *U.S. Geological Survey* |
| 8 | Understanding water movement, nitrogen dynamics and fate of atrazine in the vadose zone of a wastewater irrigated critical zone observatory | Blanca Prado *Instituto de Geologia, Universidad Nacional Autónoma de México* |
| 9 | Evapotranspiration and land-cover response to multi-year dry periods in the semi-arid Western United States | Joe Rungee *University of California, Merced* |
| 10 | Impact of subsurface tile drainage on distribution of concentration and age of inorganic soil nitrogen | Dong Kook Woo *University of Illinois at Urbana–Champaign* |
| 11 | Seasonal variation in the potential for iron reduction in soils of the Calhoun CZO | Caitlin Hodges *University of Georgia* |
| 12 | Accounting for travel times and sediment delivery in intensively managed landscapes using a Bayesian Framework | Christos Giannopoulos *The Univ. of Tennessee* |
| 13 | Mapping depth to the clay horizon on historically farmed soils within the Piedmont Region of the Southeastern United States | *Rachel Ryland University of Georgia* |

## 5. New Approaches to Advancing CZ Science at Regional-to-Continental Scales

Rm. 4 **(Session II)**

| | | |
|---|---|---|
| 34 | CZO common measurement network data products and a cross-czo data repository proof of concept | Miguel Leon<br>*University of Pennsylvania* |
| 35 | Streams as integrators of landscape processes: An example from the Upper Colorado River Basin | Scott Hynek<br>*USGS* |
| 36 | Measuring 7Be with AMS and the potential for large datasets | Alan Hidy<br>*Lawrence Livermore* |
| 37 | Biochemical and environmental studies in Utopia CZO (Colombia) | Rosalina Gonzalez<br>*La Salle University* |
| 38 | Effects of filling gullies to create farmland on water table rise and soil salinization in the Loess Plateau of China | Zhao Jin<br>*Inst. of Earth Environment, Chinese Acad. of Sciences* |
| 40 | Climatic influences on hydrologic baselines in the Critical Zone during the Quaternary | Bryan Shuman<br>*University of Wyoming* |
| 41 | The National Water Model as a hydrologic modeling framework for the Critical Zone | Rick Hooper<br>*Tufts University* |
| 42 | Insolation-driven, monsoon-mediated changes in Earth Surface Processes in mid-latitude China since the late deglacial interval | Selvaraj Kandasamy<br>*Xiamen University* |
| 43 | Progress toward an international CZO soil Carbon data survey and synthesis | Timothy Filley<br>*Purdue University* |
| 44 | Improving microbial metagenomic data standards for Critical Zone research | Lee Stanish<br>*NEON* |
| 45 | Concentration- discharge relationships across sites in the Critical Zone Network | Arnulfo Aguirre<br>*Cornell University* |

ABBAN, Benjamin  - *University of Tennessee; Intensively Managed Landscapes (IML) CZO*

## Quantifying the changes of soil surface microroughness due to rainfall-induced erosion on a smooth surface

Benjamin K.B. Abban, Thanos Papanicolaou, Christos P. Giannopoulos, Dimitrios C. Dermisis, Kenneth M. Wacha, Christopher G. Wilson, and Mohamed Elhakeem

This study examines the rainfall induced change in soil microroughness of a bare smooth soil surface in an agricultural field. Smooth soil surfaces with microroughness on the order of ~2-5 mm are common in agricultural landscapes subject to long, undisturbed exposure to rainfall impact and runoff and freeze-thaw cycles. There are quantitative indications in the literature that under such conditions, roughness may increase subject to rainfall action. The focus is on the quantification of soil surface roughness due to rainfall for initial microroughness length scales of 2 mm or less, which represent generic extreme conditions. These conditions have not been extensively examined in the literature as most studies have focused on disturbed initial surface conditions with roughness on the order of ~5-50 mm.  Three rainfall intensities of 30 mm/h, 60 mm/h and 75 mm/h were applied to a smoothened bed surface in a field plot via a rainfall simulator. These intensities represent the range from typical to extreme rainfall intensity conditions that appear in the region of study.  Soil surface elevations were obtained via a surface-profile laser scanner. Several indices were utilized to quantify soil surface microroughness, namely the Random Roughness (RR) index, the crossover length, the variance scale from the Markov-Gaussian model, and the limiting difference. Findings show a consistent increase in roughness under the action of rainfall, with higher rainfall intensities resulting in higher relative roughness increase. This contradicts the commonly adopted notion in existing literature that a monotonic decay of soil surface roughness with rainfall is expected regardless of initial surface roughness conditions. The study results highlight the need for a better understanding of the phenomenon of microroughness evolution on a bare surface under rainfall action and its potential implications on hydrologic response.

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AGUIRRE, Arnulfo Andrés - *Cornell University; National Office*

## Concentration-Discharge relationships across sites in the Critical Zone Network

The Critical Zone Observatories (CZO) offer a unique opportunity to make cross-site comparisons of concentration-discharge (CQ) patterns. The Boulder Creek, Calhoun, Luquillo and Southern Sierra observatories were selected to investigate the factors that give rise to unique CQ relationships. These observatories will be used to test how state variables like climate, hydrologic regime and vegetation type affect CQ relationships under similar granitoid parent material. Silicon is of interest in CQ studies due to its dominant source from rock weathering and negligible contributions from atmospheric deposition. End-member mixing models have focused on understanding the contributions of dissolved silicon (DSi) from various reservoirs. However, these models do not require knowledge of the sources and weathering reactions that generate DSi.

The Ge/Si in stream water has been used as a tracer of weathering reactions and hydrologic pathways that offer some insight into processes that give rise to Si-Q patterns. In the Rio Icacos catchment of Puerto Rico, DSi concentrations show strong dilution effects with increases in discharge (Shanley et al., 2011). During baseflow Ge/Si ~ 0.4 µmol/mol, indicating incongruent dissolution of plagioclase and precipitation of clays at the bedrock-saprolite interface. As Q increases, new hydrologic pathways supply DSi from shallower clay sources low in Si but enriched in Ge (Ge/Sikaolinite ~ 4.5 µmol/mol) (Lugolobi et al., 2009; Kurtz et al., 2011). In contrast, the Gordon Gulch catchment of Boulder Creek

shows constant DSi as discharge increases by two orders of magnitude. Additionally, both DSi and Ge/Si increase during higher discharge. The mobilization colloids composed of kaolinite and illite formed during drying and wetting cycles, are likely responsible for this pattern (Mills et al., 2017; Aguirre et al., 2017). Further research in Southern Sierra and Calhoun will help in expanding the knowledge of Si dynamics across the CZO's.

ALESI, Sara - *Syracuse University*

## Estimating the rate of release of base cations via chemical weathering in soils in the Catskills Region

Sara C. Alesi and Chris E. Johnson

While there have been substantial reductions in acidic deposition in the northeastern United States, the acid-neutralizing capacity (ANC) in stream water has been slow to recover.  This hindered recovery of surface-water acidity has been attributed to decreases in basic cation concentrations, most notably calcium.  The objective of this study is to estimate the rate of release of calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) through chemical weathering in soils in 25 headwater catchments in the Catskills region of New York.  The release rates were estimated using two techniques: a watershed mass-balance approach and cation depletion in soil profiles using Zr as an immobile tracer.  Based on the mass-balance method, it is estimated that Ca was released at an average rate of 640 mol/ha-yr in the Catskills region (range 270 to 1000 mol/ha-yr) and accounted for, on average, 59% of the total base cation weathering between 2010 and 2013.  However, the cation depletion method indicates that Ca has accumulated in Catskills soils at an average rate of 0.68 mol ha-1 yr-1 (range: -0.5 to 3.01 mol/ha-yr) in the period since deglaciation.  These large differences suggest that modern-day weathering rates are much faster for Ca and other base cations than long-term rates. The long-term trend of accumulation of Ca indicates

that external inputs, through precipitation and other atmospheric inputs, has exceeded weathering release in the period since the last glacial retreat.

ANDERSON, Bob - *University of Colorado, Boulder; Boulder Creek CZO*

## Weathering the hillscape: Water, rock, and soil on the move

Robert Anderson, Suzanne Anderson, Harihar Rajaram, and Daniel Richter

A goal of the CZO mission is to generate numerical models that reveal the roles of rock type, tectonics, and climate in creating the architecture of the CZ. Processes that damage rock as the surface is neared, that release this damaged rock into the mobile layer, and that transport the mobile layer downslope shape the CZ architecture of an evolving interfluve. The interfaces between damaged and fresh rock, and between mobile and immobile regolith serve as modeling targets and have recently been imaged as contrasts in seismic velocity across several CZOs.

We build upon existing chemical weathering models in which alteration of feldspars to clays occurs as a first order reaction. We track the concentration of feldspar in the rock (reaction progress) and the concentration of reactive species in the water (affinity) along flowpaths. Water passes first vertically through the vadose zone and then along hyperbolic flowpaths below the water table, toward a channel. Subsurface flow and transport are treated as quasi-steady on timescales of landscape evolution and mineral weathering; flowpaths advect weathering agents into the rock at a rate governed by the incision of the bounding channels. If significant chemical power remains at the water table, as may occur in wet, slowly eroding landscapes, deep weathering can result to levels approximating the base of the bounding channels. Our modeling framework can also capture flow and reactive transport in fractured systems using analytic solutions for reaction front progress into blocks.

Release into mobile regolith may be either damage-limited or trigger-limited, and chemical evolution continues in mobile regolith. Incorporating the process of lessivage, in which clay-sized particles are entrained in the near surface and move downward, suggest that over long timescales this process can enhance significantly the clay content of the subsurface (B-horizon); at least some of this clay is generated not locally but at great depths.

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ANDERSON, Suzanne - *University of Colorado; Boulder Creek CZO*

## High-intensity rainstorm delivers water and sediment to channels in a steep semi-arid catchment

Suzanne Anderson, Sheila Murphy, Matt Rossi, Garret Hammack, and Robert Anderson

Hydrologic transport in ephemeral streams is inherently limited to times of stream flow. Hence, the conditions that shape channels and the effects of overland flow on water and sediment delivery to the channel are rarely observed. On Aug. 30, 2016 in the 0.45-km2 Betasso catchment of Boulder Creek CZO, a convective storm delivered about 95 mm of rain, nearly 17% of the mean annual precipitation, in just over two hours. Betasso drains to Boulder Creek, where a stream gage, located 0.2 km downstream of the confluence, recorded a 7-fold increase in discharge from 0.8 to 5.8 m3s-1 during the 15-minute interval of highest rain intensity.

Betasso catchment (elev. ~1930 m) has an open Ponderosa pine forest and small meadows. Evidence of overland flow during the storm was widespread, particularly in canopy gaps. Some rills, delineated by bent grasses, scour of mineral soil, or levees of pine needles, connected to the main gully system. In other areas, discontinuous rills redistributed organic matter but terminated above the channel. Few rills were found in grassy meadows or dense stands of trees.  Conservatively, 17-170 m3 of sediment was mobilized from hillslopes, representing centuries of sediment production.  Some rills were located in subtle convergent areas (swales) that lack evidence of channels, i.e. bank erosion or deposits from concentrated water flow.  These swales must be maintained by erosive flows that export sediment before diffusive transport obliterates the feature.  This reconnaissance study aims to 1) reconstruct peak discharge in the Betasso gully system from mapped flow markers, 2) map rills on hillslopes, and 3) consider the significance of sediment transport by Horton overland flow in landscape denudation.  These analyses will offer insight into the hydrology of extreme climatic events and their role in the redistribution and export of sediment and organic matter in small, mountain catchments.

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ARONSON, Emma - *University of California, Riverside; Southern Sierra CZO*

## Describing Microbial Community of the Critical Zone with CZIMEA: Critical Zone Integrative Microbial Ecology Activity

Keshav Arogyaswamy, Mia Maltz, Emilio Mayorga, Aaron Packman, and Emma Aronson

Little is known about microbial communities below the surface of soils, and Critical Zone Observatories (CZOs) are the perfect systems to investigate the mysteries of the depths. The 9 CZOs have well characterized geology, vegetation, hydrology and soils, but this is the first effort to analyze the microbial communities of all CZOs. Our project has launched a cross-disciplinary research activity involving many universities affiliated with the CZOs across the country. The scientific goal of this project is to gain insights into the differences between soil microbial communities as they vary across ecosystems, and with depth within a given soil profile. To that end, we are using a wide range of soil and environmental methods, as well as both metagenomic and amplicon high throughput sequencing, to analyze nearly 200 unique soil samples. In order to assemble and share this huge

and diverse dataset, we are working with EarthCube and related projects to make the data accessible across the Critical Zone network, as well as being available to the broader community. We are developing procedural and datastream workflows to enable these capabilities, and are interested in building our capacity with relevant EarthCube tools. We here present the project and its current datasets and workflows.

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Presentation   1:50pm Mon

ARVIN, Lindsay - *University of Wyoming; Southern Sierra CZO*

## Reevaluating the role of dust in mountain ecosystems using tracer isotopes, microbial genomics, and global databases

Lindsay Arvin, Clifford Riebe, Chelsea Carey, Sarah Aciego, Sarah Aarons, Molly Blakowski, Steve Hart, and Emma Aronson

Dust can be a vital nutrient source in slowly-eroding tropical ecosystems where intense weathering limits nutrient inputs from underlying bedrock. In contrast, dust is often thought to be relatively unimportant in mountain ecosystems where bedrock conversion to soil provides continuous nutrient supply. Here we challenge this assumption using observations spanning a range of scales. Sr isotopes in dust deposited across an altitudinal gradient in the Sierra Nevada, California, reveal contributions from both transoceanic and regional dust sources. They also help explain observed phylotypes in study-site soils, implying that distant dust sources influence soil microbial communities across the sites. Moreover, measured aeolian fluxes, cosmogenic 10Be, and bulk geochemistry demonstrate that dust dominates over bedrock in the supply of plant-essential P to Sierra Nevada ecosystems. The ecological significance of dust is further supported by analyses of Nd isotopes in pine needles, dust, and bedrock, which demonstrate that dust contributes as much as 88% of Nd (a potential tracer of P) to vegetation at one site. To evaluate whether the large measured effects

of dust are widespread, we coupled a global dust model with basin-wide erosion rates from cosmogenic nuclides. Across more than 1000 basins around the world, we found that dust deposition is often on par with bedrock conversion to soil. Moreover, erosion rates are often slow enough and soil residence times are therefore long enough that high dust fluxes during the Last Glacial Maximum have likely imparted a legacy of nutrient inputs to many modern soils. In addition, new analyses show that dust fluxes may often contribute to large overestimation in denudation rates from cosmogenic 10Be, exposing potentially profound errors in previously measured landscape evolution patterns. Together, our analyses suggest that the paradigm of dust as a relatively minor contributor to mountain soils and ecosystems needs to be revised.

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Poster Session I Rm. 3 #3

AUSTIN, Jay - *Duke University; Calhoun CZO*

## Clay mineral alterations in response to land-use change in the kaolinite dominated residual soil of the Calhoun Critical Zone Observatory

Jason C. Austin and Paul A. Schroeder

Soil cores were collected in adjacent plots on similar landscape positions: 1) hardwood plot (HP) not cultivated in the past 150 years, 2) old-field pine plot (PP) planted in 1958, and 3) a managed cultivated plot (CP). Oriented slides of the <2 m equivalent spherical diameter size fraction were prepared for X-ray diffraction (XRD). XRD pattern modeling using NEWMOD2® simulated layer types, ordering schemes and relative proportions of clay minerals present.

The three plots showed different concentrations of "illite-like" 2:1 layer weathered biotite, with a trend from a maximum in HP, intermediate in PP, to a minimum in CP. We hypothesize that the HP and CP as end-members on a continuum representing the soil degradation that devastated the Piedmont at the height of Antebellum plantation agriculture. The PP

represents changes in the soil in response to the rehabilitation efforts of the U.S. Forest Service beginning in the 1958. Illite-like 2:1 minerals act as reservoirs for K+ in soils, changing in concentration in response to K+ supply or demand (Barre et al., 2007). This experiment was designed to further test the hypothesis that the pine forest would increase K+ concentration in the soil via nutrient uplift (Jobbagy and Jackson, 2004) and this would result in increased concentrations of illite-like minerals in the pine plot as compared to the cultivated plot.  The measured increase in illite-like minerals in the PP as compared to the CP suggests that the capacity of the soil to preserve nutrients has been increased in the 60 years of pine growth.

Barre, P., Velde, B., Catel, N., and Abbadie, L., 2007, Soil-plant potassium transfer: impact of plant activity on clay minerals as seen from X-ray diffraction: Plant and Soil, v. 292, no. 1-2, p. 137-146.
Jobbagy, E. G., and Jackson, R. B., 2004, The uplift of soil nutrients by plants: Biogeochemical consequences across scales: Ecology, v. 85, no. 9, p. 2380-2389.

balance thus provides a framework for quantifying mineral weathering processes. However, recent hydropedologic studies show that weathering processes and relative contributions of soil, rock fragments, and bedrock vary in predictable ways in different portions of the catchments. Hillslopes, where shallow soils force lateral hydrologic fluxes through accumulated organic matter, produce downslope gradients in mineral depletion, weathering product accumulation, soil development, and solute chemistry. We propose that linked gradients in hydrologic flow paths, soil depth, and vegetation lead to predictable differences in the location and extent of mineral dissolution in regolith (soil, subsoil, and rock fragments) and bedrock, and that headwater catchments within the upland glaciated northeast share this common architecture. This provides an opportunity to reinterpret the results of catchment-scale mass balance studies and to develop methods to assess Critical Zone function at finer hillslope or forest stand scales. Understanding patterns in mineral depletion and product accumulation are essential for predicting how ecosystems will respond to stresses, disturbance, and management.

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BAILEY , Scott - *USFS*

## Spatial variation in the development of the Critical Zone at Hubbard Brook Experimental Forest, NH

Scott Bailey, Kevin McGuire, Donald Ross, Brian Strahm, and Madeline Schreiber

Mineral dissolution and the distribution of weathering products are fundamental processes that drive development and habitability of the Earth's critical zone; yet, the spatial configuration of these processes in some systems is not well understood. Hubbard Brook Experimental Forest, NH has monitored solute mass balance of headwater catchments since 1963. Inputs in precipitation are measured in weekly samples of rain and snow while outputs are measured through scheduled and event-based stream water sampling. Catchment scale mass

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BARCELLOS, Diego - *University of Georgia; Calhoun CZO, Luquillo CZO*

## Hot spots and hot moments for redox, iron and carbon cycling in soils across Luquillo and Calhoun CZOs

Diego Barcellos, Whendee Silver, Daniel Markewitz, Nadia Noor, Caitlin Hodges, Chunmei Chen, Christine O'Connell, Daniel Richter, and Aaron Thompson

Soils from humid forests can undergo spatial and temporal variation (hot spots and hot moments) of oxygen concentrations leading to changes in redox potential, iron reduction rates, and carbon mineralization and stabilization. We hypothesized that: (a) hot moments of days to weeks generate redox fluctuations that affect Fe reduction rates and

C release in forest soils; and (b) these hot moments do not occur concurrently across topographic positions. To test these hypotheses we measured Fe and C pools in 3 catenas at valley, slope, and ridge positions, every 3 to 10 days for a 3-month-period, in both Luquillo and Calhoun CZOs. Measurements included 0.5M HCl extractable-Fe(II), total Fe, pH, DOC, and total carbon. Sensors were installed in field to measure redox potential, soil oxygen, soil moisture, and CO2 emissions. In addition, we incubated the soils under anoxic conditions with or without Shewanella oneidensis MR-1 to assess the potential for Fe reduction and the relative abundance of rapidly-reducible Fe oxides [i.e. Fe(III)RR]. We found that rainfall and soil moisture were the main drivers for changes in iron reduction, pH, and DOC. Periods of higher precipitation led to higher Fe(II) concentrations, varying across valleys to slopes and ridges (1 to 100 mmol Fe(II) kg-1 soil). Rates of iron reduction available for iron-reducing bacteria [Fe(III)RR] during soil incubations were also correlated to high or low rainfall events and soil moisture contents, varying 5 to 25 mmol Fe(II) kg-1 soil day-1. Comparing topographic positions, the valleys were the most responsive in terms of shifting redox potential and Fe(II) concentrations. Overall, this work supports the notion that hot moments of high soil-moisture/rainfall likely stimulate Fe-reduction and C-cycling for different redox conditions and topographic positions across the CZOs. The dynamics of redox conditions can constrain rates of Fe reduction and C loss/accumulation, and influence ecosystem processes.

BARNHART, Theo - *University of Coloradol, Boulder; Boulder Creek CZO*

## The Cross-Scale Influence of Snowmelt Rate, Timing, and Amount on Runoff Production Across the Western United States

Theodore Barnhart, Noah Molotch, Christina Tague, Ben Livneh, Adrian Harpold, John Knowles, and Dominik Schneider

The mountain snowpack is critical for runoff generation across the western United States. We ask how changes in the rate, timing, and amount of snowmelt influence runoff production from the point to the continental scale. Using a combined observation and hydrologic simulation approach we first evaluate how changes in snowmelt rate, timing, and amount influence runoff production during the snowmelt season at Niwot Ridge (CO), Providence Creek (CA), and the Valles Caldera (NM). Additionally, we use the Variable Infiltration Capacity model to investigate large-scale drivers of snowmelt derived streamflow production across the western United States. At CO, CA, and NM, observations of evapotranspiration, precipitation, and snowmelt reveal that snowmelt magnitude is most important for runoff productions; however, this does not account for the collinearity between snowmelt rate, timing, and amount. We used 250,000 synthetic snowmelt scenarios at each site to remove this collinearity and reveal that snowmelt timing and snowmelt rate were most important for runoff production at CO and CA, respectively. At CA and CO, runoff production primarily occurs by driving water to the subsurface where it is not susceptible to atmospheric demand. Neither snowmelt rate nor timing were acceptable predictors of runoff production. At the larger scale across the western United States, snowmelt rate was a good predictor of runoff production corrected for water and energy availability. We also found that different ecoregions had different runoff production sensitivities to changes in snowmelt rate, which is congruent with

our findings from CO and CA. As climate warming diminishes the mountain snowpack causing earlier, slower melt, these findings suggest that runoff production will likely decline disproportionately to snowpack amount due to slower snowmelt. However, this decrease in runoff may be offset at some sites by increased runoff production from earlier snowmelt.

BASTOLA, Satish - *Georgia Institute of Technology*

## Parameterization of Nitrogen Limitation for a Dynamic Ecohydrological Model: a Case Study from the Luquillo Critical Zone Observatory

The interaction between hydrology and vegetation affects the cycling of nutrients in the soil-plant system and plays a critical role in removing and mobilizing nutrients in an ecosystem. Therefore, knowledge of the soil nutrient cycle and associated interactions with eco-hydrological processes is vital for the understanding of ecosystem response to environmental changes. Feedbacks between vegetation and the soil nutrient cycle are important in ecosystems where nitrogen limits plant growth. However, many biosphere models do not include such feedbacks, because interactions between carbon and the nitrogen cycle can be complex, and remain poorly understood. In this study we coupled a nitrogen cycle model with an eco-hydrological model by using the concept of carbon cost economics. This concept accounts for different "costs" to the plant of acquiring nitrogen via different pathways. This study builds on tRIBS-VEGGIE, a spatially explicit hydrological model coupled with a model of photosynthesis, stomatal resistance, and energy balance, by combining it with a model of nitrogen recycling. The model (referred to as tRIBS-VEGGIE-CN) simulates the dynamics of carbon and nitrogen in the soil-plant system; the dynamics of vegetation; and different components of the hydrological cycle. The tRIBS-VEGGIE-CN is

applied in a humid tropical watershed at the Luquillo Critical Zone Observatory (LCZO). We drive the model under contemporary $CO_2$ and hydro-climatic forcing and compare results to a simulation under doubling $CO_2$ and a range of future climate scenarios. The preliminary results show that the carbon cost of the acquisition of nitrogen is 20% of the net primary productivity (NPP) and this cost is sensitive to the leaf nitrogen content, turnover rates of carbon in soil and nitrogen cycling processes. Furthermore, an experiment with doubling of the $CO_2$ concentration level shows a significant increase of the NPP and turnover of plant tissues.

BERHE, Asmeret Asefaw - *University of California, Merced; Southern Sierra CZO*

## Deep Soil Carbon in the Critical Zone: amount and nature of carbon in weathered bedrock, and its implication for soil carbon inventory

Asmeret Asefaw Berhe, Kimber Moreland, Zhiyuan Tian, and Anthony O'Geen

Globally, soils store more carbon (C) than the vegetation and the atmosphere combined. Up to 60-80% of the C stored in soils is found in below 30cm soil depth, but there is little data on C storage in weathered bedrock or saprolite. Deep soil organic matter (SOM) can be a mixture of new and old SOM; that is rendered relatively stable due to burial, aggregation, its disconnection from decomposers, and chemical association that organic matter forms with soil minerals. The limited data available on deep SOM dynamics suggests that stock, distribution, and composition of deep SOM are strongly correlated to climate. The overall objective of this research is to investigate how climate regulates OM storage, composition, stability, and stabilization mechanisms. Expecting that the amount of OM stored in deep soil and the stability are a function of soil thickness and availability of weathering products (i.e. reactive minerals), the stock and stability of deep SOM is expected to follow

a similar relationship with climate, as does the intensity of weathering. This research is conducted in the NSF funded Southern Sierra Critical Zone Observatories that is located along a climosequence, the western slopes of the Sierra Naevada Mountains of California. Here we will present results derived from characterization of soils and weathered bedrock using elemental and stable isotope elemental analysis, and Fourier Transformed Infrared Spectroscopy to determine OM concentration and functional group level composition of bulk SOM. Our findings show that adding in subsoil and weathered bedrock C stocks increases estimates of soil C stock by 1/3rd to 2/3rd.

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Poster Session II Rm. 6 #28

BILLINGS, Sharon - *University of Kansas; Calhoun CZO*

## Biotic controls on deep CZ evolution reflect persistent susceptibility to change with ecosystem disturbance at the Calhoun CZO

Sharon Billings , Pam Sullivan , Dan Richter , Christoph Lehmeier C, Kyungjin Min , Samik Bagchi , Rebecca Flournoy , and Emma Hauser

Biotic control of the depth and persistence of mineral reaction fronts is enigmatic. Deep root and microbial production of $CO_2$ and organic acids, plant generation of organic reductants, and deep root water uptake all control chemical weathering. We assert that biogeochemical processes accompanying root-removing disturbances play a more significant role in regolith evolution than is currently appreciated, and that the weathering impact of disturbance is greatest where minerals exhibit high reactive surface energy. We demonstrate that disturbance modifies root depth distributions for many decades after relaxation of the disturbance regime. At the Calhoun CZO, old-growth forests exhibit ~60% greater root abundance than ~60 y old regenerating forests at 1 m depth; regenerating forest roots are absent at 2 m but are still present in 10% of old-growth forest samples at that depth.

These altered root distributions influence deep biogeochemistries. For example, agricultural fields and regenerating forests exhibit barely detectable dissolved organic C at 4.5 m, but old-growth forest soils contain ~2.5 times those values. DOC comprised a larger proportion (~20%) of total soil organic C at 4.5 m in old-growth soils than disturbed lands (~3%). These differences were associated with a two-fold enhancement in $CO_2$ production rates in old-growth relative to agricultural soils in Bt horizons. Reductions of soil acids where roots have been absent for centuries relative to old-growth systems prompt consequences for soil weathering: modeled bicarbonate fluxes indicate that old-growth forest profiles experience a ~70% and ~20% enhancement in regolith weathering relative to agricultural fields and regenerating forests, respectively. These distinctions likely are more prominent where reactive mineral surface area is more abundant, an idea we are exploring across CZs with different mineralogies. Our work offers a conceptual framework for assessing biotically-mediated, deep CZ evolution.

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Poster Session II Rm. 3 #6

BLAIR, Neal - *Northwestern University; Intensively Managed Landscapes (IML) CZO*

## Sediment dynamics and C-sequestration in the Midwestern USA reservoir, Lake Decatur: The fate of eroded C in the IML-CZO

Neal Blair, Thanos Papanicolaou, Chris Wilson, Lonnie Leithold, and Laura Keefer

The interception of fluvial sediments and nutrient run-off by dams has resulted in the sequestration of 150-300 Tg OC/yr in reservoirs, which is nearly equivalent to the burial rate of OC in the global ocean. The accumulation of OC also drive significant production of the greenhouse gas, methane. Predicting how this globally important anthropogenic biogeochemical niche will behave in the future in response to land use and climate change is especially challenging due to the large

number of reservoirs world-wide, which have relatively short lifetimes (~100 yrs).

A study of Lake Decatur has been undertaken to evaluate how sedimentation and OC burial evolve over the lifetime of an impoundment. The 12 km2 impoundment in Illinois was created by damming the Sangamon River in 1922. The Sangamon River watershed is a study site within the Intensively Managed Landscape Critical Zone Observatory.

Lake bed age models were developed from historical sediment thickness surveys, coring to pre-dam surfaces, and 137Cs and 210Pb distributions in the lake bed. The highest observed sediment accumulation rate (~2 cm/yr) was from the pre-dam river channel. Slower rates (< 1cm/yr) were from the shallower, flanking pre-dam floodplain surfaces.

The shallower sites exhibited a mixing profile between pre-dam sediments and incoming eroded soils created by resuspension events. The dam was raised by ~ 1m in 1956, thereafter the deposition of soil-derived mud dominated over mixing. A pronounced depletion of 13C in the OC after ~1970-1980 likely reflects the eutrophication of the lake in response to fertilizer application in the watershed. Sediment dynamics and the changes in OC provide empirical information concerning how the coupled watershed-reservoir will behave in response to future land-use and climate change.

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BONETTI, Sara - *Duke University; Calhoun CZO*

## Forward and backward evolution of the Calhoun CZO landscape

Sara Bonetti and Amilcare Porporato

The Calhoun Critical Zone Observatory is characterized by a distinct topography with the combination of gullies, interfluves, hillslopes and significantly eroded areas. Understanding the relative importance of different geomorphological processes that led to these conditions in relation to the hydroclimatic and land-use forcing that have shaped this peculiar landscape is crucial to reconstruct sediment and soil carbon fluxes, predict critical conditions of landscape degradation, and manage their recovery. Toward this main goal, an extension of the analytical theory of the drainage area (which represents a surrogate for water surface runoff responsible for fluvial incision) is presented here to include critical and singular points of the topographic surface. This allows us to represent, in a mathematically consistent way, the evolution of drainage area and ridge and valley lines in landscape evolution models. Preliminary results of backward and forward evolution in time are presented for different formulations of soil creep diffusion and advective river incision to reconstruct possible scenarios at younger stages and explore possible future evolutions.

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BRECHEISEN, Zach - *Duke University; Calhoun CZO*

## Ordering interfluves: landscape patterns in critical zone structure and evolution

Zachary Brecheisen, Patrick Halpin, Seulgi Moon, and Daniel Richter

A geomorphic interfluve-"landshed" ordering system, a reciprocal to the Horton-Strahler stream-order network, was developed at the Calhoun Critical Zone Observatory (CCZO) in SC. Earth's critical zone (CZ) is the near-surface environment in which rock, soil, water, air, and living organisms interact to regulate habitat and determine the availability of life-sustaining resources. While the nature of stream networks and watersheds have been widely discussed, the patterning of the land's residual terrain has received less attention. In the ordered interfluve-landshed system, the narrowest and most highly dissected interfluves (ridges) and isolated hilltops are considered 1st order and increase in rank dendritically as interfluve branches join uphill and become more massive and voluminous up to 5th order within the 150km2 CCZO

landscape. Interfluve-order is positively correlated to upland landshed elevation and area and negatively correlated to landshed slope. Considered more intricately, increased branching proximity of low-order interfluves to higher order interfluves has a strong positive control on elevation and negative control on slope. Slope, elevation, area, and other variables strongly related to interfluve-order are central parameters in many models and CZ processes. Understanding their patterns and distribution across landscapes will increase our ability to analyze and explain landscape environmental processes in the context of neighborhood geomorphology as captured by hierarchical interfluve-ordering. Landscape patterns of terrain as well as land cover, soil erosion potential, and modeled geochemical weathering depth are considered from an ordered-interfluve framework.

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Presentation   9:00 am Tue

BRESHEARS, Dave - *University of Arizona; Catalina-Jemez CZO*

## A critical zone perspective on ecosystem services

David D. Breshears, Jason Field, Laura López-Hoffman, Juan Villegas, Jon Chorover, Jon Pelletier, Jennifer McIntosh, Bryan Moravec, and Darin Law

Assessing ecosystem services is a key way to link environmental processes to human well-being. Critical Zone science can expand insights on the context, constraints, and currencies most often considered for ecosystem services.  Here we recap the development of ecosystem services, discuss expansions that a Critical Zone perspective can enable, and consider ways in which Critical Zone scientists might integrate their work more directly with ongoing advances related to ecosystem services.

BRUBAKER, Kristen - *Hobart & William Smith Colleges; Susquehanna Shale Hills CZO*

## Using LiDAR to reveal patterns of above-ground biomass from deciduous trees and shrubs in the critical zone

Kristen Brubaker, Quincey Johnson, and Margot Kaye

Understanding patterns of aboveground carbon storage across forest types is increasingly important as managers adapt to the threats of global change. Although airborne LiDAR has been used extensively to model aboveground biomass, it has not been used to understand the difference between tree and shrub biomass in closed canopy forests. We compared the fine-scale aboveground biomass in two watersheds; one watershed was underlain by sandstone bedrock and the other by shale. We measured tree and shrubs across three topographic positions for both watersheds, and calculated biomass in each. Using random forest, we modeled shrub and tree biomass across both watersheds, using a combination of leaf-on and leaf-off LiDAR point cloud metrics and topographic metrics. We found that there is an inverse relationship between tree biomass and shrub biomass across sites, and that LiDAR can be used to model these relationships across a broader, watershed scale. We also found differences in the ratio of biomass in trees versus shrubs between watersheds.

BUI, Elisabeth - *CSIRO Land & Water*

## Predictive spatial geochemical modelling of the Australian Critical Zone from local to continental scales

John R. Wilford, Patrice de Caritat, and Elisabeth N. Bui

The geochemistry of the Earth's surface reflects the composition of the uppermost continental crust (geosphere) and its interactions with the atmosphere, hydrosphere and biosphere, which change dynamically through time. The concentration and distribution of geochemical elements is important in mineral exploration, agriculture, environmental toxicology and geohealth.

Proxy datasets for the factors that control geochemical landscapes include geological maps, geophysics (magnetics, gravity, and gamma-ray spectrometry), digital elevation models and derived terrain attributes (e.g. slope), climate surfaces, and satellite (e.g. Landsat TM, MODIS, SPOT) and airborne imagery. These datasets are available from local to global scales. Archival of satellite images allows time-series analysis and generation of coefficients reflecting temporal changes.

We have used machine learning and rule induction techniques to map and explore the relationships between soil (sampled at 0-10 cm and 60-80 cm depth) geochemical survey site data in Australia with the environmental proxies above. The geochemical site data are used to train and evaluate the model performance. The resultant spatial models can be mapped at the resolution of the datasets used in the prediction and not at the much lower density of the geochemical site data.

The methodology couples a quantitative data-driven component that generates predictive models (with associated model uncertainties) with a knowledge-based component to explore relationships between geochemistry and environmental proxies against existing process knowledge.

We have used this approach to generate a suite of predicted geochemical landscape maps for individual elements, element ratios and geochemical indices over the Australian continent. The predictive models provide inputs for managing agricultural land and exploring for minerals and are also providing insights into weathering patterns and processes and the evolution of Australian landscapes.

CALABRESE, Salvatore - *Duke University; Calhoun CZO*

## Impact of stochastic bioturbation and transport on the formation of argillic horizons at the Calhoun CZ

Salvatore Calabrese, Daniel Richter, and Amilcare Porporato

The vertical movement of clays along a soil profile may give rise to argillic horizons. The formation of these horizons is generally attributed to the long-term balance between the downward transport by the percolating water and random particle mixing at the surface by bioturbation (tree throw and soil fauna). Using field observations, we quantify, using a simple stochastic model, the importance of the various processes underlying clay translocation. The novel transport model for clay dynamic redistribution accounts for uplifting by tectonic processes, eluviation by water during percolation events and bioturbation. The preliminary application of the model to clay content profiles at the Calhoun CZO provides realistic estimates of eluviation and bioturbation rates.

explained by subsurface water-holding capacity and rock-derived nutrient supplies.

CALLAHAN, Russell - *University of Wyoming; Southern Sierra CZO*

## Bedrock controls on mountain ecosystems evaluated using geophysics, geochemistry, and remote-sensing

Russell Callahan, Clifford Riebe, Mike Goulden, Nicholas Taylor, Sylvain Pasquet, Brady Flinchum, and Steve Holbrook

Understanding the processes that moderate water and nutrient availability in soil and weathered rock is fundamental to understanding the distribution of life at Earth's surface and to evaluating ecosystem vulnerability to climate change and land-use intensification. To tackle this problem, we employ a combination of geochemical and geophysical tools that quantify nutrient supply and subsurface weathering in the Sierra Nevada, California. Here we discuss results from three mid-elevation sites where forest cover varies markedly due to variations in lithology. To quantify subsurface weathering at our sites we used active-source seismic refraction techniques with a surface-wave dispersion inversion to quantify both subsurface P and S-wave velocity structures. We used the P and S-wave data to infer the thickness of saprolite and its porosity structure using a Hertz-Mindlin rock-physics model. We then combined the geophysical data on porosity with bedrock bulk geochemistry from previous work to evaluate the influence of water-holding capacity and nutrient supply on ecosystem productivity, which we measured using remote sensing techniques. Our results show that more than 80% of the variance in ecosystem productivity can be explained by differences in bedrock P concentration and subsurface porosity. This suggests that bedrock geology exerts a strong bottom-up control on the ecosystem, driving variations in both nutrient supply and water-holding capacity due to differences in bulk composition and weathering susceptibility. We evaluate the hypothesis that vegetation vulnerability to drought stress and mortality can be partly

CHAPELA, María - *UNH & University of Bristol; Luquillo CZO*

## Magnesium isotopes reveal a decoupling of Mg sources to the vegetation and the stream at the LCZO

María Chapela, Heather Buss, Philip Pogge von Strandmann, Jan Schuessler, and Oliver Moore

Magnesium is cycled through biological and geochemical processes in the critical zone (CZ), while its isotopes are fractionated by vegetation uptake and chemical weathering reactions. Therefore, we used Mg isotopes as tracers to investigate the influence of different CZ processes on the Mg isotopic signature of the stream in a highly weathered, volcaniclastic andesitic catchment at the Luquillo CZO.

Our results indicate that [Mg] and $\delta^{26}Mg$ in the upper 1m of regolith are mainly controlled by atmospheric inputs (rain in the short-term and dust in the long-term), with weathering inputs being more important at sites with thinner regolith. In addition, an isotopic fractionation process is taking place between dissolved Mg and the regolith on a thick ridgetop regolith (>10 m), likely during dissolution or recrystallisation of Fe-(hydro)oxides. Bulk regolith is isotopically heavier than the bedrock and the exchangeable fraction, consistent with the preferential incorporation of heavy $^{26}Mg$ into secondary minerals.

Mg in the stream shows a typical dilution behaviour, but the [Mg] – $\delta^{26}Mg$ pattern during a storm event cannot be explained by rain+porewater mixing. Time constraints and a correlation with TSS suggest ionic exchange with isotopic fractionation is taking place, with data best explained by a steady-state fractionation model. During baseflow, the stream has $\delta^{26}Mg$ higher than any of the water samples or

the bedrock. In-situ analysis of the bedrock minerals δ26Mg points at the dissolution of Mg-rich chlorite as the most likely source of this isotopically heavy Mg, with mass balance calculations indicating it is also the main source of Mg to the stream.

Overall, our study highlights the importance of atmospheric input of metals to the vegetation in tropical areas covered by thick, highly leached regolith, whereas the Mg flux and Mg isotopic signature of watershed exports are dominated by bedrock dissolution delivered to the stream through deeper CZ pathways.

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CHEN, Xing - *Duke University; Calhoun CZO*

## Impact of gullying on hillslope hydrology at the Calhoun Critical Zone Observatory

Xing Chen, Mukesh Kumar, Daniel D. Richter, and Yair Mau

The South Carolina piedmont area underwent severe gully erosion (GE) during a century of cotton farming (1800s to 1930s). Even nowadays, GE still occurs in hurricane seasons. Most studies on GE have focused on soil loss, soil carbon exchange and storm water response, while the impact of GE on soil moisture, groundwater, and transpiration remain unexplored. This study developed a 2D hydrologic model with interception, evapotranspiration, and subsurface flow processes to analyze the effects of GE on hydrologic states. The equations were solved using a finite-volume scheme on a representative 2D hillslope from the Calhoun Critical Zone Observatory (CCZO). Numerical experiments with different gully incision (GI) depths (from 0.5 m to 3.5 m below the toe of the hillslope), soil properties (from high to low conductivities), soil types (including sand, silt and clay), hillslope steepness (from 0.05 to 0.15) and bedrock depths (from 6m to 10m) were conducted. Results indicate that increase in GI leads to reduced groundwater storage, root zone soil moisture and transpiration. The reductions are greatest in summer and near the toe of the hillslope. The impact of

incision is larger for shallow incisions, and diminishes as the incision goes deeper. Hillslopes with higher conductivity and steepness experience larger impacts. Notably, subsurface heterogeneity can significantly mediate the impacts. In fact, impact of GI is weak in the characteristic CCZO hillslope due to the presence of a clay layer between loamy sand and loam, which serves as a low permeable buffer attenuating the recharging of groundwater. These results imply that localized GE, a soil loss phenomena, is accompanied by diffused water loss over the hillslope, which might force ecohydrologic adaptations in vegetation communities. The presented model and analysis will facilitate impact assessment in highly gullied landscapes and may be used to understand the impacts of stream dredging on hillslope hydrology.

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CHOROVER, Jon - *University of Arizona; Catalina-Jemez CZO*

## Concentration-flux relations in the vadose zone

Jon Chorover, Yaniv Olshansky, and Ty Ferre

Concentration-flux relations in the vadose zone: Concentration-discharge results for surface waters represent the mixing of several upgradient sources whose relative contributions are often non-uniquely determined. Meanwhile, it remains unclear as to how variable the chemistry of individual catchment components is across a wide range of water flux. In this study, collocated measurements of volumetric water content, matric potential, gas concentrations and pore water geochemistry are being used to calculate solute fluxes in the Catalina-Jemez CZO unsaturated zone. Initial results suggest chemostatic behavior across a wide range of water flux values despite large fluctuations in soil $CO_2$ partial pressures, presumed to stimulate carbonic acid induced weathering reactions.

CLARK, KC* - *University of Pennsylvania; Luquillo CZO*

## River particulate load transport, drivers and yields in the Luquillo Critical Zone Observatory

Kathryn Clark, Robert Stallard, Martha Scholl, James Shanley, Alain Plante, Sheila Murphy, Julia Perdrial, Nicolas Perdrial, Grizelle Gonzalez, and William McDowell

Physical erosion in mountain catchments mobilizes large amounts of sediment, while exporting carbon and nutrients from forest ecosystems into the river system for export. Climate models for the Caribbean project a drier future, but also more variable, with more intense cyclonic activity.  Better understanding of the response of rivers to extreme rainfall and drought is vital, given they are projected to occur more intensely and more frequently in the future. Rainfall, stream runoff, and collections of river suspended sediment (SS), particulate organic carbon (POC), particulate nitrogen (PN), and dissolved organic carbon (DOC) have been measured over storm events or on a weekly basis over the past 25 years in the Río Mameyes at Puente Roto and Río Icacos catchments. These long-term data were collected as part of multiple projects, including the Luquillo Long Term Ecological Network (LTER), the USGS Water, Energy, and Biogeochemical Cycles (WEBB) project, the Luquillo Critical Zone Observatory (LCZO), and the USDA FS International Institute of Tropical Forestry (IITF). We calculated SS, POC, and PN yields for the two catchments using robust streamflow data and hundreds of river SS samples. Next, we evaluated the influences on river SS, POC and PN due to extreme rainfall events and to extreme drought, with samples collected during drought and extreme rainfall events. Our research demonstrates: 1) the resistance of river biogeochemistry towards drought conditions by maintaining long-term C-Q patterns, and 2) the importance of large rainfall events, as the top runoff events, with a return time of 40%/yr, delivered half of the suspended load to the rivers. Our research highlights 1) the robustness of the river system in the face of drought, and 2) the likely role of major storms in controlling carbon storage in the critical zone and the surrounding coastal ocean deposits of the LCZO.

COLLINS, Caitlin - *Colorado School of Mines; Southern Sierra CZO*

## Using an integrated hydrologic model to assess the ecohydrologic impacts of change on a mountain headwaters Critical Zone

Caitlin Collins and Reed Maxwell

The critical zone is the region of the Earth's crust where hydrogeology, ecology, and climate interact. As many critical zone processes are fundamental, the significance of studying critical zone processes goes beyond understanding the local ecohydrological setting. Therefore studying critical zone governing processes requires an interdisciplinary approach that integrates simulation and observation. In this study, a high-resolution integrated hydrologic model, ParFlow-CLM, was developed for the Providence Creek watershed. Providence Creek is a highly instrumented critical zone observatory (CZO) located in the southern Sierra Nevada Mountains, a region currently experiencing a range of short-term responses (i.e. tree mortality) to a severe four-year drought. Sources of plant water use, pathways and residence times of water through the subsurface are identified using a suite of isotopic signatures and numerical particle tracking. Implications of using a fully coupled integrated hydrologic model accompanied by tracer analysis include better understanding of water partitioning and water storage in the regolith and vegetation water use during drought time conditions. The importance of subsurface storage, plant available water and lateral flow during the 2012-2015 drought to mitigate vegetation stress are addressed and verified against observed tree

mortality. The stream flow response to tree mortality in the aftermath of the drought, analogous to the Colorado Mountain Pine Beetle case, provides insight into the potential effects of proposed forest management practices.

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COMAS, Xavier - *Florida Atlantic University*

## Understanding the architecture of the deep critical zone and its relation to knickpoint evolution in the Rio Icacos watershed (Luquillo Critical Zone Observatory, Puerto Rico) using hydrogeophysical methods

Xavier Comas, William Wright, Mario Job, Neil Terry, Dimitrios Ntarlagiannis, Finn Whiting, Scott Hynek, Susan L. Brantley, and Raymond Fletcher

The Rio Icacos in the Luquillo Mountains of Puerto Rico is characterized by a sharp knickpoint associated to changes in relative baselevel during isostatic uplift, that define the front of a slow-moving wave of erosion that propagates upstream. Previous studies have shown differential rates of denudation across the watershed associated with the positioning of the knickpoint, with slower rates of erosion at higher relict positions above the knickpoint when compared to areas below the knickpoint. Furthermore, bedrock along the watershed has been characterized by a system of heterogeneous fractures that apparently drive the formation of corestones and associated spheroidal fracturing and rindlets. However, how the near-surface critical zone architecture (i.e. spatial patterns in regolith thickness or fracture distribution) may dictate changes in weathering rates and potential knickpoint migration, has not been properly characterized and is mainly based in a few cores scattered within the watershed. In this study we used an array of near-surface geophysical methods (including ground penetrating radar, terrain conductivity, electrical resistivity imaging and induced polarization, capacitively-coupled resistivity,

and shallow seismic, constrained with direct methods from previous studies) to better understand spatial variability of the critical zone architecture. These methods were combined with stress modeling to: 1) image changes in regolith thickness within the watershed; and 2) understand how the spatial distribution and density of fractures varies with topography and proximity to the knickpoint, showing increased dilation of fractures with proximity to the knickpoint. Our results are consistent at showing the potential of geophysical methods for imaging the architecture of the critical zone and its relation to knickpoint migration.

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CONKLIN, Martha - *University of California, Merced; Southern Sierra CZO*

## Forest thinning in Sierra Nevada mixed-conifer headwater forests: evapotranspiration, runoff and drought resiliency

Martha Conklin, Phil Saksa, Naomi Tague, and Roger Bales

Headwater catchments in the mixed-conifer zone of the American and Merced River basins were selectively thinned in 2012 to reduce the risk of high-intensity wildfire. Distributed observations of forest vegetation thinning, precipitation, snowpack storage, soil-water storage, energy balance and stream discharge from 2010 to 2013 were used to calculate the water balance and constrain a hydro-ecologic model. Using the spatially calibrated RHESSys model, we assessed thinning effects on the water balance. In the central-Sierra American River headwaters, there was a mean annual runoff increase of 14% in response to the observed thinning patterns, which included heterogeneous reductions in Leaf Area Index (-8%), canopy cover (-3%), and shrub cover (-4%).
In the southern-Sierra Merced River headwaters, thinning had little impact on forest structure or runoff, as vegetation growth in areas not thinned offset reductions from thinning. Observed thinning

effects on runoff could not be confirmed in either basin by measurements alone, in part because of the high variability in precipitation during the measurement period. Results show that when thinning is intensive enough to change forest structure, low-magnitude vegetation reductions have greater potential to modify the catchment-scale water balance in the higher-precipitation central Sierra Nevada versus in the more water-limited southern Sierra Nevada. Hydrologic modeling, constrained by detailed, multi-year field measurements, provides a useful tool for analyzing catchment response to forest thinning.

COSANS, Cassandra - *Johns Hopkins University*

## Modeling structural controls on sub-surface flow in a 2-D Hillslope

Cassandra Cosans and Ciaran Harman

Understanding how subsurface structure generates flow paths and ultimately water transit times through hillslopes is a current focus of critical zone research. Critical zone evolution through chemical weathering may be dependent upon flow paths and flow rates. Flow paths have important ramifications for chemical conditions water parcels pass through and hence influence the solutes in discharging water. . Transit times similarly influence solute concentrations by controlling flushing times of legacy pollutants. Transit times further control the time sensitivity of systems to climate change. We modeled flow paths and permeability to improve the understanding of a hillslope system and gain insight into how subsurface structure controls the quantity and quality of discharging water. A two dimensional model of a hillslope transect discharging to a spring in the Pond Branch catchment in Oregon Ridge Park, Maryland was generated. We also determined the contributing area for the spring, along with subsurface permeability and hydraulic conductivity profiles that could reproduce spring mean baseflow age and subsurface conductivity observations. The model was limited to two dimensions with flow in

the vertical and horizontal directions of the hill transect. Fracture flow was not included in the preliminary model.  Subsurface flow paths bypassing spring flow were included to achieve a water balance. Heterogeneity in subsurface conductivity played a key role in modifying flow paths to the spring. Clarifying structural controls on flow through hillslope is essential to understanding the evolution of critical zone structure through chemical weathering.

COWARD, Liz - *University of Pennsylvania; Calhoun CZO, Luquillo CZO*

## Soil organic matter stabilization by Fe-C interactions in temperate and tropical soils: A cross-CZO comparison

Elizabeth Coward, Alain Plante, and Aaron Thompson

Increasing evidence suggests that the long-term stability of soil organic matter (SOM) is dominated by organomineral interactions, particularly those involving Fe-bearing mineral phases. These phases are capable of disproportionate SOM complexation through sorption or co-precipitation, and thus Fe-SOM associations are hypothesized as a critical driver of SOM stabilization capacity in highly weathered soils lacking 2:1 phyllosilicate clays. The Luquillo and Calhoun soils of the Critical Zone Observatory (CZO) network provide an ideal framework for comparative research into the role of Fe-SOM associations, as they are formed from highly weathered, metal-rich parent materials, yet differ drastically in surface processes.

Twenty surface (0-20 cm) and subsurface (50-80 cm) samples from Luquillo, stratified across two parent materials, were compared to 26 Calhoun samples from similar horizons, spanning three distinct land treatment types. Inorganic selective dissolution techniques were used to isolate three forms of Fe-C interactions: sodium pyrophosphate to isolate dispersable/chelated Fe, HCl-hydroxylamine and

ammonium oxalate to isolate short-range-order (SRO) Fe, and inorganic dithionite to isolate more crystalline phases. Results indicate a dominance of crystalline and SRO Fe phases in surface horizons across both sites, well-correlated with DOC concentrations. However, the distribution of surface DOC associated with Fe pools differ across the two sites, suggesting a detectable signal of contrasting surface processes. At depth, we observe a decline in SRO phases at both sites, accompanied by an increase in Fe-DOC in Luquillo and crystalline Fe-DOC in Calhoun soils. These findings illustrate the importance of Fe crystallinity in SOM stabilization both at the surface and at depth, and informs a broader understanding of C biogeochemistry across the Critical Zone network.

Poster Session I Rm. 7 #15

DARROUZET-NARDI, Anthony - *University of Texas at El Paso*

## Stable microbial biomass and soil hydrolytic enzyme potential despite dynamic carbon exchange during summer in a Chihuahuan desert shrubland

Anthony Darrouzet-Nardi, Jennie McLaren, Kathleen Roman, Eleanor Keats, and Craig Tweedie

Arid shrublands are often characterized by spatially structured biogeochemical cycling patterns known as 'islands of fertility' in which biologically relevant elements including carbon and nitrogen become concentrated under shrub canopies and depleted in interspaces. Following these elemental distributions, biogeochemical fluxes also tend to be higher under shrub canopies. Here we investigate the relationship between the island-of-fertility effect and seasonal carbon dynamics in a Chihuahuan desert creosote bush and mesquite-dominated shrubland. We test the hypotheses that (i) during monsoon rains, greater biotic activity leads to higher microbial biomass and potential soil hydrolytic enzymatic activities and that (ii) despite these seasonal fluctuations, the island-of-fertility relationships in

which cycling is higher under shrub canopies remains intact. Our results showed a surprising lack of dynamics in both soil microbial biomass and potential soil enzyme activity rates throughout the summer season despite large swings in soil moisture and a reversal of carbon balance from sink to source with monsoon rains. We did however see some changes in soil-core-extractable NO3- and NH4+ pools consistent with active cycling during wet periods. While these findings were counter to our first hypothesis, our second hypothesis that shrubs would show more cycling activity throughout the season was true for all measured variables including total C and N stocks, soil respiration, nutrient concentrations, microbial biomass and hydrolytic enzyme activities. These results suggest that the microbial communities responsible for organic matter breakdown in these soils maintain population size and enzyme pools even during frequent dry periods.

Poster Session II Rm. 3 #5

DERE, Ashlee - *University of Nebraska - Omaha; Intensively Managed Landscapes (IML) CZO, Susquehanna Shale Hills CZO*

## Investigating weathering and solute fluxes in intensively managed critical zones

Ashlee Dere, Kathleen Goff, and Art Bettis

In the Midwestern United States, widespread agricultural disturbance has potentially altered weathering and soil formation in the critical zone. The Intensively Managed Landscapes Critical Zone Observatory (IML-CZO) in eastern Iowa and Glacier Creek Preserve (GCP) in eastern Nebraska were both formed in thick Peoria loess overlying glacial till. The watersheds were intensively modified by agriculture and both contain small fragments of restored prairie, but differ in mean annual precipitation, providing contrasting conditions to study the effect of disturbance on soil and solute geochemistry. Meteorological stations at the study sites record baseline atmospheric and soil parameters, and

precipitation collectors, stream sondes, wells and soil lysimeters monitor solute chemistry to track geochemical and hydrologic fluxes through the watersheds. Initial observations from deep soil cores (5 – 25 m deep) collected from ridgetops under both agriculture and prairie land use document Ca and Mg enrichment (up to 200%), but the depth of this weathering front varies between sites and land use. At the IML-CZO, Ca and Mg enrichment is deeper under agriculture land use compared to prairie (4 and 2.5 m, respectively) and soil water flushes rapidly through the upper 1 m of soils under agriculture. At GCP, although similar patterns of Ca and Mg enrichment are observed, the enrichment is deeper in restored prairie soils than agriculture soils (4 and 2 m, respectively) and water appears to flush more rapidly through the prairie soils. The wetter IML-CZO (89 cm compared to 78 cm mean annual precipitation at GCP) may be driving deeper weathering but land use also appears to be important in controlling the depth and extent of weathering in the thick loess profiles. Such measurements of soil weathering and geochemical fluxes in intensively managed landscapes are necessary to help quantify land use impacts on critical zone evolution and resilience.

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Poster Session II Rm. 5 #48

DERMISIS, Dimitrios - *McNeese University; Intensively Managed Landscapes (IML) CZO*

**Evaluation of the effects of landscape attributes on overland flow using a conceptual modeling framework that accounts for the spatiotemporal evolution of flow resistance**

Dimitrios C. Dermisis, Benjamin K. B. Abban, Christos P. Giannopoulos, Thanos Papanicolaou, Dennis C. Flanagan, and James R. Frankenberger

A framework is developed using the Water Erosion Prediction Project model that is capable of capturing the spatiotemporal evolution of resistance under the different types of roughness in intensively managed landscapes. The developed framework is used to examine the net effects of the spatiotemporal evolution of flow resistance offered by different landscape attributes on runoff hydrograph characteristics on hillslopes with different profile curvatures. The results suggest that the conversion of the landscape from vegetation to a bare surface or a surface with isolated roughness elements has a more profound effect on the runoff hydrograph than the effects of profile curvature. Vegetated surfaces result in drawn out hydrographs that are less peaky and have wider spreads than the bare surface and the surface with isolated roughness elements. Convex hillslopes tended to have higher runoff rates on the rising limb of the hydrograph due to higher runoff rates from the steeper, downslope sections whereas concave hillslopes tended to have higher runoff rates on the falling limb due to contributions from its steeper, upslope sections. An examination of the effect of storm magnitude and hillslope gradient on the spatiotemporal evolution of resistance suggests that the influence of the landscape attributes reduces with increasing storm magnitude and gradient up to a threshold where their impact becomes negligible. The combined influence of vegetation patchiness and curvature is found to have an effect on the characteristics of the runoff hydrograph. This suggests that the effectiveness of Best Management Practices (BMPs) such as grassed waterways (GWW) is likely to be different for different profile curvatures and highlights the need for further studies to examine the role of curvature on the BMP effectiveness.

DIBIASE, Roman - *Pennsylvania State University; Susquehanna Shale Hills CZO*

## Shallow critical zone architecture of a headwater sandstone catchment quantified using near-surface geophysics

Roman A. DiBiase, Joanmarie Del Vecchio, Gregory J. Mount, Jorden L. Hayes, Xavier Comas, Li Guo, Henry Lin, Fardous Zarif, Brandon Forsythe, and Susan L. Brantley

The composition and structure of Earth's surface and shallow subsurface control the flux of water, solutes, and sediment from hillslopes into rivers. Additionally, bedrock weathering profiles and the stratigraphy of soil and colluvium preserve a record of past surface processes. However, landscapes often exhibit heterogeneity in critical zone architecture that is difficult to capture with remote sensing and costly to characterize through direct measurement in soil pits or drill cores. Here we present results from a multifaceted approach to quantifying spatial variability in critical zone architecture using a suite of geophysical surveys. We focus on Garner Run, a first order sandstone catchment in the Susquehanna Shale Hills Critical Zone Observatory situated in the valley and ridge province of central Pennsylvania, 80 km southwest of the last glacial maximum ice limit. Geomorphic mapping of Garner Run indicates pervasive modification by Pleistocene periglacial surface processes, but the extent to which these processes are recorded in weathering profiles and colluvial deposits is unclear. Through the use of shallow geophysical techniques, including cross-valley transects of seismic refraction, multiple frequency ground-penetrating radar (GPR), and electrical resistivity tomography (ERT), we image spatial patterns in subsurface architecture at a range of scales (10-1,000 m horizontal; 1-10 m depth), and high spatial resolution (cm). By using diverse subsurface methods, we highlight structural (dip-slope) and aspect controls on weathering zone thickness, as well as spatial variations in the depth of colluvium that are consistent with surficial observations. Additionally, our results are consistent with and leverage geologic interpretations based on a 10 m drill core across the entire catchment, and serving as a template for studying modern critical zone processes.

DIETRICH, Bill - *University of California, Berkeley; Eel River CZO*

## Lithologic control on critical zone development and the consequences for the persistence and spatial extent of wetted channels during the summer dry season

William Dietrich

The advance of a weathering front into fresh bedrock typically increases porosity and hydraulic conductivity, effectively drawing hydrologic processes into the interior of hillslopes. The resulting water storage dynamics may in turn drive runoff magnitude and duration, erosion processes, solute chemistry, as well as water availability to the terrestrial ecosystem. In Northern California, the dominant bedrock is the Franciscan accreted terranes, which have been divided into Coastal, Central, and Eastern belts. The Coastal belt is weakly metamorphosed turbidities sequences of shale and greywacke whereas the Central Belt is typically lithologically similar but is intensively deformed into mélange. In the Coastal Belt, the depth to fresh bedrock systematically increases upslope from a few meters near channels to greater than 25 m at the hillslope divide. In contrast, the depth to fresh bedrock is less than 2 m in the Coastal Belt. This much shallower critical zone thickness appears to be due to the exceptionally low saturated hydraulic conductivity of the fresh bedrock. Runoff in the Coastal Belt landscapes arises from deep penetration of rainfall to the fresh bedrock boundary, development of a perched groundwater and then subsurface runoff, leading to sustained summer base flows in channels (and to salmon

production). In the mélange Central Belt, saturation overland across the landscape prevails in winter, little water is stored and streams are dry in the summer. Channel surveys were conducted in two headwater drainage networks (2.7 to 17.0 km2) in each of the belts during late summers of 2012, 2014 and 2015. Springs, fixed in location, controlled the extent of flow. The Coastal Belt channels remained flowing throughout late-summer months even as discharge decline from the hillslopes. Only 23 km away, in the Central Belt mélange the only summer surficial flowing water initiated from coherent, deep-rooted sandstone blocks embedded in the melange

DOVE, Nicholas - *University of California, Merced; Southern Sierra CZO*

## Over half of potential soil extracellular enzyme activity occurs below 20 cm

Nicholas C. Dove, Keshav Arogyaswamy, Chelsea J. Carey, Aaron I. Packman, Stephen C. Hart, and Emma L. Aronson

Soil extracellular enzymes (EEs) are the principal agents of organic matter decomposition and nutrient mineralization, yet the vast majority of studies examining EE activities have been confined to only the upper soil layers (< 20 cm depth). While the controls of EE activity in the topsoil are reasonably well-understood, we know little of how these enzyme activities change with soil depth. The controls and subsequent patterns of EE activity at depth may diverge from those at the soil surface due to changing physical, chemical, and nutritional conditions in subsurface soils. We assessed EE activity to a depth of 1 m at 10 cm increments in 20 soil pits across the Critical Zone Observatory Network. Activities of four carbon (C)-degrading, two nitrogen (N)-mineralizing, and one phosphorus (P)-mineralizing enzymes were measured fluorometrically. We used mixed effects models to investigate the effects of depth, soil order, and their interaction on EE activity and enzyme stoichiometry.

For all EEs, activities decreased exponentially with depth. However, over half of potential soil EE activity occurred below 20 cm for all measured EEs. Although the effect of depth on EE activities depended on soil order for certain EEs, no generalizable patterns emerged. Depth showed varied effects on enzyme stoichiometry, which serves as a relative index of nutrient demand. Across all sites, we found no significant effect of depth on C:N or C:P enzyme stoichiometry; however, there was a significantly negative correlation between depth and N:P enzymatic activity. Although P is generally considered more available at depth than N, this suggests that P pools at depth may not be bioavailable, as microbial P demand increases relative to N demand with depth. Overall, these results suggest that assessing EE activities only in the upper 20 cm misses a large proportion of the total soil EE activity and that patterns which are robust in the upper soil layers may diverge with depth.

DRALLE, David - *University of California, Berkeley; Eel River CZO*

## Modeling Critical Zone controls on ecohydraulics and stream temperature in a Mediterranean watershed

David Dralle, William Dietrich, Sally Thompson, Jesse Hahm, and Daniella Rempe

Critical Zone structure mediates hillslope water transport to streams and the availability of subsurface moisture for use by plants. The corresponding effects on catchment runoff characteristics and the composition of near-stream vegetation communities has profound consequences for the hydraulic and thermodynamic characteristics of terrestrial aquatic ecosystems. Here, we use observations from two intensively monitored sites with contrasting CZ architecture in the Northern California Coast Ranges to develop a coupled flow-temperature model for the South Fork Eel River watershed. We adopt a "CZ functional approach", upscaling phenomenological understanding of

hillslope runoff generating mechanisms to examine the effects of CZ architecture on the ecological quality of streams throughout this highly seasonal watershed. Model validation shows that watershed behavior is well represented by superposing the response of sub-watersheds comprised of one of two proto-typical hillslopes from neighboring belts of the Franciscan Formation: Coastal Belt – Hillslopes exhibit a thick CZ consisting of weathered, fractured mudstone with high water storage potential; Central Belt – Hillslopes exhibit a thin CZ consisting of relatively impermeable soils with low storage potential. Hydrologic model output is then used to drive a simple stream temperature model. Results demonstrate that CZ mediated vegetation structure and runoff generating mechanisms exert strong controls over stream temperature. In the Coastal Belt, shading by coniferous-hardwood forests paired with a slowly draining, hillslope groundwater system results in cold and elevated summer baseflow. In contrast, rapid runoff pathways and sparse vegetation cover result in high temperature, low volume summer flows in the Central Belt. These results represent an important step toward development of predictive frameworks that link watershed-scale physical qualities of stream ecosystems to CZ structure.

by which solutes are derived, transported and transformed across the unique structure of the DVZ are largely undocumented as a result of the difficulty associated with direct observation. Here, we report solute chemistry as a function of depth collected over a full year across the shale-derived DVZ of the Eel River CZO using a set of novel sub-horizontal wellbores, referred to as the Vadose zone Monitoring System (VMS). The results of this first geochemical glimpse into a DVZ indicate a dynamic temporal and depth-resolved structure. Major cation concentrations reflect seasonal changes in precipitation and water saturation, shifting to dilute values in the winter months, whereas redox active iron and sulfur species are mobilized at depths corresponding to seasonal water table height. These data are used in combination with preliminary $CO_2$ and $O_2$ gas phase measurements to illustrate the depth-segregated regimes of carbonic vs. sulfuric acid driven weathering, and indicate significant oxidative respiration of organic carbon as deep as 10 m below the ground surface. In total, these preliminary observations from the VMS suggest that DVZ systems store and actively cycle carbon in weathered regolith below the soil horizon, and may constitute a significant and unconstrained component of the terrestrial carbon cycle.

DRUHAN, Jenny - *University of Illinois Urbana Champaign; Eel River CZO, Intensively Managed Landscapes (IML) CZO*

## Balancing reactivity and transport across the deep vadose zone.

Jennifer Druhan, Jia Wang, Alison Tune, Nicole Fernandez, and Daniella Rempe

In uplands, such as those found across the western continental United States, hydrologic recharge predominantly occurs through large sections of periodically saturated, partially weathered bedrock – the deep vadose zone (DVZ) – that represents a physical boundary between soils and aquifers. The hydrologically and biologically-mediated pathways

DUGGAN-HAAS, Don - *Paleontological Rresearch Institution (PRI); National Office*

## CZ science as a platform for science education reform.

Don Duggan-Haas

While it is simple to identify innovations that have made substantial improvements in user outcomes for millions of users in the energy, and transportation systems, in information and communications, and in medicine. Critical Zone science may ultimately prove to be such an innovation in Earth and environmental sciences. Successful innovations, those that have improved

the outcomes for a large percentage of users, are considerably harder to identify in the educational system generally, and specifically in science education. Such innovations are, indeed, essentially impossible to identify in at least the last four decades. This stagnancy, coupled with outcomes that have long been regarded as disappointing, is a problem.

Successful innovations and successful research combine the familiar and well understood in unconventional ways. They are "optimally distinct" - different enough to change results substantially but not so different that the innovation cannot be understood. Further, they have user interfaces that are easily understood. Science education reforms in recent decades have neither of these attributes. Critical Zone science has both of them. Can approaches of CZ science be adapted to drive change in the educational system?

The growing importance of interdisciplinary scientific research is in sync with the growing value of interdisciplinarity in the educational system, but the user interface in science education is nearly incomprehensible. Certain CZ science approaches are applicable to the K-12 science classroom - the basic ideas of CZ trees, for example, combine relatively easily understood measurements and instruments in novel ways that yield deeper understanding of the complex system that is a tree - but potentially more important is that the broader concepts upon which CZ science is built. Can schools and the system of schooling follow the lead of CZ science and break disciplinary walls?

DUNCAN, Jon - *UNC, Penn State*

## Variability in nitrate concentration-discharge relationships in forested and urban watersheds: towards a unified conceptual model of Critical Zone controls

Claire Welty, John Kemper, Lawrence Band, and Peter Groffman

Concentration-discharge (c-Q) relations have been used to infer processes governing solute transport at watershed scales. Prior studies have documented inconsistent concentration-discharge patterns driven by changes in end-member concentrations. We utilize a combination of long-term weekly and shorter term high-frequency data at a forested and an urban watershed in the Baltimore, MD region to assess critical zone controls on nitrate c-Q relationships. The forested watershed reveals a difference in composite c-Q relationships between long-term weekly and short-term (3 months) of 15-minute concentration that is likely due to the ecosystem controls on nitrate concentrations. At the urban watershed we examine a novel data set consisting of three-years of high-frequency nitrate and discharge data to quantify temporal variability at storm-event, seasonal, and interannual time scales. On a storm-event scale, we observe a watershed-specific dQ/dt threshold when storms switch from counter-clockwise to clockwise c-Q behavior. On a composite scale, the c-Q data exhibit chemostasis for 14-years of weekly data (676 data points) but not for 3 years of high-frequency sensor data (52,560 data points). Furthermore, the slope of the c-Q high frequency data differs between dry and wet years. We examine plausible hydrologic and metabolic controls on stream nitrate concentrations and fluxes. This work highlights the value of long-term, high-frequency c-Q data collection for resolving the critical zone controls on the production, transformations, and transport of nitrate in watersheds of differing land uses.

DWIVEDI, Ravindra - *University of Arizona; Catalina-Jemez CZO*

## Characterization of water sources and flowpaths and their influence on groundwater geochemical evolution and mineral weathering rates in a high elevation mountain catchment

Ravindra Dwivedi, Thomas Meixner, Jennifer McIntosh, Paul A. Ferré, G.-Y. Niu, and Jon Chorover

Groundwater fluxes play a significant role in Critical Zone evolution and long-term functioning by dictating water-rock contact time, which, in turn, affects mineral dissolution rates and solution equilibrium with respect to host rock chemical composition. While there has been significant prior work on coupled hydrologic and geochemical processes occurring in humid catchments, our understanding of hydro-geo-chemical functioning in (semi-)arid climate systems is more limited. Therefore, the main goal of this work is to combine a multi-tracer approach with numerical modeling to understand hydrologic functioning, including water sources and the transient nature of flow paths, and how these flow paths influence geochemical evolution of groundwater in a high elevation catchment, i.e., Marshall Gulch, where there are no deep monitoring wells, located within the Santa Catalina Mountain Critical Zone Observatory (Tucson, AZ). Our results indicate that stream baseflow is mostly composed of soil water and perched aquifers under dry conditions. The deeper fractured bedrock aquifers contribute to streamflow only during wet conditions such as snowmelt. The contribution of deep groundwater ranges from 0 % (in a dry season) to 94% (during a wet season).

Our preliminary mineral weathering work for a sub-catchment located within our Marshall Gulch field site indicates long-term solute efflux rates calculated from pedon mass balance are 438 mol/ha/yr for Na and 2001 mol/ha/yr for Si, consistent with Na-

plagioclase weathering at our field site. Furthermore, we found that, in general, soil-pedon-based weathering rates are higher by a factor of ~3 (for Na) to ~10 (for Si) than the stream water chemistry-based weathering rates. Additionally, the soil pedon-based weathering rates are qualitatively higher near divergent zones than near convergent zones, which we hypothesized is related to higher saturation indices of solutions in convergent relative to divergent zones.

FAIRBANKS, Dawson - *University of Arizona; Catalina-Jemez CZO*

## Seasonality and disturbance: assessing microbial response in two adjacent high-alpine catchments in northern New Mexico.

Dawson Fairbanks, Marci Caballero-Reynolds, Jon Chorover, and Rachel Gallery

Fire frequency and severity are increasing across the western United States with enormous impacts on regional carbon and nutrient cycling. Central to the understanding of ecosystem recovery are the microbial communities that transform nutrients in the environment. Temporal changes in precipitation patterns influence the stress response of resident microbiota, in combination with abiotic controls, and in part, controls ecosystem level CO2 and greenhouse gas flux. We explored the relationship between timing of precipitation, terrestrial nutrient cycles on microbial ecology post- fire by sampling across a topographic gradient from two adjacent mountain catchments (north and south-facing) in a high elevation mixed conifer forest three years following a high severity fire disturbance. To best understand microbial community response and recovery to a) a major fire disturbance and b) pulsed precipitation dynamics we analyzed the 16S ribosomal rRNA community metrics, seven hydrolytic enzyme activities, biomass carbon and nitrogen and geochemical parameters following snowmelt, pre and post-monsoon. Six sites were

sampled from each catchment across a topographic transect from surface (0-10 cm) and deep (30-40 cm) soil profiles. Samples taken from the south facing catchment were co-located with CO2, O2, redox (platinum electrode) and temperature probes. Results show greater greenhouse gas flux in the convergent zones of the landscape occurring at deeper depths with simultaneous oxygen consumption. These results can be used to integrate our understanding of 'hot spots' as a function of landscape position and the pulse coupling of precipitation dynamics influencing the stress response of microbes and the co-occurring nutrient cycling.

FELLOWS, Aaron - *USDA-ARS*

## Rapid recovery of gross production and respiration in a mesic mountain big sagebrush site following prescribed fire

Aaron Fellows, Gerald Flerchinger, Kitty Lohse, and Mark Seyfried

The impact of fire on ecosystem dynamics remains a key uncertainty in understanding the spatio-temporal patterns of carbon cycling in the Western US. We therefore tracked the recovery of carbon exchange and aboveground carbon stocks following prescribed fire in a mountain big sagebrush ecosystem located in the northern Great Basin, USA. We quantified the change in plant function type, leaf area index, standing aboveground carbon stocks, Net Ecosystem Production (NEP), Gross Ecosystem Production (GEP), and Ecosystem-level Respiration (Reco) for 2 years before and 7 of the 9 years after the prescribed fire. Post-burn GEP and Reco exceeded pre-burn GEP and Reco within 2 years and remained elevated. The variation in GEP and Reco provided no evidence of a large and prolonged net efflux of carbon in the 9 years after the fire. Rather, NEP indicated the site was a sink before and after the fire, with little change in sink strength associated with the fire. Re-sprouting and recruitment of grasses and forbs drove the post-burn increase in

GEP. Woody shrub growth was the dominant control on aboveground biomass accumulation after fire, with aboveground biomass reaching ~15% of pre-fire biomass after 5 years. The rapid recovery of GEP and the growth of mid-successional shrubs suggest ecosystem-level carbon stocks recover rapidly after fire in mesic big mountain sagebrush ecosystems, ameliorating the atmospheric carbon burden associated with fires in sagebrush.

FILLEY, Timothy - *Purdue University; Intensively Managed Landscapes (IML) CZO*

## Progress toward an international CZO soil carbon data survey and synthesis

Timothy Filley, Asmeret Berhe, Jenny Dungait, and Jim Tang

On December 11, 2016 an international group of critical zone (CZ) scientists representing a variety of field sites and networks from around the world met in a half-day long workshop aimed at establishing a detailed working plan to catalog critical zone observatory activities and methods for soil carbon (C) accounting, modeling, and analysis. The ultimate goal of this activity is to facilitate large-scale, global data syntheses products related to shallow and deep soil C in the CZ. Convened by the National Office of the U.S. NSF Critical Zone Observatory Network, this working group on soil organic carbon (SOC) dynamics discussed the need to assess C flux balances across the range in soil parent material, below ground primary production, geomorphology, climate, and hydrologic regimes represented by the international CZOs. They also recognized the need to develop conceptual and numerical models with the capability to highlight and quantify the controls on geospatial and vertical carbon accumulation and loss—and assess CZ controls on the dynamics of stabilized, mineral-associated plant and microbial SOC. Unfortunately, there has been no centralized accounting of the scale, density, and methodology for SOC data acquisition among the individual CZOs,

and so critical data gaps may exist limiting the possibility of global CZ modeling syntheses.

The working group recommended that a comprehensive survey be undertaken cataloging the various soil sampling and analysis methodologies of the U.S. and international CZOs to promote data intercomparability and data synthesis. The proposed survey, to be constructed by the members of the working group, will be activated in early April 2017 with the results to be first discussed at the 6th International Symposium on Soil Organic Matter (SOM2017, 3–7 September 2017) at Rothamsted Research, UK.  The data presented will also provide the necessary platform for SOC modeling workshops planned by the international CZO community in 2018.

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GASPARINI, Nicole - *Tulane University*

## Using the Landlab modeling toolkit to understand earth surface dynamics in CZOs

Nicole Gasparini and Nathan Lyons

Landlab is an open-source Python modeling library that provides tools to numerically explore earth surface dynamics. Landlab is designed to make modeling accessible to all geoscientists, including undergraduates. Modeling is relatively painless because the Landlab library provides the essential building blocks for making a model along with extensive documentation. Users can build a uniform or nonuniform grid in one line of code. The library has tools for setting boundary conditions, adding data to a grid, and performing basic operations on the data, such as calculating gradients and curvature. The library also includes process components, or numerical implementations of physical processes. The current library has components for modeling a range of processes, from overland flow generation to bedrock river incision, from soil wetting and drying to vegetation growth, succession and death. The code is freely available for

download, can be installed as a Python package, and built models can be run on Hydroshare, an online collaborative environment for sharing hydrologic data, models, and code.

We illustrate Landlab model outcome to explore how a knickpoint, or convexity, was generated in the South Fork Eel River (SFER), part of the Eel River CZO. The watershed has a complicated history of spatially and temporally variable rock uplift due to the passage of the Mendocino Triple Junction. However, yet to be determined is whether the knickpoint is a product of the uplift history, or due to other variables, such as rock properties and/or climate. Outcome of model scenarios, the uplift history, and SFER morphology and erosion patterns are incongruent. This implies that a translating, tectonically-induced uplift wave—commonly invoked as the driver of landscape change in this region—is not the sole driver of landscape transience. Model data will be used to direct future field data collection to better understand the dominant controls on landscape evolution in the SFER.

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GIANNOPOULOS, Christos - *The University of Tennessee; Intensively Managed Landscapes (IML) CZO*

## Accounting for travel times and sediment delivery in intensively managed landscapes using a Bayesian Framework

Christos Giannopoulos, Thanos Papanicolaou, Benjamin Abban, Christopher G. Wilson, O. Abaci, and Ken Wacha

An enhanced Bayesian, Markov Chain Monte Carlo fingerprinting framework for estimating sediment source contributions and their associated uncertainties is presented.  The framework includes two key stochastic parameters that reflect the spatial origin attributes of sources and the time history of eroded material delivered to and collected at the watershed outlet.  Probabilistic treatments of

these parameters in the enhanced framework are to account for these variabilities in landscape properties and travel times.  We evaluate the effects of the parameters on source partitioning in the South Amana Sub-Watershed (SASW) in the US Midwest.  The enhanced framework is found to estimate mean source contributions that are in good agreement with estimates from other studies in SASW.  The enhanced framework is also able to produce expected trends in uncertainty during the study period.  Overall, the enhanced framework is found to be more robust and desirable from a management standpoint for determining source contributions.

GIESBRECHT, Ian - *Hakai Institute*

## The Hakai Critical Zone Observatory: exploring critical zone connections from land to sea in the Pacific rainforest of Canada

Ian Giesbrecht, Paul Sanborn, Suzanne Tank, Bill Floyd, Ian Walker, Brian Menounos, Allison Oliver, Brian Hunt, and Ken Lertzman.

The critical zone observatory (CZO) framework has the potential to reorganize the way we think about coastal margins, where land meets sea. For example, freshwater runoff has long been recognized as an important contributor to coastal ocean dynamics, yet watersheds are often treated as simplistic sources of flux to the ocean. The CZO concept emphasizes integrated analysis of the vertical column "where rock meets life", prompting deeper investigation of factors driving dynamic watershed exports to the coastal ocean. Conversely, coastal ocean research questions can provide a strong driving purpose for coastal CZOs. We present a case study of an emerging coastal margin observatory that uses a CZO framework to investigate land-sea interactions.

In the rainforest region at the western edge of North America, atmosphere, land, and ocean interact in complex ways to create rich coastal margin ecosystems. At the heart of the region lies the Great Bear Rainforest of Canada. Despite having global profile in popular media, this remote area has long been a gap in scientific products and the global network of long-term observatories. To begin addressing this gap, the Hakai Institute and partners are establishing a long-term coastal margin observatory that investigates land-sea interactions in the context of environmental change. In 2013, we established seven observatory watersheds on boggy 'hypermaritime' islands. These systems generate globally high yields of dissolved organic carbon to the coastal ocean, due to a particular combination of climate, lithology, glacial history, soils, and vegetation. Here, the critical zone is thin and rain-storms are common, resulting in rapid water table dynamics and flashy stream exports, which are in-turn coupled with dynamic ocean conditions. We expect that our application of critical zone concepts and techniques will reveal integrative insights into the long-term connections of atmosphere, land, and sea at the coastal margin.

GONZALEZ, Rosalina - *La Salle University*

## Biochemical and Environmental Studies in Utopia CZO (Colombia)

Rosalina Gonzalez

Utopia is a social-scientific project located in a rural area in Colombia, the project looks for create a positive impact on sovereignty and food security, economic and sustainability of agriculture and make improvements in living conditions of Colombians in rural areas. This project is led by La Salle University and has as objective: forming young graduates from rural areas affected by violence and poverty to become Agricultural Engineers with the best possible training, making them leaders for social, political and environmental transformation and field production entrepreneurship in their places of origin. As Utopia has many agricultural productive lines at the same time, La Salle University has a great opportunity to

study the impact of weathering and land use in the environment and at the same training the students in sustainable techniques to prevent the devastation that have occurred in different places through the world. Utopia CZO has a group of people of different areas and they are mapping the place in a transversal way characterizing the physical, chemical and biological characteristic in the zone and determine how is the impact of the traditional agricultural techniques versus the ecological ones to produce reports to the community, and government. The studies involve the effect of some fungus in the growing crops, for example the Rhizophagus irregularis in Cocoa; the hydric balance in different crops, the fauna associated to crops and the effects of them in plants, bio-indicators of the state of soils in crops, the relationship between weathering conditions and physicoquemical characteristics in soils, modelling the environmental fate of pesticides and toxicity studies. Utopia has learnt from the CZO Hybam in Brazil to make proposals that contribute to the fact that the extreme climatic phenomena and land use that we are experienced do not cause the damages to which we are affected by lack of adequate tools of scientific and social prevention.

multivariate nature of forcing and feedbacks in the system. We use a Temporal Information Partitioning Network (TIPNet) approach to reveal connectivity between atmospheric, vegetation, and root-soil processes as they are influenced through the energy and water balances in addition to spatial connectivity between sites along gradients in elevation and climate. Along two flux tower transects at the Reynolds Creek and Southern Sierra CZOs, we find that detected influences to heat and carbon fluxes from atmospheric, soil, and radiation drivers shift from dominantly synergistic during the spring to redundant later in the summer growing season as conditions become more dry. Additionally, non-local information flow between sites along each transect indicates the timescale and directionality of weather forcing versus the influence of locally driven dynamics at each site. This study distinguishes the nature of information flow between ecohydrologic variables, in addition local connectivity between processes at a site versus non-local influences. This understanding could enhance the understanding and prediction of a range of complex systems that exhibit various types of forcing and feedback behaviors.

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GOODWELL, Allison - *University of Illinois; Intensively Managed Landscapes (IML) CZO*

## Local and non-local information flow along an elevation gradient

Allison Goodwell and Praveen Kumar

Ecohydrologic variables related to fluxes of energy, water, and nutrients participate in forcing and feedback interactions at a range of timescales and over a spatial gradient. The entire set of these interactions constitutes a complex ``process network''. In this framework, nodes are time-series variables and links are measures of time dependencies. The connectivity of this network can indicate aspects of larger scale system behavior that would go undetected based on the analysis of individual or pairs of variables, due to the

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GRANT, Katie - *Cornell University*

## Iron loss promotes SOC destabilization on a Hawaiian soil gradient

Katherine Grant, Valier Galy, Negar Haghipour, Timothy Eglinton, and Louis Derry

Soil organic carbon (SOC) is a heterogeneous mixture of carbon compounds with varying reactivity. Changing environmental conditions can lead to destabilization of SOC through disruption of protection mechanisms, which is incompletely understood. We can test the impact of soil redox variability using andisols derived from a 400 ka basaltic lava flow formed on a precipitation gradient on Kohala Volcano, HI. Increasing precipitation with elevation leads to frequent saturation and extensive

iron loss. Two soil profiles, where differences in MAP lead to markedly different levels of Fe depletion (τFe), were sampled by genetic horizon (~1m). Mineral soil horizons (50-70cm) were freeze-dried, homogenized and analyzed on the Ramped PyRox (RPO) system at Woods Hole NOSAMS facility and isotopic analysis of lipid biomarkers was carried out at ETH Zurich. Carbon isotopes (14C and 13C) were measured on each RPO fraction, the n-alkanoic acids, and bulk samples. Each technique aims to dissect the complex mixture of SOC components in a given sample, either by thermal separation or specific chemical extraction. RPO analyses have uniform age distributions, meaning the 14C age of all fractions is nearly identical, suggesting that each thermal fraction contains a mixture of carbon compounds with the same activation energy distributions (p0(E)). Calculated mean p0(E) range from 150kJ/mol at the Fe enriched site to 171kJ/mol at the Fe depleted site. The short chain fatty acids (SCFA) (C16-C18) and long chain fatty acids (LCFA) (C24-C32) were measured for 14C. At both sites, average SCFA are younger with Fm values of 0.90 and 0.76 than the average LCFA of 0.63 and 0.18 respectively. However, at the Fe depleted site, the Fm values of both the SCFA and the LCFA are much higher indicating faster turnover of microbial-derived and plant-derived SOC. Combining RPO and biomarker analysis gives a thermal, age, and structural spectrum, which provide a powerful new perspective on SOC stability.

Presentation   8:20am Mon

GROFFMAN, Peter - *CUNY*

## Opportunities for integrating and leveraging LTER, NEON, and CZO Networks.

GU, Xin - *Pennsylvania State University; Susquehanna Shale Hills CZO*

## Investigating the porosity development of shale to understand hydrologic controls on hillslope scale weathering

Xin Gu, Daniella M. Rempe, Joshua West,  and Susan L. Brantley

To understand the controls on the evolution of weathering profiles that underlie hilly and mountainous regions, we investigated the porosity formation and chemical weathering of shale (Coastal Belt of the Franciscan Formation) samples from four boreholes at Eel River Critical Zone Observatory (ERCZO) in Northern California and compared to the well studied Rose Hill shale at Susquehanna Shale Hills Critical Zone Observatory (SSHCZO) in central Pennsylvania. These two sites have similar mineralogical composition, but are located in vastly different climate and tectonic settings. In particular, the erosion rate at ERCZO (0.2-0.4 mm/yr) is much faster than at SSHCZO (0.015 mm/yr), and the average annual precipitation at ERCZO is higher (1.7 m/yr vs. 1 m/yr at SSHCZO).

Analysis of the chemical and mineralogical compositions of samples throughout the weathering profile reveal that, at both sites, chemical weathering reactions occur at similar depths despite large differences in erosion rate: 1) carbonate and pyrite deplete sharply near the water table. 2) Chlorite oxidation also initiates near water table but shows a wider reaction front. In both settings, the interface between weathered and unweathered rock roughly coincides with the water table and the porosity and water-accessibility increase toward the land surface. However, at ERCZO, the porosity and the density of micro-fractures are higher in the weathered zone than observed at SSHCZO. It is possible that both sites are moving toward a balance between rates of erosion and weathering advance, and that higher density of microfractures at the rapidly eroding ERCZO promotes faster water

infiltration and faster weathering advance relative to the more slowly eroding SSHCZO. Further investigation of the origin and role of these microfractures is needed to understand the interplay between climate, erosion, and weathering that controls hillslope weathering profiles.

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GUTIERREZ-JURADO, Hugo - *University of Texas at El Paso*

## The cascading effects of hillslope aspect on the dynamics of water and energy fluxes of the Critical Zone: onto novel instrumental approaches for dryland research.

Hugo A. Gutierrez-Jurado, Huade Guan, Jingfeng Wang, Eddy Banks, Luis A. Mendez-Barroso, Lin Ma, and Lixin Jin.

Hillslope aspect is widely recognized as one of the primary modulators of many Critical Zone processes in areas with complex topography. Variability in aspect within a catchment changes the timing, intensity and duration of the incoming energy and water fluxes that drives hydro-bio-geochemical processes within the soil-vegetation-atmosphere continuum, and thereby imprinting unique dynamics to contrasting aspect-slopes. In this work, we discussed the cascading effects of aspect on the way energy and water are partitioned at different hillslopes using examples from a number of experimental catchments in both the northern and southern hemispheres. In those field sites, innovative approaches to estimate those fluxes using a limited number of standard micrometeorological instrumentation were tested and validated. Insights of seasonally enhanced (diminished) soil evaporation rates dictated by topographic and vegetation cover conditions on equator-facing (pole-facing) slopes affect the availability of water for vegetation use during the dry season. Hence, aspect-induced changes differentially altered the partition of energy within the basins, suggesting a feedback mechanism

that self-reinforces the observed variability of vegetation structure within these landscapes and its differing hydrologic dynamics.

Additionally, the novel instrumentation approach used for this study, especially its advantages and challenges is discussed in light of its potential application for helping understand the energy and water dynamics of current and future Critical Zone Observatories. Particularly, we present a proposed integration of this approach with existing soil and water chemistry monitoring schemes to investigate the effect of irrigation practices on the Critical Zone of dryland riparian areas.

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HAHM, Jesse - *University of California, Berkeley; Eel River CZO*

## Variable Critical Zone water storage capacity constrains ecosystem productivity and resilience to drought in the Northern California Coast Ranges

W. Jesse Hahm, William E. Dietrich, Todd Dawson, Daniella Rempe, Sky Lovill, Alex Bryk, and David Dralle

In Mediterranean climates, winter rains arrive months before peak energy availability in the summer. The Critical Zone (CZ) plays an important role in these regions by storing winter precipitation and making it available for summer ecosystem functioning. In the Franciscan Formation of the Northern California Coast Ranges, mixed broadleaf-coniferous evergreen forest grows adjacent to deciduous-oak savanna and woodlands in an area of similar climate. We show that differences in CZ water storage capacity developed in the underlying lithologic belts of the Franciscan explain this stark contrast in plant community composition. In the Coastal belt turbidite sequences, where water storage capacity can exceed 500mm, an old growth forest transpires through the summer, with roots tapping a deep, seasonally-recharged unsaturated rock moisture zone. In the Central belt melange,

where storage is limited to <200mm, a drought-tolerant deciduous oak (Q. garryana) is the principal tree species in a grass-dominated landscape. Although CZ water storage capacity sets an upper limit on plant productivity in Mediterranean climates, it may also buffer ecosystems from the effects of drought when mean annual rainfall exceeds potential CZ storage; this is the case for the Coastal and Central belts, which both receive ~2000mm of rain annually. We hypothesize that variation around this mean has little effect on growing season productivity, as excess moisture beyond the CZ storage capacity is shed in the winter as stormflow. We test this by exploring the relationship between year-to-year precipitation patterns and ecosystem productivity, inferred from >30 years of Landsat- and Modis-derived Enhanced Vegetation Index (EVI). At both sites, water year average EVI is largely insensitive to water year rain. This suggests a mechanism of forest resilience to California's highly variable inter-annual precipitation, and may explain lack of widespread forest die-off in this region in the recent drought.

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Poster Session II Rm. 5 #47

HALL, Steven - *Iowa State University; Luquillo CZO*

### Finding the "missing" cations: biogeochemical mechanisms that liberate occluded nutrients from highly weathered soils

Steven J. Hall, Ann E. Russell, and James W. Raich

The cations potassium (K), calcium (Ca), and magnesium (Mg) potentially co-limit plant productivity in highly weathered soils, yet biogeochemical controls on cation availability have received much less attention than for nitrogen and phosphorus. During soil development, cations are leached and occluded within secondary minerals or organo-mineral co-precipitates. Accessing these "occluded" cations may be critical for sustaining nutrient demand. In La Selva, Costa Rica, four tree species were planted on a common soil (degraded pasture) in a replicated experiment. After 25 years, cation stocks in biomass differed across species by 1.9-, 2.8-, and 3.5-fold for Ca, K, and Mg, respectively. Differences could not be explained by differential depletion of exchangeable cations, atmospheric deposition, or primary mineral weathering, implying that cations were released from "occluded" pools.

Alteration of the geochemical state variables Eh and pH may have contributed to differential cation availability—hypotheses supported by work in the Luquillo Critical Zone Observatory, Puerto Rico. Reduction of iron (Fe) in surface soil anaerobic microsites can increase pH, disperse colloids, and solubilize organic matter and P sorbed or occluded within short-range-ordered (SRO) Fe phases. These mechanisms could also potentially release cations. Surface soils were assayed for cations and reduced and oxidized Fe (Fe(II) and Fe(III), respectively) in weak acid (0.5 M HCl) extractions. On ridges, Fe(II) and Fe(III) were the strongest single predictors of K, Ca, and Mg (R2 0.57 - 0.75). Calcium and Mg decreased with Fe(III), while K, Ca, and Mg increased with Fe(II). These trends are consistent with cation occlusion within SRO Fe phases, and release following Fe reduction. In incubation experiments, Fe reduction correlated with increased cation concentrations. Elaboration of the mechanisms that provision cations to plants in highly weathered soils remains a critical knowledge gap.

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Presentation   8:00am Tue

HAMBURG, Steven - *Environmental Defense Fund*

### The practitioner's perspective: Value of critical zone science for environmental management and protection.

important factor controlling soil C. This study highlighted the importance of accurate hydrological modeling to ecosystem simulations.

HARMAN, Ciaran - *Johns Hopkins University; National Office*

## The control of critical zone architecture on water age and storage selection functions in hillslopes.

HE, Yuting - *Pennsylvania State University; Susquehanna Shale Hills CZO*

## Observing and simulating spatial sariations of forest carbon fluxes and stocks in complex terrain

Yuting He, Kenneth J. Davis, Yuning Shi, David M. Eissenstat, Jason Kaye, Margot Kaye, and Henry Lin

Terrestrial Carbon (C) cycle remains the least constrained component in the global C cycle, partly due to the difficulty in quantifying C sources and sinks in complex terrain. In this paper, we used observations at Shale Hills Critical Zone Observatory and a biogeochemistry model - Biome-BGC to study the spatial distribution of C stocks in a first-order watershed. With only three model parameters adjusted, Biome-BGC could represent the average C pools and fluxes in the watershed. The model was also able to generate the spatial patterns of C pools in the watershed, with higher vegetation C and soil C in the valley and lower C on the ridge-top, although the model underestimated the spatial contrast along the topography. We also explored the environmental causes (i.e. soil moisture, soil temperature, N availability and solar radiation) of the spatial distribution of C pools. Among the four factors, soil water and N availability interacting with each other, dominated the spatial distribution of above-ground biomass. Soil water was also the most

HECKMAN, Christopher - *University of California, Santa Barbara; Southern Sierra CZO*

## How soil water storage moderates climate changes effects on transpiration, across the different climates of the Critical Zone Observatories

Christopher Heckman, and Christina (Naomi) Tague

While the demand side of transpiration is predicted to increase under a warmer climate, actual evapotranspiration (AET) will be moderated by the supply of water available to vegetation. A key question to ask is how will plant accessible water storage capacity (PAWSC) affect the partitioning of precipitation between AET and runoff. Our results indicate that whether AET increases or decreases, and how much, is significantly based upon interactions between PAWSC and characteristics of precipitation such as the amount, frequency, and skew as well the partitioning between rain and snow. In snow dominated climates, if PAWSC cannot make up for the loss of storage as snowpack then AET could decrease, and in rain dominated climates, PAWSC could significantly limit the increase in AET. These results highlight the importance of critical zone research: constraining PAWSC is critical in predicting not only the magnitude but also the direction of the change in AET with climate warming. Due to the highly heterogeneous nature of PAWSC and the difficulty of measuring it across large scales, we use a well-tested hydrologic model to estimate the impacts from a range of PAWSC on the partitioning of precipitation between runoff and AET. We completed this analysis for the range of precipitation and vegetation characteristics found across 9 of the Critical Zone Observatories.

HIDY, Alan - *Lawrence Livermore National Laboratory*

## Measuring 7Be with AMS and the potential for large datasets

Alan Hidy, Susan Zimmerman, and Zachary Kayler

The short-lived fallout radionuclide 7Be is a powerful tracer of soil and watershed processes over short timescales (days to <2 years), and particularly useful for examining the effects of climate and land-use activities on fluxes of sediment and nutrients. Recent work has demonstrated the potential of 7Be as a tool for investigating rates of soil erosion, establishing watershed sediment budgets, and fingerprinting runoff and suspended sediment. However, the current method for measuring environmental 7Be is by gamma counting, which requires large sample sizes and long measurement times (1-2+ days counting per sample). These logistics are prohibitive of large datasets and low-level measurements. Recently, an accelerator mass spectrometry (AMS) capability for 7Be has been developed at the CAMS facility at Lawrence Livermore National Laboratory. This approach can measure ultra-trace levels of 7Be (detection limit of ~1000 atoms) with high precision, and measure dozens to hundreds of samples in less time than it takes to gamma count a single sample. Thus, AMS offers the potential to increase sample throughput and decrease sample size both by more than an order of magnitude.

HINCKLEY, Eve-Lyn - *Institute of Arctic and Alpine Research; Boulder Creek CZO*

## New directions in CZO biogeochemistry: Mechanisms controlling the fate and transport of nitrogen in the Colorado Front Range

Eve-Lyn Hinckley, Youchao Chen, Chiara Forrester, and Anna Hermes

Several decades of research have demonstrated that humans have more than doubled the amount of reactive nitrogen (N) cycling through air, land, and water systems. There is increasing recognition that not only demand of biological sinks, but integrative ecological, hydrological, and physical factors within the critical zone (CZ) control the residence time of N in terrestrial ecosystems, particularly in high-elevation regions. Previous research by members of our group explored the fate of atmospheric N deposition in the high montane catchment of the Boulder Creek Critical Zone Observatory (BcCZO), and found stark contrasts in the movement of water and N on north- versus south-facing aspects. In the next phase of our research, we are conducting a series of studies to explore mechanisms controlling these patterns of N retention and transport within the CZ, and expanding our focus to include not only the high montane zone of the BcCZO, but also sub-alpine and alpine zones of the Niwot Ridge Long-term Ecological Research site, where the effect of aspect breaks down. Specifically, we are (1) evaluating the roles of temperature and moisture in controlling N cycling processes (net N mineralization and nitrification) in different plant communities across the elevation gradient, and exploring how shifts in these drivers may influence N cycling under climate change; (2) determining the influence of spring fungal blooms on N mineralization, immobilization, and residence times; and (3) extending our coupled hydro-biogeochemical studies conducted at the BcCZO to the alpine, where we are using field and modeling approaches to scale the fate and transport of N from vegetation patches to

the catchment. This presentation will outline our next wave of research and present preliminary results. Ultimately, these studies will continue to build our understanding of N cycling in a multi-disciplinary context and improve predictions of how ecosystems will respond to global change drivers.

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HOCKADAY, Bill - *Baylor University*

## Influences of kerogen-rich bedrock on the molecular and isotopic composition of soils; implications for the carbon cycle

Todd L. Longbottom and William C. Hockaday

Ancient sedimentary organic matter (kerogen) represents the largest terrestrial organic carbon (OC) reservoir on earth and is vulnerable to remineralization upon exposure to earth's atmosphere during the oxidative weathering of sedimentary rocks on the continents. Anthropogenic activities have enhanced the continental weathering and denudation rates by several orders of magnitude. Despite the potential for large carbon-cycle implications, the mechanism of kerogen transformation by oxidative weathering and flux values are not well-constrained in contemporary models of the global carbon cycle. The weathered residuum of organic-rich sedimentary rocks serves as the parent material for many soils. Therefore, some aspects of the chemical structure and biogeochemical cycling of the soil organic matter are likely to be inherited from the bedrock. We used a combination of solid-state 13C nuclear magnetic resonance (NMR) spectroscopy, and carbon isotope techniques to describe molecular and isotopic changes that occur throughout oxidative weathering of marine kerogens, and the subsequent formation of modern soils, in two outcropping Cretaceous mudstones of the Eagle Ford and Pepper Formations in Central, Texas. Gradational production of O-containing functionalities was observed, coupled with reductions in characteristically abundant polymethylenic components of marine kerogen. Organic matter structural parameters, derived from

NMR experiments, also provide the basis for a novel weathering index that accounts for the degree of post-sedimentary diagenetic alteration of kerogen samples along the bedrock-soil continuum. Vulnerability of ancient OC under climatic shifts in temperature and/or precipitation is discussed.

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HODGES, Caitlin - *University of Georgia; Calhoun CZO*

## Seasonal variation in the potential for iron reduction in soils of the Calhoun CZO

Caitlin Hodges, John Mallard, Daniel Markewitz, and Aaron Thompson

Soil Iron reduction influences ecosystem form and function by altering the cycling of carbon, nutrients, and trace elements in both the aqueous and solid phases. Nearly all of our understanding of soil iron reduction comes from work on seasonally or continuously inundated soils. However, a growing body of work indicates that iron reduction can be a pivotal process in upland soils that experience dynamic redox conditions. We hypothesized that in upland soils, iron reduction intensity and prevalence would be affected by seasonal variations in soil moisture. We tested this by delineating the spatial and temporal distribution of the potential for iron reduction to 70 cm depth in upland forested watersheds at the Calhoun CZO using rusted steel "Indicators of Iron Reduction in Soil" (steel IRIS) probes, and non-invasive moisture sensing at three time-points over the course of a year: (a) after an extreme rainfall event in October 2015; (b) during the end-of-winter warming in March 2016; (c) and during a period of high evapotranspirational demand in June 2016. Our results indicate that the potential for iron reduction varied with depth and intensity over the year. Iron reduction was greatest at depth (40 – 60+ cm) following a rainfall event that generated prolonged subsurface soil saturation; whereas iron reduction was greatest near the

surface (0 – 30 cm) in late winter/early spring when biological oxygen demand was likely high due to labile carbon and soil warming. In June 2016, the potential for Fe reduction was low across all depths but the deepest. Our results indicate that soils of the Southeastern Piedmont likely experience strong seasonal trends in Fe reduction, as well as periodic spikes in response to large rain events. Our work illustrates that the biogeochemical functioning of oxic upland soils are likely to be shaped by Fe reduction processes at various points throughout the year.

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HOLBROOK, Steve - *University of Wyoming*

## Geophysical constraints on deep CZ structure and processes

Steve Holbrook

A major challenge in understanding the critical zone (CZ) is measuring deep CZ properties over its full depth range and at landscape scales.  The deep CZ is inaccessible except through (expensive) drill holes, (random) roadcuts and geophysics. Geophysics can image the deep CZ across scales and across gradients in climate, lithology, topography, biology and states of stress. Here I present insights into deep CZ structure through the lens of geophysical data (surface and borehole) acquired at 6 CZO's.

Although the critical zone is often defined as extending from the top of vegetation to the lower limits of groundwater, the "lower limits" of groundwater are difficult to define and much deeper than typical processes of interest. I adopt a different definition: The critical zone comprises surface ecosystems and subsurface material whose bulk chemical and physical properties are altered by virtue of a connection to Earth's surface. This definition inherently links the CZ to surface processes and captures the connections between surface ecosystems and subsurface properties. I will show geophysical evidence that there is a perceptible zone, 40-50 m thick in places, where

these connections are manifest in physical and chemical properties.

Our results show: (1) Chemical weathering initiates deep in the CZ, in concert with mechanical weathering (opening of fractures). While plagioclase weathering begins at the base of fractured bedrock, the major porosity boundary occurs at the base of saprolite. (2) The ambient stress field (tectonic + topographic stress) may control weathering (both physical and chemical) and porosity in the CZ, especially at sites underlain by crystalline bedrock. (3) Local geological factors, however, can complicate or overwhelm these simple patterns, however: at the Catalina CZO a strong north-south aspect asymmetry is explained by the dip of metamorphic foliation, and at the Reynolds Creek CZO regolith is much thicker in basalt than in granite.

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HOOPER, Rick - *Tufts University*

## The National Water Model as a Hydrologic Modeling Framework for the Critical Zone

Richard Hooper and Alva Couch

The National Water Model (NWM) is a high-resolution continental-scale hydrologic model being developed by the US National Weather Service, to make comprehensive water resource forecasts including forecasting floods, droughts, and water quality. A unique attribute of the NWM is its discretization of the landscape into catchments draining into each of the 2.7 million stream reaches defined by a reference hydrography (the National Hydrography Dataset Plus); the average area of these reach catchments is 3 km2. This discretization allows the dominant streamflow generation processes for each reach to be considered independently and attributes relevant to hydrologic properties such as flowpaths to be calculated more directly than other landscape discretization approaches such as grids based upon computational

requirements or nested catchments defined by successive downstream pour points.

We wish to explore whether the NWM and its use of reach catchments will be more effective than existing modeling frameworks for
* Converting conceptual models into quantitative process models because the landscape units are meaningful
* Transferring streamflow generation processes from headwater catchments to higher order catchments
* Making quantitative comparisons of dominant streamflow generation processes among experimental watersheds, and
* Transferring research findings to operational models.

We will initially focus on humid basins where the groundwater is expected to be extensive and well connected to the stream. In addition, we wish to employ a data-centric approach to infer groundwater-surface water interactions rather than imposing a Richards-Darcy framework; in other words, we will treat the groundwater as unobservable and infer its behavior from hydrometric and tracer measurements made at multiple points in the river basin, This data centric focus will provide feedback to the field programs indicating where more data would be most valuable.

Poster Session I Rm. 6 #24

HUANG, Mong-Han - *Jet Propulsion Laboratory*

## Imaging subsurface properties along and across soil-mantled ridges

Mong-Han Huang, Mariel Nelson, Kristen Fauria, Alexander Bryk, and William E. Dietrich

The elevation of unweathered bedrock beneath hillslopes (Zb) is a dynamic subsurface boundary. Theory suggests that the position of Zb across a hillslope could be influenced by hydraulics of groundwater, regional stress state, and physical and chemical weathering processes. Although this subsurface region plays an important role in the ecosystems by influencing the water storage and runoff, direct measurement of Zb along hillslopes and the hydraulic properties within this region reminds difficult. We aim to use geophysical tools to probe Zb and understand the dominated process that controls Zb in soil-mantled hillslopes. Our study area is in a predominantly soil-mantled hill landscape north of the Cortina Ridge near Williams, CA. Most of the Mesozoic bedrock is roughly N-S in strike and east in dip. We use LiDAR based Digital Elevation Model to characterize surface geomorphology and shallow seismic refraction to image subsurface structure along and across the ridges. Preliminary cosmogenic dating in sediment deposits in the valley shows ~0.1 mm/yr long-term exhumation rate. By assuming steady state and a nonlinear sediment transport law, the estimated soil diffusivity is ~$2\times10^{-2}$ m2/yr. Results of shallow seismic refraction here show a change of velocity gradient when the seismic velocity is ~2000 m/s. The depth of this velocity transition could indicate the depth to Zb, implying a change in rock properties such as fracture density, rock moisture, chemistry, etc. Our surveys show that the depth to Zb generally increases upslope to the hillslope divide. We use an analytical model for groundwater drainage in fresh bedrock to predict Zb depth along seven hillslopes, and find that saturated hydraulic conductivity of ~$10^{-11}$-$10^{-12}$ m/s successively predicts the general trends. This result suggests that a long-term hydrologic interaction with bedrock controls the boundary between weathered-to-unweathered bedrock along hillslopes in this region.

HYNEK, Scott - *USGS*

## Streams as integrators of landscape processes: An example from the Upper Colorado River Basin

Scott Hynek, Ryan Rowland, Diego Fernandez, and David Susong

The Colorado River is a critical source of water for ~50 million people in the southwestern United States. Active management of salinity in the river is a priority economic target with direct impact on infrastructure, agriculture, industry, and human consumption.  Landscape management decisions aimed at reducing salinity rely upon firm knowledge of solute sources.  Nonpoint source salinity dominates much of the basin, and knowledge of processes and geologic units that yield salinity is of high priority to federal agencies that guide land management practices in the basin.  As such, we have initiated a case study of two parallel streams which cross an anticline of exposed Mesozoic marine strata.  Synoptic sampling of these streams during baseflow and stormflow conditions provides insight into solute sources.  Both streams have comparable baseflow salinity loads, of which ~60% of the mass is dominated by sulfate.  Using a combination of elemental ratios and isotopic compositions (B, SSO4, Sr), we are able to identify at least three geologic units that are important solute sources. Conventional wisdom suggests that the Cretaceous Mancos Shale is the dominant solute source. This largely holds for the San Rafael River where the majority of solutes are derived from areas of agricultural land use upstream of the anticline with minor contributions from the Triassic Moenkopi Formation in the core of the anticline.  For Muddy Creek, evaporite deposits of the Jurassic San Rafael Group contribute the majority of solutes from rangeland within the anticline.  Solute sources for both streams during a regional scale storm event are dominated by evaporite deposits of the San Rafael Group.  The combination of Cl/Br with SSO4 and Sr isotopes clearly identify an important new geologic

source unit for salinity in the Upper Colorado River Basin and focus salinity related land management decisions away from agricultural land use towards potential mitigative actions on rangeland.

JAIMES, Aline - *Texas A&M University*

## Texas Water Observatory - Utilizing advanced observing system design for understanding water resources sustainability across climatic and geologic gradients of Texas

Aline Jaimes, Nandita Gaur, Mark Everett, Gretchen Miller, Georgianne Moore, Christine Morgan, Michelle Lawing, and Binayak Mohanty

The Texas Water Observatory (TWO) is a new distributed network of field observatories in the critical zone across Texas (starting at Brazos corridor) designed to improve the spatiotemporal understanding of the energy, carbon, and hydrologic cycles. The climatic and geologic gradient combined with the mosaic of land uses (cultivation agriculture, range/pasture, forest) comprised in South-Central Texas are critical to investigate the sensitivity and resilience of fertile soils and the ecosystems goods and services relative to the increasing water demand of 50 million habitants of Texas and the Gulf States. TWO is a four-prong initiative: Observatory network, Data portal, Modeling Systems, Analyses, and data assessment. Following standard protocols of national and international environmental networks, TWO will develop and maintain web-based data access portal, real-time web query, data retrieval, normalization, analysis, and interpretation. Our goal is to build a versatile platform that allows for easy interfacing across networks (Ameriflux, CZO, NEON, Oklahoma Mesonet, etc.). The Texas Water Observatory would integrate surface and groundwater fluxes and decision-making modeling; apply, test and refine existing biophysical models; develop modeling software and provide technical assistance on problems related to models. Application of these Texas Water Observatory

models for decision makers would provide critical data on climate, surface and groundwater resources, water quality, and threats to water supplies.

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JIANG, Peishi - *Intensively Managed Landscapes (IML) CZO*

## A Service-Oriented Architecture for coupling web service models using the Basic Model Interfaces (BMI)

Peishi Jiang, Mostafa Elag, Praveen Kumar, Scott Peckham, Luigi Marini, and Rui Liu

Coupling models from different domains (e.g., ecology, hydrology, geology, etc.)is usually difficult because of the heterogeneity in operating system requirements, programming languages, variable names, units and tempo-spatial properties. Among multiple solutions to address the issue of integrating heterogeneous models, a looselycoupled, serviced-oriented approach is gradually gaining momentum. By leveraging the World Wide Web, the service-oriented approach lowers the interoperability barrier of coupling models due to its innate capability of allowing the independence of programming languages and operating system requirements. While the serviceoriented paradigm has been applied to integrate models wrapped with some standard interfaces, this paper considers the Basic Model Interface (BMI) as the model interface. Compared with most modeling interfaces, BMI is able to (1) enrich the semantic information of variable names by mapping the models internal variables with a set of standard names, and (2) be easily adopted in other modeling frameworks due to its framework-agnostic property. We developed a set of JSON-based endpoints to expose the BMI-enabled models as web services, through storing variable values in the network common data form file during the communication between web services to reduce network latency. Then, a smart modeling framework, the Experimental Modeling Environment for Link- ing and Interoperability (EMELI), was enhanced into a web application (i.e., EMELI-Web) to integrate the BMI-enabled web service models in a user-friendly web platform. The whole orchestration was then implemented in coupling TopoFlow components, a set of spatially distributed hydrologic models, as a case study. We demonstrate that BMI helps connect web service models by reducing the heterogeneity of variable names, and EMELI-Web makes it convenient to couple BMI-enabled web service models.

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JIN, Zhao - *Institute of Earth Environment, Chinese Academy of Sciences*

## Effects of filling gullies to create farmland on water table rise and soil salinization in the Loess Plateau of China

Zhao Jin, Yunlong Yu, Yunqiang Wang, Henry Lin, Guangchen Chu, and Jing Zhang

In recent years, a large project called "filling gullies to create farmland" has been implemented in Yan'an City of Shaanxi Province, China. Filling gullies to create farmland involves removing soil from the surrounding hill slopes and using this material to fill gully channels. The flat fields created in the channels are used for cultivation to increase farmland area. However, the environmental and ecological effects of this project have not been fully evaluated. In this study, we examined the effects of filling gullies to create farmland on water table rise and soil salinization. We found that most of the investigated farmlands experienced a water table rise; the soil depth, which is obviously influenced by the groundwater table, was less than 3 m, and only 3 sites had a groundwater table deeper than 4 m. Moreover, reservoirs (dams) built along the gully channel were found to have a significant impact on the water table rise of the near-dam farmlands. The closer the farmland is from the reservoir, the greater is the impact on farmlands with respect to water table rise. The results demonstrate that the farmland soil is alkaline and that approximately one-third of the farmlands suffer from light salinization. If the groundwater is not well managed, the salinization

trend will be accelerated. Ion analyses show that Na+ and SO42- are the major saline ions in the water bodies and that the concentrations of Cl- have increased in the salinized soils. We conclude that water table rise is the primary factor that leads to soil salinization. Considering the risk of soil salinization in the newly created farmlands, we suggest that groundwater management, such as establishing effective drainage facilities, is essential to the success of the project "filling gullies to create farmland".

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JOHNSON, Chris - *Syracuse University*

## The biological Si filter in temperate hardwood forest ecosystems

Chris E. Johnson, Wim Clymans, and Daniel J. Conley

In terrestrial ecosystems, a large portion (20-80%) of the dissolved Si (DSi) in soil solution has passed through vegetation. While the importance of this 'terrestrial Si filter' is unquestioned, few data exist on the pools and fluxes of Si in forest vegetation and the rate of release of Si from decomposing plant tissues.
Previous work suggested that the decomposition of CWD may have significantly contributed to the excess DSi reported in stream  waters following experimental deforestation of Watershed 2 at the Hubbard Brook Experimental Forest (HBEF) LTER site in New Hampshire, USA. We quantified the pools and fluxes of Si through vegetation and coarse woody debris (CWD) in the hardwood forest ecosystems of the HBEF. We found that Si in woody biomass (wood + bark) and foliage account for approximately 65% and 31%, respectively, of the total Si in biomass at the HBEF. Our budget calculations suggest that a minimum of 50% of the DSi annually produced in the soil of a biogeochemical reference watershed derives from biogenic Si (BSi) dissolution. The major source is fresh litter, while only ~2% comes from the decay of CWD. Deforestation of W2 resulted in significant

increases in DSi export from the watershed, which have continued for 50 years. Decay of dead tree boles could only account for 9% of the excess DSi release observed following the experimental deforestation of W2. Our data suggest that disruption of tree growth resulted in the leaching loss of DSi that would normally have been taken up by the trees. Dissolution of BSi in forest floor soils is the main source of DSi in soil solution. However, the persistent excess DSi losses from W2 50 years after deforestation suggest a fundamental alteration in mineral weathering and/or secondary mineral formation processes. Further investigation of terrestrial Si cycling at CZO and LTER sites represents an interesting opportunity to study the linkages between ecological and geochemical processes.

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KANDASAMY, Selvaraj - *Xiamen University*

## Insolation-driven, monsoon-mediated changes in Earth Surface Processes in mid-latitude China since the late deglacial interval

Selvaraj Kandasamy, Jianbao Liu, Baozhi Lin, Qianqian Liu, Huawei Wang, and Fahu Chen

Here we reconstruct erosion-weathering-vegetation interactions since the late deglaciation (~14.7 ka) using geochemical records of a radiocarbon-dated sediment core from Gonghai Lake in the monsoon-arid transitional zone of North China. Detrital (Al, Ti, K, Rb) and authigenic (Ca, Sr) elemental records revealed a distinct late deglacial-Holocene pattern with the former elements show higher values in warm intervals due to increased influx of highly weathered fine sediments, and vice versa. Chemical Index of Alteration (CIA) molar, a humidity proxy of mid-latitude East Asia, indicate low humidity during the late deglacial ~11.5–14.7 ka, high humidity during the early-mid Holocene ~11.5–3.2 ka, and intermediate humidity during the late Holocene interval since ~3.2 ka. Such millennial-scale humidity patterns correspond with the changes in pollen-based mean annual precipitation (PANN), the

variations in East Asian monsoon strength, the changes in solar insolation, and the changes in the western Pacific sea surface temperatures, indicating orbitally-forced humidity changes in mid-latitude East Asia. Cross-spectral analysis of geochemical and PANN records revealed a 1400-yr periodicity of spectral power, confirming that the humidity in mid-latitude East Asia (China) was primarily controlled by the fundamental and/or derived modes of solar forcing. Earth surface processes reconstructed here further provide evidence that the functionality of critical zone mechanism has been deviated with the decreasing insolation at ~1.9 ka in the mid-latitude East Asia, although the role of human impact on this decoupling is unknown.

KARWAN, Diana - *University of Minnesota; Christina River Basin CZO, Susquehanna Shale Hills CZO*

## Short term fallout radionuclides track mixing and transport in the Critical Zone

Diana Karwan, Jim Pizzuto, Rolf Aalto, and Susan Brantley

Short-term radionuclides, such as Beryllium-7, Lead-210, and Cesium-137 (7Be, 137Cs, 210Pb) provide numerous insights into Critical Zone processes. We present examples of studies using these isotopes to quantify age and time of critical zone processes in CZOs. First, fallout radionuclides and their ratios associated with precipitation and suspended sediment were used to determine suspended sediment source and age in the Christina Basin CZO. Single-event deposition of 7Be varies from 29 – 177 Bq m-2 and 210Pbxs varies from 2 – 16 Bq m-2. 7Be/210Pbxs ratios vary from 2.5 to 17.0 in precipitation and from 0.8 to 12.8 on suspended sediment. Over a series of events, age dating indicates suspended sediment during summer thunderstorms (age = 21 days) was significantly younger than during hurricanes (age = 110 days). Isotope mass balance models indicate a different

source of these sediments, with suspended sediment resulting from in-channel mobilization during thunderstorms.  However, during hurricanes, some of the suspended sediments resulted from watershed landscape erosion.

Second, 137Cs and 210Pb have been used to locate and date areas of mixing and sediment mobilization within the Critical Zone in Shale Hills CZO. Based on total 137Cs fallout estimates, SSH CZO received 4000 – 6000 Bq/m2 137Cs during atomic weapons testing in the mid-twentieth century (c. 1954 – 1964). The total inventory in a mid-slope planar profile confirms this activity. However, swale transects in a similar slope position have a lower inventory, indicating net erosion since fallout. 137Cs also indicates soil mixing and erosion in mounds associated with older upturned trees, for which the bole is no longer intact. With a total inventory of 850 Bq/m2 and consistent vertical pattern of low concentration through the entirety of the mound, 137Cs profile implies the tree throw occurred after c.1963. These results narrow the time estimate of disturbance provided by other chemical makers.

KELLY, Gene  - *Colorado State Univ. & NEON*

## Enhancing continental-scale understanding of soils: Integrating the National Ecological Observatory Network (NEON) with existing research networks to address global change

Gene Kelly, Hank Loescher, and Michael Kuhlman

either vegetation health or streamflow runoff to a warming climate. Through this, key research challenges are summarized to help advance collective knowledge on this topic.

KLOS, Zion - *UC Santa Barbara & UC Merced; Southern Sierra CZO*

## Plant accessible water in the subsurface of mountain landscapes within Mediterranean climate-types: Insights gained from the Southern Sierra Critical Zone Observatory

P. Zion Klos, Roger C. Bales, Asmeret Asefaw Berhe, Martha H. Conklin, Michael L. Goulden, Stephen C. Hart, Peter Hartsough, W. Steven Holbrook, A. Toby O'Geen, Clifford S. Riebe, Mohammad Safeeq, and Christina L. Tague

Research on plant accessible water in the subsurface, and the processes controlling reservoirs and stores of this water, helps elucidate the coupled dynamics of biogeochemical and physical processes within the critical zone. Here, we summarize our view of this integrated system to share current advances in knowledge about these subsurface reservoirs and stores of water, and to showcase their particular importance and implications for semi-arid, Mediterranean climate-type, mountain ecosystems under a changing climate. We use insights gained from both the broader literature and a case study of the Southern Sierra Critical Zone Observatory to: (1) Define the reservoirs (void spaces) and stores (held quantities) of water in the subsurface of mountain landscapes – including a hierarchy from total pore space available for water storage to what is actually available and extracted for use by plants; (2) Discuss the spatial and temporal patterns of these reservoirs and stores within a site and across the landscape – using overlaps of in-situ, geophysical, and remotely sensed techniques and datasets; (3) Elucidate the mechanisms that give rise to these patterns over varying time scales – focusing on a synthesis of recent advances in the literature; and (4) Highlight the implications of these patterns and mechanisms for both the management of natural resources and advancement of critical zone science – showing how more or less subsurface storage capacity can create associated trade-offs between the vulnerably of

KORMOS, Patrick - *ARS-USDA; Reynolds Creek CZO*

## More rain and less snow at the Reynolds Creek CZO

Patrick Kormos, Danny Marks, Mark Seyfried, Kathleen Lohse, Scott Havens, and Andrew Hedrick

Precipitation phase depends on the temperature and humidity conditions during storms. At the Reynolds Creek CZO and much of the mountainous western U.S, precipitation falls when surface dew point temperatures are close to 0 °C. Therefore small changes in humidity conditions may have large impacts on the seasonal snow cover. Spatially distributed precipitation volume, air temperature, and relative humidity data provide the foundation for basin-integrated values of precipitation, phase, and humidity. Thirty-one years of hourly precipitation, temperature, and humidity data over the Reynolds Creek Experimental Watershed and CZO are used to track changes over the period of record. Our analysis shows that the proportion of the watershed that is snow-dominated has declined, the rain snow transition zone has increased in elevation, and while RCEW was initially snow-dominated, it is now dominated by mixed phase precipitation and rain.

LEFTICARIU, Liliana - *Southern Illinois University; Intensively Managed Landscapes (IML) CZO*

## Dynamics of the water/ soil system in an agricultural catchment of the Midwestern U.S.

Liliana Lefticariu

Intensively Managed Landscapes (IML) are regions where anthropogenic transformations have produced major changes of the natural systems, including altering the cycles of water, sediments and nutrients, thus affecting their vulnerability and resilience. Most of these transformations are driven by water movement and, therefore, it is important to evaluate the contribution of precipitation, evapotranspiration, surface water runoff, groundwater, and soil water to the local water budget in both non-cultivated and agricultural systems.

For the past 5 years, we have measured the stable isotope composition of individual precipitation events in Southern Illinois. Factors that may affect stable isotope composition of precipitation include the source of moisture, temperature, and local distillation and evaporation processes. To better understand the temporal variation in the contribution of different precipitation sources in our area, the isotope data were integrated with climate parameters as well as HYSPLIT modeling. We find that moisture originating from local recycled water driven in part by land surface moisture availability for evapotranspiration has been a major component to local precipitation. Concurrently, increasing average temperature is found to coincide with significant trends in precipitation intensity and frequency as well as isotope patterns of precipitation events.

Future work on this project will include investigating trends in soil water dynamics in a catchment in Southern Illinois with the main goal to produce a soil water dynamics model that can be extrapolated to

the Midwest United States. Since in the Midwestern US most of the surface water is stored in soil and vegetation, changes in the amount as well as transfer rates among these reservoirs can have a significant effect on the regional land-atmosphere water fluxes with direct implications on critical zone functions and economic activities.

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LEON, Miguel - *University of Pennsylvania; Luquillo CZO*

## CZO common measurement network data products and a cross-CZO data repository proof of concept

Miguel Leon, Luigi Marini, Colin Bode, Jeri Fey, Matej Durcik, Dan Shapich, Xiande Meng, Eric Parrish, Susan Parsons, and Rick Book

The CZO Data Managers Committee is developing a set of CZO Network Data Products to be made available at criticalzone.org. The planned network products include data for stream chemistry, precipitation and throughfall, eddy correlation flux tower measurements for carbon and water exchange, soil measurements for chemistry, vadose zone gas chemistry, water content, electrical conductivity, temperature, carbon and other biogeochemical measurements. Some of these CZO Network Data Products will also be incorporated into a cross CZO Data Repository proof of concept. This proof of concept will include versions of several CZO supported data management systems including ODM2 Admin (Luquillo CZO), Dendro (Eel CZO), Geodashboard (IML CZO), Clowder (IML CZO) and possibly others. These systems will be deployed in a central location so that CZOs can learn about each other's data, technologies, and workflows. The proof of concept will also help inform requirements for a successor cross CZO Data Repository based on feedback and lessons learned.

LI, Li - *Pennsylvania State University; Susquehanna Shale Hills CZO*

## Integrating data, models, and disciplines in Critical Zone Science using process-based modeling

Li Li, Susan Brantley, Pamela Sullivan, Chris Duffy, Chen Bao, and Peyman Heidari

The past decades have witnessed rapid advances in unprecedented generation of novel data for earth processes varying from scales as small as nanometers to those as large as the globe (i.e., remote sensing from satellites). Data collection has become increasingly coordinated through research community networks including the Critical Zone Observatories (CZOs), the Long-Term Ecological Research (LTER), the Great Lake Ecological Observatory Network (GLEON), the U. S. Geological Survey (USGS), and the National Ecological Observatory Network (NEON), many of which are supported by NSF. Such a luxury of rich data presents significant opportunities for understanding complex earth processes.

In parallel, process-based models have advanced at different complexity levels. These models allow integration and differentiation of distinct processes, thus providing a way to identify critical processes that drive system response to external forcings. They can be used to serve as a repository of knowledge, to optimize observation system design, and to carry out numerical experiments under conditions where data are not available, thereby expanding forecasting capabilities beyond measurement limitations.

Here we will present two examples of using process-based modeling tools for integrating data and models, and for understanding CZ processes. The first example uses a reactive transport model CrunchFlow to understand chemical weathering and soil formation at geological time scales. The second example uses a watershed hydrobiogeochemical model to identify key processes that drive chemostatic and chemodynamic behavior in stream chemistry at hydrological time scales.

We advocate for coordinated modeling efforts to integrate data across disciplines and across sites under a variety of climate, ecosystem, and geology conditions. We hypothesize that coordinated efforts will lead to understanding of general principles that govern CZ processes and will advance CZ sciences.

LIN, Henry - *Pennsylvania State University; Intensively Managed Landscapes (IML) CZO, Susquehanna Shale Hills CZO*

## Toward a global network of Critical Zone Observatories

Henry Lin, William E. Dietrich, Praveen Kumar, Daniel Richter, Harry Vereecken, Tim Filley, Susan Trumbore, Suzanne Anderson, Susan Brantley, Steve Banwart, Bojie Fu, Jerome Gaillardet, Congqiang Liu, Dirk Mallants, William McDowell, Mingan Shao, Joerg Voelkel, Tim White , and Yongguan Zhu

The Earth's Critical Zone (CZ) offers a unifying framework for understanding diverse and complex surface and near-surface processes in terrestrial ecosystems. Given the emerging global interests in CZ science and investments in Critical Zone Observatories (CZOs), it is timely to discuss key issues to guide the development and operation of a global network of CZOs. We call upon the international CZ community to collectively address shared key questions of broad significance and raise the level of CZ research from place-based to principle-based. A global network of CZOs can provide physical, digital, and human infrastructures for interdisciplinary investigations of complex interactions and feedback among rocks, soils, water, air, organisms, and human activities across space and time. While many characteristics of CZOs exist that are evolving, common emphasis on three foci signifies unique contributions of CZOs in terrestrial environmental research: 1) deep time from

instantaneous to geologic, 2) deep depth from vegetation canopy to weathered bedrock, and 3) deep coupling across biotic and abiotic processes. Fundamentally, it is the integration of hydrology, pedology, ecology, geology, geomorphology, geophysics, geochemistry, geobiology, and other related bio- and geosciences at multiple spatial and temporal scales and across natural to managed landscapes that is key to advancing CZ science. A global network of CZOs can deepen our understanding of the structure, function, and evolution of the CZ and its services to ecosystems and humanity. Three levels of comparative studies using a global network of CZOs are suggested in this paper, along with perspectives from countries currently active in pursuing CZ research, including the U.S., E.U., Germany, France, China, and Australia. Collectively, these efforts can forge a new thinking in global comparative studies, terrestrial model inter-comparisons, innovative data sharing, as well as new discoveries of the Earth's CZ.

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LIN, Yu-Feng - *University of Illinois at Urbana-Champaign; Intensively Managed Landscapes (IML) CZO*

## The investigation of thermogeology in the Critical Zone

Yu-Feng F. Lin and Andrew J. Stumpf

Understanding subsurface heat transport processes, which are impacted by the geological background, groundwater flow, atmospheric conditions and Earth's deep thermal profile greatly impact the stocks and fluxes of carbon (C) in critical zone. Soils and sediments are the largest reservoir of C, and the rate of microbial decomposition is dependent upon the moisture and thermal conditions. But there is a paucity of data that document shifts in subsurface temperature, especially in the "deep critical zone" or below 10 m from the ground surface. Our previous studies suggest that temporal changes are more dynamic than once thought. Thermal variations can potentially cause changes in physical, mechanical,

microbiological, and chemical properties, and in the subsurface water quality.

To predict and evaluate the thermal impact or contribution, high spatial resolution thermal properties and basic physical properties of the soil and sediments were acquired. In this study, located in the Intensively Managed Landscapes-Critical Zone Observatory of central Illinois, the main thermal properties (thermal conductivity, heat capacity, and thermal diffusivity) together with primary physical properties (grain size, water content, dry bulk density, geophysical, and mineral composition) were measured on drill core samples representing depths from 0-100 m. These data were compared regional and site-specific hydrogeologic measurements and borehole temperatures with a fiber-optic distributed temperature sensing (FO-DTS) system. The thermal conductivity showed a non-linear decrease with increasing gravimetric water content and a non-linear increase with increasing dry bulk density, respectively. Because magnetic minerals have a higher thermal conductivity than quartz, there is a positive relationship between magnetic susceptibility and thermal conductivity. We are using these results to better inform our high-resolution models for heat transport and geothermal exchange.

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LOHSE, Kathleen - *Idaho State University; Reynolds Creek CZO*

## How can critical zone science and CZOs help to resolve landscape management and societal issues?

MA, Lin - *University of Texas at El Paso*

## Impacts of dryland irrigation and land use changes on inorganic carbon dynamics in southwest USA

Lin Ma, Syprose Nyachoti, Lixin Jin, and Craig Tweedie

Drylands cover 40% of the terrestrial land surface and support more than two billion people. As the human population continues to grow, the increasing demand on food has converted more drylands into agricultural systems. Once driven by irrigation water and growing crops, drylands become hydro-bio-geo-chemically dynamic. However, such human-induced changes also lead to significant impacts on soil quality, ground water recharge and quality. For example, natural accumulation of pedogenic carbonates in drylands has been well studied but few have focused on carbonate formation in agricultural drylands. Here, we aim to determine annual accumulation rates of pedogenic carbonates in intensively irrigated soils, and to define key linkages between flood irrigation, salt loading and soil-atmospheric $CO_2$ exchange in cultivated drylands. We used a combination of elemental chemistry, mineralogy, and U-series disequilibrium dating techniques.

Our study sites include an irrigated alfalfa field near El Paso in western Texas and a natural dryland site in the Jornada Basin Range (LTER) of southern New Mexico. Our results showed that high dissolved calcium and inorganic carbon were loaded onto agricultural fields through irrigation waters in El Paso, TX while dust and rainfall were important for salt loads into natural soils in Jornada. U-series dating revealed the presence of younger pedogenic carbonates in the El Paso alfalfa soils compared to the older carbonates from the natural Jornada soils. Pedogenic carbonate formation rates in the alfalfa soils were much higher than those in the Jornada soils. This study clearly demonstrated that land use change from natural habitats to irrigated agricultural fields increased rates of pedogenic carbonate accumulation in dryland soils.

MARSHALL, Jill - *UC Berkeley & CU Boulder; Boulder Creek CZO, Eel River CZO*

## Considering the role of trees as Critical Zone architects

Jill Marshall, Robert Anderson, Susan Brantley, Zsuzsanna Balogh-Brunstad, William Dietrich, Diana Karwan, and Josh Roering

Despite our numerous and common conceptual models, little is known regarding how trees damage rock, create and enlarge fractures, roughen and control the boundary between mobile material and weathered bedrock, and generate soil in competent bedrock or saprolite. We are therefore neither able to explore how changes in tree density and tree species might influence rates of CZ evolution, nor can we confidently discern the role of trees in governing various Critical Zone processes. Here we present several testable hypotheses developed as an outgrowth of a 2015 NSF SAVI workshop regarding trees as CZ architects and plumbers. Additionally, we present preliminary results from a novel technique that quantifies root and wind-induced forces at the rock-tree interface measured at the Boulder Creek and Eel River Critical Zone Observatories. Together the preliminary field data and the hypotheses developed by our team of geomorphologists, plant physiologists, geochemists, microbial ecologists and hydrologists suggest that in actively eroding settings, even in the absence of tree throw, trees (and associated fungi) can convert fractured or weathered rock into soil and set the boundary between the mobile soil and underlying bedrock, thus controlling soil thickness.

study illustrated that the amplitude of O2 fluctuations affect the coupled Fe-C redox cycles.

MEILE, Christof - *University of Georgia*

## Fe and C cycling is modulated by O2 levels in redox-fluctuating environments

Chunmei Chen, Christof Meile, Jared Wilmoth, Diego Barcellos, and Aaron Thompson

Fe oxyhydroxides play a critical role in soil C cycling by retaining organic carbon (OC) in solid-phase or mediating OC decomposition. The rates of homogeneous $Fe(II)$ oxidation in aqueous systems by $O_2$ govern the crystal order of the resulting $Fe(III)$ oxyhydroxides and their reactivity towards subsequent dissimilatory reduction under anoxic conditions, which is coupled with anaerobic OC mineralization. But it remains unclear if this same behavior occurs in soils, where $Fe(II)$ is mainly present as surface complexes. The objective of this study is to assess how varying $O_2$ concentrations affects $Fe(II)$ oxidation in soils from the Luquillo Critical Zone Observatory and its subsequent microbial $Fe(III)$ reduction and anaerobic OC mineralization flowing a transition from the oxic to anoxic conditions. We amended isotopically-labeled $^{57}Fe(II)$ to soil slurries at pH 6 and exposed them to 21 or 1% $O_2$ for 9 d, followed by a 20 d anoxic incubation. Our results demonstrated that relative to low $O_2$ levels, high $O_2$ levels led to a faster $Fe(II)$ oxidation and resulted in partitioning of the amended $^{57}Fe$ into less crystalline $Fe(III)$-oxyhydroxide populations, based on Mössbauer analysis. With the higher rates of $Fe(II)$ consumption in rapid-oxidizing incubation at high $O_2$ levels, the lower sorbed $Fe(II)$ concentration might have resulted in a lower degree of recrystallization relative to low $O_2$ levels. A numerical model was developed to simulate the experimental data and calculate the atom exchange rate. During the anoxic cycle following the oxidation of $Fe(II)$ at high $O_2$ levels, we observed a greater rate of $Fe(III)$ reduction. The anaerobic $Fe(II)$ and $CO_2$ production was well correlated, suggesting that Fe reduction was coupled to microbial OC mineralization. This

MOORE, Alex - *Paleontological Research Institution; National Office*

## "Where Rock Meets Life," a film series by WSKG and CZONO

Alexandra Moore

Travel with the WSKG Public Media and CZO National Office science stunt team on an unforgettable adventure that spans the breadth of Critical Zone science. From Rocky Mountain summits to the reefs of Puerto Rico we explore the zone "Where Rock Meets Life." Experience the Critical Zone as you've never seen it before. Through dazzling video footage and behind-the-scenes interviews with leading CZO researchers we uncover the untold stories of CZ science. The winding path of nutrients through porous media, the dramatic interplay of water with a vibrant landscape, and the thrill of interdisciplinary research – all this and more – "Where Rock Meets Life."

"Two thumbs up!" Justin Richardson, CZO News

Special Features: Educational featurettes include (1) Overview of the CZO Network, (2) The Hydrologic Cycle, (3) The Carbon Cycle, and (4) Spanish-language introduction to the Luquillo CZO. Each episode is accompanied by a suite of classroom activities that support and extend film content. The films will become part of the collection of PBS LearningMedia in order to maximize their reach and impact. In Dolby Stereo.
Watch the trailer: https://youtu.be/8gW-Vy7zFdU

MOORE, Joel - *Towson University*

**Talk Urban ecosystems and CZOs**

**Poster -  Elevated major ion concentrations and fluxes from urban watersheds with no major point sources**

Joel Moore, Darcy Bird, Seth Dobbis, and Gregory Woodward

An increasing number of studies have documented elevated major ion concentrations in urban streams. In regions receiving frozen precipitation, road salt has been well characterized as a clear contributor to elevated concentrations. Much less characterized are the contributions of concrete to increased $Ca^{2+}$ and $HCO_3-$ concentrations in urban streams. In work to date, a number of factors have precluded attribution of increased $Ca^{2+}$ and $HCO_3-$ in urban streams to natural versus concrete contributions, including mixed bedrock geology (particularly carbonate rocks), point sources with unknown chemistry (such as wastewater treatment plants), and/or the lack of a forested watershed that provides a baseline for comparison. We investigated major ion concentrations and weathering fluxes in five small watersheds in the Maryland Piedmont with 0 – 25% impervious surface cover (ISC), similar bedrock chemistry, and no major point sources. In the forested watershed (0% ISC), ion concentrations were low resulting in weathering fluxes (for cations and Si) that were 80% lower than the global average. As ISC increased, major ion concentrations increased with average concentrations in the most urban watershed that were enriched by a factor of 25. As a result, preliminary weathering fluxes from the most urban watershed were 13x higher than the forested watershed and >2.5x the global average. These data demonstrate that weathering of the urban built environment, particularly due to concrete weathering and road salt addition, cause substantial changes in ion concentrations and fluxes. High major ion concentrations have the potential to impact organisms in stream ecosystems through direct toxicity (e.g., Cl–) and osmoregulatory stress and also have implications for drinking water quality. The high weathering fluxes for major ions, particularly $Ca^{2+}$ and $HCO_3-$, have important implications for carbon cycling in urban watersheds and for downstream estuarine and coastal ecosystems.

MORAVEC, Bryan - *University of Arizona; Catalina-Jemez CZO*

**Architecture of the deep critical zone, Jemez River Basin Critical Zone Observatory, Valles Caldera National Preserve, Northern New Mexico**

Bryan Moravec, Alissa White, Jennifer McIntosh, Robert Root, Jon Pelletier, Craig Rasmussen, Steve Holbrook, Bradley Carr, and Jon Chorover

The critical zone (CZ) has recently been the focus of interdisciplinary Earth systems science research that aims to describe coupled processes to understand the past and present CZ and the impact human activities will have on future CZ processes and ecosystem services. The Catalina-Jemez Critical Zone Observatory (CZO) has focused primarily on near surface processes; including remote sensing and direct sampling of vegetation, soils, saprolite and waters. However, water/rock interaction, weathering and solute mobility along flowpaths in the deep (>10 m) CZ that echo near surface CZ processes (i.e. water, energy, and mass fluxes) are not well understood. We postulate a deep groundwater reservoir in fractured rhyolite exerts strong controls on solute discharges in upland catchments of the Jemez CZO within the Valles Caldera National Preserve in northern New Mexico. To investigate weathering processes in the deep CZ, we extracted three continuous cores to 40-50 m depth in summer of 2016 in one of our instrumented forested sub-catchments prior to instrumenting the boreholes as monitoring wells. The research goal is to understand depth- and aspect-dependent trends in the physical, chemical and biological structure,

identify mineralogy that results from hydrologic and bio-geochemical dynamics, and describe lateral and vertical groundwater flow and its contribution to the geochemical evolution of the deep CZ. We used multifaceted tools to deconvolute the impacts on observed variation of geologic origination versus subsequent weathering processes. Preliminary results show complex weathering profiles at each of the three watershed positions likely due to a combination of hydrothermal alteration, textural controls on weathering, development of preferential flowpaths, and differing hydrologic base levels. Observed zeolites and phyllosilicate clays infer a potential weathering trajectory and pathways that may play a critical role in solute transport as a function of depth.

MOSQUERA, Giova - *Universidad de Cuenca*

## Critical Zone Observations in the Tropical Andes

Giovanny M. Mosquera, Patricio Crespo, and Rolando Célleri

The páramo, known as the "water tower" of northern South America, is a high-elevation tropical ecosystem that develops above the tree line and below the perennial snow line. As such, and due to its rapid reaction to environmental changes, this ecosystem can provide valuable information as an early indicator of global change. It consists of a series of wetlands, grasslands, and lakes/ponds that provide high-quality water that sustains the economic development (e.g. hydropower generation, food production) and the rich biodiversity of the Andean region. However, despite its economic and ecological importance, the processes governing the functioning, feedbacks, and interactions among the hydrological, ecological, and biogeochemical components of the páramo, remain poorly understood.

In order to advance the global understanding of these processes in the critical zone and improve the

management of natural resources in the region, the Zhurucay River Ecohydrological Observatory (ZREO, 7.5 km2), a páramo catchment located in south Ecuador (3,400-3,900 m a.s.l.), was implemented with a nested monitoring network for the collection of hydrometric (e.g. rainfall, runoff, soil moisture) and biogeochemical (stable isotopes, metals, nutrients) data at different scales (from plot to catchment) since 2012. The ZREO is equipped with a broad range of sensor types, which vary from traditional water level sensors, rain gauges, and weather stations; to more advance technologies such as automatic spectrometers, laser disdrometers, eddy covariance, and weather radar sensors.

This presentation aims at introducing the ZREO monitoring network and some of the main findings and research in progress through these unique field observations and modeling efforts in the region. These findings include the determination of: 1) the main sources of water contributing to runoff; 2) the mechanisms governing rainfall-runoff processes; 3) the influence of landscape features on the hydrology of the ecosystem; and 4) the factors influencing the ecosystem high water production and regulation capacity.

MOUNT, Greg - *Indiana University of Pennsylvania; Susquehanna Shale Hills CZO*

## Application of near surface geophysics to constrain coal bed and biogenic methane releases in an acid mine drainage wetland in Western Pennsylvania

Greg Mount, Aaron Seidel, Garret Sharp, and Nick Santoro

The release of methane from energy industry activities such as drilling  and from legacy wells is a focus for scientific and legislative inquiry. However, in order to develop a full understanding of the carbon cycle in the area, contributions from other natural and artificial systems such as wetlands are

also needed. Often overlooked due to more visible contamination issues, waters produced from abandoned coal mines which contain dissolved methane and the wetlands that are often constructed to mitigate these waters are also a significant contributor to the carbon cycle. We use a combination of indirect non-invasive geophysical methods (ground penetrating radar), aerial imagery, and direct measurements ( coring and gas traps) to estimate the contribution of wetlands designed to mitigate the impacts of acid mine drainage on surface water.

Our approach uses common offset GPR surveys to define the thickness from the wetland surface to the bedrock interface in order to create a volume model of gas-producing organic soils. Depth-profile cores are extracted to confirm soil column interfaces and determine changes in soil carbon content with depth. In addition, gas traps placed across the wetlands measure the spatial and temporal variability of methane gas released. Carbon stocks across the monitoring site are estimated from aerial photographs and are used to determine surface area of each wetland type and develop a relationship between surface area and total carbon stocks within those wetlands.  These values can be up scaled to estimate carbon stocks across similar landscapes within broader regions.

This research demonstrates the ability of indirect geophysical methods to quickly estimate carbon stocks within irregular wetlands.  This will be important when trying to understanding the environmental impact of methane released from both naturally occurring sources and commercial extraction and distribution activities.

NAVARRE-SITCHLER, Alexis - *Colorado School of Mines; Boulder Creek CZO*

# Insights into chemical weathering patterns from hydrologic data in Gordon Gulch: Boulder Creek CZO

Alexis Navarre-Sitchler, Rania, Eldam, Aaron Bandler, and Kamini Singha

Rock weathering, clay mineral formation, and soil forming processes change not only rock chemistry but also rock properties. These changes affect the way water is transmitted and stored in the subsurface, which in turn alters weathering reactions. Understanding the relationships between rock weathering and water flux in the critical zone will advance our understanding of geochemical and hydrological processes that operate in the critical zone.

Samples from 4, 10-13 meter deep boreholes in the Boulder Creek Critical Zone Observatory were evaluated for evidence of chemical weathering with bulk chemistry, clay fraction, and exchangeable cation concentrations. Unfortunately, heterogeneity of the metamorphic bedrock obscures the 1D weathering profile signal we expect commonly used mass balance methods to define. We find that on north facing slopes exchangeable cation concentrations are similar regardless of depth, compared to a decreasing trend in exchangeable cations with depth on south facing slopes. Clay fractions do not show these trends clearly, possibly due to mechanical grinding of rocks during drilling.  If we use exchangeable cation concentrations to estimate weathering patterns on north vs. south facing slopes it appears that north facing slopes are weathered to depths >10 meters, but that weathering extends to depths of ~ 7 meters on south facing slopes. Seismic anisotropy data show that depths of broken up rock (or saprolite) on both slope aspects are the same, but that saprolite on northern facing slopes is more fractured and granulated than south facing slopes. Comparing geochemical

observations with seismic observations tells a story of water infiltration through a connected network to greater depths on north facing slopes pushing chemical weathering deeper into the critical zone, with water infiltration through a less connected fracture network on the south facing slopes limiting chemical weathering to shallower depths.

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PAPANICOLAOU, Thanos - *The University of Tennessee; Intensively Managed Landscapes (IML) CZO*

## Telling the story of a sediment particle: its source and pathway

Thanos Papanicolaou

A movement of particle can be intermittent.  In intensive managed landscapes, that movement is affected by the continuous transformation of the surface landscape characteristics and the flow pathways.  Tillage, tiles, and extreme events have modified the delivery and travel time of particles creating preferential pathways.  The use of Radiofrequency Identification tags that provide identification of particles, location, burial depth, and virtual velocities can become a valuable tool for event-based monitoring and modeling.  Selective sites within IML provide representative travel times and reflect a non-stationarity effect of management to sediment delivery.  We have found sites that sediment delivery is affected by a small scale periodicity, usually introduced by the turbulence in the runoff.  At other sites, movement is dominated by large-scale periodicities.  These are sites with patches of grassed waterways, which affect stream power and, thus, travel time.

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PAPUGA, Shirley - *University of Arizona; Catalina-Jemez CZO*

## Rebuilding the Critical Zone: A case for Detroit and the Great Lakes Region

Shirley A. Papuga

Post-industrial Detroit represents a unique opportunity to understand how the Critical Zone can be "rebuilt".  Here I present material to support how we might conduct research in this city and the surrounding region to understand how Critical Zone processes have changed under the influence of urbanization and how conditions might be improved.

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PATTON, Nick - *Idaho State University; Reynolds Creek CZO*

## Predicting soil thickness and total organic carbon on soil mantled hillslopes

Nicholas Patton, Kathleen Lohse, Mark Seyfried, Benjamin Crosby, and Sarah Godsey

Soil thickness is a fundamental variable in many earth science applications but difficult to predict. We find a strong inverse linear relationship between soil depth and hillslope curvature ($r2=0.89$, RMSE=0.17 m) at a field site in Idaho.  Using other published datasets over a diverse range of ecosystems, similar relationships are present, although the slopes and y-intercepts vary widely. We show that the slope of this function is highly correlated with the variability in curvature ($r2=0.96$, RMSE= 0.026 m2, $p<0.0034$) and that the mean of the curvature distributions is zero. Our simple empirical model predicts the spatial distribution of soil depth in a variety of catchments based only on high-resolution elevation data and a few soil depths. Utilizing spatially continuous soil depth datasets enable total soil organic carbon (SOC)

predictions to be made at the pedon and landscape scales. We use a second order polynomial between soil thickness and total SOC for both the north- and south-facing aspects (r2=0.90 and r2=0.89, respectively) to determine the spatial distribution and stocks of total SOC. Across the watershed, total SOC on the north-facing aspect was 7038 Mg C or ~51% of the total soil carbon, despite comprising only ~38% of the total land area. South-facing aspect totaled 6740 Mg C, or ~49% of the total SOC. When partitioning the landscape into equal topographic regions, ~58% of total SOC fell in convergent topography, ~30% in planar topography, and ~12% in divergent topography. We compare our extrapolation approach to other common methods, such as kriging, and find these methods fail to predict the distribution of SOC by under- and overestimate SOC as much as 40% to 138% and 31% to 353% with aspect and microtopography, respectively.

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Poster Session I Rm. 5 #57

PEREZ FODICH, Alida - *Cornell University; National Office*

## Extreme basalt weathering results from high soil CO2, unsaturated conditions and organic acids

Alida Perez-Fodich and Louis A. Derry

The intensity of weathering across the Hawaiian archipelago is strongly correlated with the surface exposure age and integrated climate history. Intense basalt weathering results from exposure to elevated soil CO2, unsaturated conditions throughout the rock/soil profile, and/or release of organic acids from plant exudates, all in a regime with high water/rock ratios from rainfall > 2000 mm/year. The result is complete loss of base cations and primary minerals within the first 20,000 years of weathering. Furthermore, this weathering regime can decrease soil pH to values between 4.0 – 4.5, depleting soil profiles from all its buffering capacity.
We have developed a set of 1-D reactive transport models (RTM), to investigate the role of these agents

driving basalt weathering. The effect of soil CO2 effect is explored in three ways: diffusion of CO2 from atmosphere, fixed CO2 fugacity in the profile, and by soil organic matter respiration. We test the sensitivity of reactive gases by studying different degrees of water-column saturation in the profile. Organic acids play a role as ligand-promoted dissolving agents. Lastly, because of the Fe-rich nature of the weathered soils, including Fe(II) oxidation is essential to understand this abundance. Depth of weathering fronts is controlled by the degree of water-column saturation: further unsaturation allows downward propagation of reactive gases (CO2 and O2) in the profile. Organic acids are the principal drivers for low soil pH, however they only play a role in the topmost part of the profile. High CO2 concentrations through the profile are necessary to produce representative pH profiles. The RTM predicts high CO2 consumption rates by silicate weathering within the first thousand years, which stabilize as buffering capacity is lost from the rock. Finally, the models predict that some of the Al is exported by ligand complexation while Fe largely is retained in soil.

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Poster Session I Rm. 4 #37

PORPORATO, Amilcare - *Duke University; Calhoun CZO*

## Hydrological controls on weathering rates across CZOs

Salvatore Calabrese, Anthony Parolari, and Amilcare Porporato

Hydrologic fluxes regulate the transport of dissolved inorganic carbon to the weathering sites, dilution, and the water transit time (i.e., the time available to the reaction to advance towards equilibrium). To quantify the importance of hydrology on mineral chemical weathering, we introduce an analytical model based on molar balance equations for the chemical species in solution that accounts for the transport of dissolved inorganic carbon by percolation and for the ecohydrological processes taking place at the soil atmosphere interface. The

model is used to characterize the interplay between the dryness index, Di, and the Damköhler number, Da, in determining solute fluxes across CZO sites.

and medium organic carbon content ensure a good filtering and buffering capacity. Large N inputs of up to 550 kg/ha are used relative efficiently by the crops, however, between 7 and 10% of the added N with each irrigation leaches beyond the crops root zone as nitrate.Overflow irrigation triggers nitrate and atrazine leaching rapidly through macropores beyond the rooting zone. The large filter capacity of the soil seems to prevent the transport of atrazine and its metabolites into the unsaturated zone

PRADO, Blanca - *Instituto de Geologia, Universidad Nacional Autónoma de México*

## Understanding water movement, nitrogen dynamics and fate of atrazine in the vadose zone of a wastewater irrigated critical zone observatory

Blanca Prado, L. Hernández, M.C. Salazar, and C. Siebe

The Mezquital Valley (MV) is the largest continuous area irrigated with untreated waste water (WW) in the world. This practice for more than 100 years, has transformed the MV into a productive agricultural area and also, has resulted in the formation of a stable shallow aquifer which supplies water to the local population (about 500 000 inhabitants). The good quality of the groundwater, contrasts with the poor one of the WW. The aim of this work was to understand the water dynamics and fate of nitrogen and contaminants, throughout the critical zone. In an extended volcanic piedmont ranging in altitude from 2071 to 2040 m.a.s.l, we quantified nitrogen and atrazine inputs, out-puts and transformations within the rooting zone and in the vadose zone down to the aquifer (i.e. in the Critical Zone) by monitoring the pore water in suction cup lysimeters and piezometers installed at different depths. During the drilling we measured in situ penetrability and collected samples for analysis. At the surface we conducted geophysical surveys, hydraulic conductivity measurements and soil characterization. The intermediate unsaturated zone is constituted by volcanic materials of varying permeability and of non-uniform thickness. The water infiltrates at a velocity of 8E-4 m/s in the first 6 dm and later slower lateral and vertical flows are established along of up to 13 strata of varying compaction and granulometry. The soils characteristics, pH slightly alkaline, silty clay texture

PUTNAM, Shane - *Johns Hopkins University*

## Model-data learning to identify runoff generation mechanisms in a small forested Piedmont watershed

Shane Putnam and Ciaran Harman

The influence of the flow pathways through and runoff generation mechanisms of individual landscape units on the transport of water and solutes at the emergent, watershed scale is not well understood. Transport is often represented by a transit time distribution (TTD), which encapsulates the emergent effects of watershed structure, but in doing so obscures how the component parts of the watershed contribute to it. For example, the time-variability of a catchment's TTD might arise largely from shifting contributions to discharge from landscape units whose individual TTDs are more stable, or it might be dominated by time-variability in the individual landscape units' TTDs. Advances in transport modeling make it possible to capture the time-variable TTDs of individual units, and their contribution to overall variability, using the rank StorAge Selection (rSAS) modeling framework. In this study, the rSAS modeling framework will be combined with simple water balance models in order to examine the hydrologic processes that control runoff generation from the riparian area landscape unit. The goal is to gain insights into the physical processes controlling transport in discrete landscape units as a first step toward understanding

the influence of these individual units on the time-variability of transport at watershed scales.

In this study, three hypotheses related to the mechanisms with which runoff is generated from the riparian area landscape unit are tested using a model-data learning approach. In this approach, each hypothesis is first transformed into a conceptual model and then the results of that model are compared to observed data. A combination of hydrometeorological and environmental tracer data collected from a 37-hectare Piedmont watershed of the eastern US, are used for this analysis. Specifically, observed time series of discharge and stable water isotopes from the study watershed are compared to modeled time series in order to test our hypotheses.

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Presentation 9:30am Mon

RAJARAM, Hari - *University of Colorado, Boulder; Boulder Creek CZO*

## Integrated science in AGU journals

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Poster Session I Rm. 5 #51

RAJARAM, Hari - *University of Colorado, Boulder; Boulder Creek CZO*

## Modeling the influence of preferential flow on the spatial variability and time-dependence of weathering rates

Sachin Pandey, Harihar Rajaram, and Masoud Arshadi

Inferences of weathering rates from laboratory and field observations suggest significant scale and time-dependence. Preferential flow induced by heterogeneity (manifest as permeability variations or discrete fractures) has been suggested as one potential mechanism causing scale/time-dependence. We present a quantitative evaluation of the influence of preferential flow on weathering rates using reactive transport modeling. Simulations were performed in discrete fracture networks (DFNs) and correlated random permeability fields (CRPFs), and compared to simulations in homogeneous permeability fields. The simulations reveal spatial variability in the weathering rate, multidimensional distribution of reactions zones, and the formation of rough weathering interfaces and corestones due to preferential flow. In the homogeneous fields and CRPFs, the domain-averaged weathering rate is initially constant as long as the weathering front is contained within the domain, reflecting equilibrium-controlled behavior. The behavior in the CRPFs was influenced by macrodispersion, with more spread-out weathering profiles, an earlier departure from the initial constant rate and longer persistence of weathering. DFN simulations exhibited a sustained time-dependence resulting from the formation of diffusion-controlled weathering fronts in matrix blocks, which is consistent with the shrinking core mechanism. A significant decrease in the domain-averaged weathering rate is evident despite high remaining mineral volume fractions, but the decline does not follow a $1/t^{0.5}$ dependence, characteristic of diffusion, due to network scale effects and advection-controlled behavior near the inflow boundary. The DFN simulations also reveal relatively constant horizontally averaged weathering rates over a significant depth range, challenging the very notion of a weathering front. We also present a new semi-analytical solution for the propagation of weathering fronts in fracture-matrix systems, showing that the weathering front propagates as $t^{0.5}$ along the fracture, and that the overall weathering rate remains constant until the tip of the weathering front exits the fracture, after which a $1/t^{0.5}$ behavior occurs.

REMPE, Daniella - *University of Texas at Austin; Eel River CZO*

## Rock moisture dynamics in the critical zone: Direct observations from the Eel River Critical Zone Observatory

Daniella Rempe, W. Jesse Hahm, Alison Tune, David Dralle, Jennifer Druhan, Todd Dawson, Inez Fung, and William E. Dietrich

In mountainous environments, tree roots often penetrate fractured rock beyond the soil layer, and return water stored in weathered rock to the atmosphere via transpiration. The roots and ectomycorrhizal fungi that occupy these fractures acidify their environment and influence long term weathering rates.  Thus, the exchangeable water stored in the matrix and fractured of weathered rock may play a significant role in the water and carbon cycles, however, due to observational challenges and limited data, the global significance of the rock moisture reservoir is unknown. Here we present the results of an ongoing multi-method investigation of the spatial and temporal dynamics of rock moisture in the 5-25 m thick critical zone at the Eel River Critical Zone Observatory.  Successive neutron probe surveys conducted over seven years demonstrate that rock moisture dynamics are vertically structured, with significant water content changes occurring in the upper 5-12 m.  At deeper depths in the profile, groundwater occupying a fracture network developed in weathered bedrock fluctuates. Monitoring in wet and dry years shows that up to one third of the annual precipitation is seasonally held as rock moisture and shows a similar pattern of slow depletion during the dry summer months. Here, we introduce a new Vadose Zone Monitoring System (VMS) which is equipped with sensors and samplers for monitoring the water content, temperature, and water composition of rock moisture.  We present results of continuous rock moisture monitoring as well as the geochemical and isotopic composition of water on its transit through fractured, weathered rock and the gases that occupy

the vadose zone.  Our results demonstrate that the spatial and temporal pattern of rock moisture in the critical zone influences the timing of water availability to trees, the timing and composition of runoff, and the composition of vadose zone gases.

RICHARDSON, Justin - *Cornell University; National Office*

## Measuring full suites of trace metals in plants, soils, rocks, and water: another person's treasure.

RICHTER, Dan - *Duke University; Calhoun CZO*

## Gilbert's soil production paradigm and the critical zone's fractionation of particle sizes

Dan Richter, Jay Austin, Bob Anderson, Allan Bacon, Susan Brantley, Zach Brecheisen, Alex Cherkinsky, Steve Holbrook, Virginia Marcon, Julio Pachon, Paul Schroeder, Aaron Thompson, and Anna Wade

n 1877, Gilbert stated with wonder, "Over nearly the whole of the earth's surface, there is a soil, and wherever this exists we know that conditions are more favorable to weathering than to transportation." Gilbert's ideas about soil would go a century before re-circulating vigorously in the Earth sciences. Today, Gilbert's simple and elegant difference expression of weathering and transportation not only motivates work on "soil-production functions" but it serves as a contemporary paradigm for critical zone evolution. Best of all, the soil-production paradigm allows us to re-think old problems. Here we explore processes of particle-size fractionation as particles ride the soil

production treadmill from bedrock to soil's surface. Coarse-over-fine textured soils (COF) are widely found and carefully studied as their texture-dependent properties are highly important to land management. COF soils are obvious examples of particle size fractionations that soil scientists attribute to lessivage, i.e., clays moving from A to B horizons. We use the weathering profiles at the Calhoun CZO to explore how bedrock is weathered into the particles of the critical zone. In the Calhoun 70m deep core, Large grains of feldspars weather to sand- and silt-sized kaolinites starting at about 30m, and sand- and silt-sized kaolinites are comminuted into clay-size micelles starting at about 4m. Clay-sized kaolinites are further concentrated by lessivage in B horizons which remarkably can peak at >70% kaolinite by mass.  Sand- and silt-sized quartz grains continue on the treadmill and dominate surficial A and E horizons where sand-sized quartz grains total about 80% by mass. Given the broad perspective provided by the soil production paradigm and the critical zone, we suggest that many COF soils may actually be COFOC soils based on the texture and formation of A, B, and C horizons.

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Poster Session II Rm. 3 #9

RUNGEE, Joe - *University of California, Merced; Southern Sierra CZO*

## Evapotranspiration and land-cover response to multi-year dry periods in the semi-arid Western United States

Joseph Rungee and Roger Bales

This study used eddy-covariance flux-tower measurements of evapotranspiration from Critical Zone Observatories and other sites in the Western United States, plus estimates of precipitation and temperature to evaluate drought resiliency. Five landcover types were represented: evergreen needle leaf forest, mixed forests, woody savannas, open shrublands, and grasslands. At most of the semi-arid watersheds where these sites are located, evapotranspiration accounts for the majority of water leaving the watershed. Most sites showed a

linear increase of annual evapotranspiration with annual precipitation up to a point, with a threshold where the rate of increase in evapotranspiration with further increases in precipitation was significantly lower. Storage at each measurement site was estimated in two ways. First was by summing annual dry-season evapotranspiration at each of the 24 sites evaluated, for all years of record. Second, for the 11 sites that exhibited a significant decline in evapotranspiration in response to drought, we calculating the cumulative storage deficit from the beginning of the multi-year dry period until the month when the decline in evapotranspiration was apparent. Four of the 24 sites had one or more years with over 450 mm of annual ET from storage, and for only 5 sites was annual ET from storage under 200 mm for all years of record. During multi-year dry periods, one site showed a drop off in ET after a cumulative depletion of 470 mm of storage over 35 months, with a total of 680 mm of storage decline through the end of the drought. Most other sites showed a much earlier response to drought, from 11 to 23 months into the dry period. This analysis highlights that some land cover types are adapted or resilient to multi-year dry periods, whereas others that are vulnerable at the evaporative demand of current biomass.

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Poster Session II Rm. 3 #13

RYLAND, Rachel - *University of Georgia; Calhoun CZO*

## Mapping Depth to the Clay Horizon on Historically Farmed Soils within the Piedmont Region of the Southeastern United States

Rachel Ryland, Dan Markewitz, and Aaron Thompson

Historic agricultural practices have led to accelerated erosion throughout the Piedmont region of the southeastern U.S. Clear-cutting of the forests coupled with tilling and no erosion control practices led to substantial soil redistribution/loss, exposing the subsoil clay horizon (argillic) in many locations

and adversely altering the hydrologic processes across the landscape. Predicting hydrologic and biogeochemical processes in this landscape require an accurate view of this soil re-distribution. Current numerical models of hillslope and watershed hydrology use characteristics from soil classification maps for parameterizing subsurface hydrologic flow paths, however, these soil maps may lack sufficient spatial detail and may not accurately represent landscapes that have been eroded from historical farming (De Alba et al., 2004). Therefore, a spatially explicit model of eroded landscapes particularly in the Piedmont area would be valuable. To achieve this, the depth to the argillic horizon (DTA) was mapped in highly eroded (historically farmed) and undisturbed watersheds (reference) using extensive soil sampling as well as geophysical sensing of the DTA using hand-held electromagnetic induction sensors. Electrical conductivity was calibrated to clay content and other topographic characteristics (i.e. landscape position, aspect, percent slope) from which the DTA has been be predicted. The results from this study will improve our understanding of how erosion redistributes soil and will evaluate the potential for geophysical sensing to describe important sub-surface features. In addition, this information will help parameterize numerical models of hillslope and watershed hydrology across a wide land area.

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Poster Session I Rm. 3 #9

SCHACHTMAN, Nathan - *University of Oregon*

## Using a paleo perspective to demonstrate climate control of critical zone processes

Nathan Schachtman, Joshua Roering, Jill Marshall, Dan Gavin, and Darryl Granger

While global chemical weathering of silicate minerals has long been postulated to modulate climate over long time scales, the feedbacks between chemical weathering, climate, tectonics and lithology are complex. However, few quantitative evaluations of chemical weathering intensity or flux variations with time exist to test this hypothesis. Here we show that climate exerts a strong control on critical zone (CZ) processes in unglaciated terrain over the last glacial-interglacial.

We used a 50 kyr record of colluvial sedimentation to investigate feedbacks among climate, erosion and chemical weathering at Little Lake, OR in the Oregon Coastal Range. Past work at this site has suggested heightened erosion rates during the Last Glacial (LG; ~29-14 ka) due to increased efficacy of periglacial abiotic processes, 2-3x higher than during the Late Holocene (LH; ~2.5 ka-present), where temperate biotic processes dominate. We analyzed sections of our sedimentary archive as well as soils from the modern catchment for major and trace elements and utilized the chemical depletion fraction (CDF) to assess the degree of weathering with respect to bedrock. CDF values average 0.19±0.02 during the LH and 0.08±0.02 during the LG. These data imply a low chemical weathering potential (CWP) during the LG, in which mineral residence times in the CZ were greatly reduced due to vigorous frost processes and parkland vegetation cover, thinning the hillslope soil. Throughout the LH, a higher CWP corresponds with the transition to warmer conditions and an expansion of forest cover, which promoted a deepening of the CZ. The inverse relationship between denudation rates and CDF results in a stable flux of weathered material over the last glacial-interglacial, despite significant variations in climate. The offsetting effects of these climate-driven CZ processes suggest that the role of weathering as a modulator of atmospheric $CO_2$ in unglaciated terrain may have been overestimated in previous studies.

SCHROEDER, Paul - *University of Georgia; Calhoun CZO*

## Quantifying mineral transformations in the Calhoun Critical Zone Observatory (CCZO): What is it and how much is there?

Paul A. Schroeder, Jason C. Austin, and Daniel Richter

Determining crystal-chemical properties of minerals in the critical zone is key to understanding reaction pathways operating in the subsurface. X-ray powder diffraction (XRD) analysis of clays and clay minerals in the CCZO show they are comprised of discrete and mixed-layered structures of different proportions and layer types. These clays vary throughout the depth in profiles, across landscape positions, and under different vegetative covers. Also realized is the need to accurately quantify the abundance of these phases. XRD is a viable method to determine both mineral structures and concentrations. For the clay fraction (<2 μm) we apply the NEWMOD method (Reynolds, 1980) for simulating the layer types, ordering schemes, and relative proportions of clay minerals. Each discrete and mixed-layer phase model is summed to simulate the observed diffraction patterns, which produces a measure of relative abundance. We also apply the Rietveld (1969) method for quantifying the bulk mineralogy. The lack of well-developed structure models for disordered and mixed-layer clay phases is a challenge for the Rietveld method (and will continue to be into the near future). Hydro-biotite, which appears in some of the CCZO regolith, can be simulated with one-dimensional site occupancies and coordinates (Brindley et al, 1983).

Deep coring into the regolith beyond several meters is common practice in engineering disciplines, but it has not been traditionally performed in the soil and earth sciences. CZ science now recognizes that biogeochemical weathering fronts propagate 10's of meters below the land surface and this collective zone is a key link to understanding the long term

cycling of elements. XRD data compare favorably to independent mass loss measurements (tau) made with independent chemistry measurements performed on the same samples. Chemical alteration indices (CAI) also determined reveal close relationships with other independent geophysical measures.

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SEYFRIED, Mark - *USDA-ARS; Reynolds Creek CZO*

## Implications of topographically induced variations in solar radiation for water balance, vegetation and soil development.

Mark Seyfried, Gerald Flerchinger, Tim Link, and James McNamara

Vegetation cover and stature in semiarid regions are highly sensitive to variations in evaporative demand and precipitation. Where the terrain is complex, this may result in a spatial mosaic of vegetation cover related to topographically induced variations in solar radiation and hence evaporative demand. The associated energy and water fluxes and carbon stocks probably do not scale linearly, but are potentially predictable. Johnston Draw, a small, semiarid, granitic catchment in the Reynolds Creek Experimental Watershed in Idaho, is dominated by steep north and south-facing slopes. Vegetation on North-facing slopes is more complete. We made spatially extensive, periodic measurements of soil temperature (Ts) soil water content (Ws) to establish the spatial variability of those parameters. In addition, we monitored Ts and Ws in profiles to bedrock, snow depth and meteorological parameters at three paired, north- and south-facing slope locations. These data were compared to simulations of water and energy flux calculated using the Simultaneous Heat and Water (SHAW) model. We found dramatic differences in Ts, with the annual average soil temperature about 5 C warmer on south-facing slopes. Differences varied seasonally, with the biggest differences in the summer, exactly

out of phase with the solar radiation differences. Each year soils dried to consistent, low values, but the north-facing soils retained water about one month longer, on average, owing mostly to the greater depth, and hence available water, on those soils. Modeling results indicate that water is retained longer in north-facing soils and the differences in Ts are due to differences in soil cover, primarily from the greater density of vegetative cover. These differences appear to have evolved over time as the result of feedbacks between atmospheric forcings and vegetation response, which promote greater carbon accumulations and deeper soil formation.

SHANLEY, Jamie - *U.S. Geological Survey*

## Luquillo loco! Insights on hot moments from in-stream optical sensors in the Puerto Rico wet forest

Jamie Shanley, JohnFranco Saraceno, Bill McDowell, and Angel Torres-Sanchez

The 326-ha Río Icacos catchment in the Luquillo Critical Zone Observatory receives more than 4 meters of rain per year. Stream runoff commonly exceeds 10 mm hr-1, accompanied by marked dilution of solutes and pulses of suspended sediment and DOC. To capture these dynamics and infer the watershed sources and processes responsible for these hot moments, we have been monitoring turbidity, fluorescence, and specific conductance at a 15-minute time step with in-stream optical sensors since mid-2011. Río Icacos is a challenging environment to make these optical measurements due to frequent high concentrations of light-quenching suspended sediment (up to 5000 mg L-1), the potential for sensor fouling by algae and iron staining and scouring by sand, and lightening strikes. Accordingly, our time series are not complete, but we have several periods of high-quality measurements. Turbidity was a strong proxy for suspended sediment concentration and during storms it peaked fairly close to the discharge peak. Fluorescence was a fairly strong proxy for dissolved

organic carbon (DOC), and it generally peaked after the discharge peak but with a long tail of elevated signal. The magnitude of the turbidity and fluorescence peaks correlated positively with the discharge peak, but the turbidity response was further amplified by rainfall intensity, as was the depression of specific conductance. We will combine these in-stream measurements at the Río Icacos outlet with previous studies of processes in the catchment to infer the hot spots contributing to these hot moments.

SHARMA, Harmandeep - *Idaho State University; Reynolds Creek CZO*

## Seasonal water and carbon fluxes at ecosystem scales in sagebrush steppe ecosystems

Harmandeep Sharma, Keith Reinhardt, and Kathleen Lohse

Sagebrush steppe is one of the largest semi-arid ecosystems in western North America, covering about 4.5 x 106 ha of total land area. This ecosystem has been identified as a potential carbon (C) sink. The greater sagebrush steppe ecosystems of the Intermountain West consist of many species and subspecies of sagebrush. It covers a wide geographical range with distinct climatic conditions (i.e. rain- to snow-dominated environments). These systems are water limited, with changing climatic conditions, the distribution and associated ecosystem functions of this ecosystem are expected to shift. However, it is hard to predict how the ability of these ecosystems to sequester C in the future will change without basic knowledge of the water and C balance of these systems. Previous studies have found phenological, morphological, and ecophysiological differences among sagebrush types, but we don't know how these differences influence the overall water and C balance. We conducted a field study to quantify both daily and seasonal water and C fluxes at ecosystem scale in three sagebrush types (Artemisia tridentata ssp. wyomingensis and A.

t. ssp. vaseyana, and Artemisia arbuscula) present along rain to snow dominated elevations at Reynolds Creek Critical Zone Observatory, in Southwestern Idaho. We conducted diel measurements of ecosystem-level $H_2O$ fluxes (evapotranspiration, ET) and ecosystem-scale $CO_2$ fluxes (net ecosystem exchange, NEE) monthly during the growing season (June-August). We observed differences in the patterns and magnitude of ET and NEE at diel scales. Both ET and NEE values were consistently greater at the snow-dominant site compared to the rain-dominant sites, irrespective of the time of the day. Cumulative seasonal ET and NEE were significantly greater at the snow-dominated site compared to rain-dominated sites. Overall, our findings indicated that the big sagebrush at the snow-dominated site is a better C sink, but with comparatively low water-use- efficiency.

Poster Session I Rm. 6 #33

SHEPARD, Christopher - *University of Arizona; Catalina-Jemez CZO*

## A probabilistic approach to quantifying soil physical properties using time-integrated effective energy and mass transfer (EEMT)

Christopher Shepard, Marcel Schaap, Jon Pelletier, and Craig Rasmussen

Soils develop as the result of a complex suite of biogeochemical and physical processes; however, effective modeling of time variable soil evolution and the resultant soil property variability is limited to individual chronosequence studies or overly broad generalizations. Traditional chronosequence studies do not account for uncertainty in soil evolution and property change. Here we develop a probabilistic approach to quantify the distribution of probable soil property values based on a review of soil chronosequence studies, with a focus on the changes in soil texture and depth with increasing time and influx of mass and energy. Bivariate normal probability distributions were parameterized using the chronosequence data, from which univariate

distributions based on the time-integrated effective energy and mass transfer (EEMT) or the total pedogenic energy (age x rate of energy flux) were calculated, allowing determination of a probable range of soil properties for a given age and energy flux. The bivariate distribution was capable of effectively representing the measured maximum clay content values with an $r^2$ of 0.54 (RMSE=14.8% clay). We extended the approach to complex terrain, using data available from the Critical Zone Observatories (CZO), and effectively predicted clay stocks across highly variable terrain and lithologies. In a small-forested catchment in the Santa Catalina Mountains-Jemez River Basin CZO, we combined the probabilistic prediction of clay percentage with a geomorphic numerical model predicting soil depth and erosion rates to effectively predict clay stocks independent of soil data. This approach has the potential to enhance our capability of predicting soil physical properties important for maintaining and managing critical zone processes and services.

Poster Session II Rm. 4 #44

STANISH, Lee - *NEON*

## Improving microbial metagenomic data standards for critical zone research

Lee Stanish, Emma Aronson, and Folker Meyer

Microbes are key biological mediators of physical and chemical processes in the subsurface. Due to their diversity and complexity, we are still far from developing an ecological understanding of the roles that they play in biogeochemical processes and their responses to environmental changes. Shotgun metagenomics of microbial assemblages provides critical taxonomic and functional data that can be used to refine our understanding of microbial processes in the subsurface, and large-scale observatories such as the CZO can play an important role. A major challenge in using metagenomics data is the lack of standardization in methodologies and data reporting across researchers that can dramatically influence the data and interpretations, thereby casting doubt on the validity of cross-site

and long-term studies in which datasets are combined. Through an NSF-sponsored grant, members of the CZO have partnered with NEON and members of the Genomics Standards Consortium to address this issue. Specifically, we are developing a package of metadata standards for soil metagenomics studies that aim to improve reporting of methods and contextual metadata. This simple approach should help standardize a rapidly growing field and enable more robust analyses across the critical zone and the globe.

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SULLIVAN, Pamela - *University of Kansas; Shale-Hills CZo*

## Earthcasting controls of vegetation on solute fluxes and soil development in the Critical Zone

Pamela L. Sullivan, Yves Goddéris, Li Li, Sharon Billings, G.L. Macpherson, Yuning Shi, Jacques Schott, and Susan L. Brantley

Earthcasting is the projection of Earth's near surface fluxes (e.g., water, solutes and sediments) and architecture (e.g., soil thickness and hydrologic properties) to examine how human and climatic perturbations will drive the evolution of the terrestrial Earth. It relies on the knowledge of Critical Zone processes that span timescales of seconds to millennia and spatial scales of mm to km. Here, we begin to focus on controls of vegetation on solute fluxes and soil formation across varying lithologies. To accomplish this goal we demonstrate how a cascade modeling approach—linking of meteorological forcing, land-surface hydrologic models, and biogeochemical models— can be used to examine how biota alter weathering rates and how land cover change governs solute fluxes.

We present two earthcasting scenarios centered on the response of solute fluxes and weathering rates to vegetation nutrient cycling and land cover change. The first is the Susquehanna Shale Hills CZO, a temperate forested watershed overlying shale,

where we explore the impact of differing temperature, hydrologic and nutrient cycling regimes on solute fluxes and shale weathering rates. The second focuses on the grassland to temperate forest ecotone boundary of eastern-central Kansas, which is underlain by repeating couplets of shale and limestone, and represented by the Konza Prairie LTER Program. Differences in burning regimes in this region support the coexistence of grasslands, shrublands and temperate forests, and providing a platform to examine the hydrologic and biogeochemical impacts of vegetation communities on weathering rates and solute fluxes.

Earthcasting at Shale Hills demonstrates that solute fluxes and shale weathering rates are more sensitive to nutrient cycling by vegetation than small changes in temperature (± 1° C) and evapotranspiration (± 10%). For the Kansan systems we are exploring the role rooting depth may play in controlling mineral weathering rates.

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TANG, Jim - *Ecosystems Center - Marine Biological Laboratory*

## Responses of CO2, CH4, and N2O fluxes from soils to temperature and nitrogen availability

Jim Tang

Soil respiration ($CO_2$ fluxes from soils) plays a major role in global carbon cycling. It is well accepted that soil respiration responds positively to soil temperature, but the constraint of other confounding factors, such as moisture, on the soil respiration-temperature response is still not clear. In addition, the responses of other greenhouse gas emissions, including methane ($CH_4$) and nitrous oxide ($N_2O$), to temperature and the relationship between $CH_4$, $N_2O$, and $CO_2$ fluxes is of increasing interest. These gas flux responses to temperature are further connected with nitrogen availability. We aim to understand how $CO_2$, $CH_4$, and $N_2O$ fluxes from soils respond to temperature and nitrogen

availability and how these fluxes are related to each other.

We take advantage of an existing long-term multifactorial warming and nitrogen addition experiment at Harvard Forest, a temperate forest in Massachusetts. The treatments include warming, low nitrogen addition, high nitrogen addition, the control, and the combination. We measured $CO_2$, $CH_4$, and $N_2O$ fluxes with a recently assembled mobile in-situ gas flux measurement system. We also collected existing published and unpublished datasets on soil respiration.

We found when moisture was not limited, $CO_2$, $CH_4$, and $N_2O$ fluxes responded positively to temperature. $N_2O$ fluxes increased with nitrogen addition, but the response of $CO_2$ and $CH_4$ to nitrogen is not significantly. The response of $N_2O$ fluxes to nitrogen addition peaked within 5 days after nitrogen was added, and the response faded gradually. We found no major differences in the temperature sensitivity of soil respiration between control and warmed plots. Soil respiration rates with and without experimental warming follow a Gaussian response, increasing with soil temperature up to a threshold of 25°C, above which, respiration rates decrease with further increases in temperature.

site comparison between these two sites becomes important. The Garner Run site differs with Shale Hills in several ways. For example, the Garner Run hillslope is longer and more planar compared with hillslope at Shale Hills. In this study, we used shallow soil moisture (10cm, 20cm, 40cm) as an indicator of different controls from these two sites. Eight Ground HOG (ground hydrological observation gear) sites at Garner Run and Shale Hills (4 for each), which collect soil moisture, soil temperature and soil gas in a 10-min interval are used to provide the data. Three steps were taken in this study. Firstly, we examined the preferential flow frequency by using a 'non-sequential response' methodology and compared the results both in-site and cross-site. Secondly, we checked the soil moisture storage ability of the 8 sites in different seasons. The final step is to use the spectrum analysis on the time series data to check the "sensitivity" and "memory" of the response of different sites to rainfall events. Results show that at Shale Hills, the precipitation has a strong impact on preferential flow frequency, while this control is mitigated by the environmental settings at Garner Run. The topography impacts the water storage ability at Shale Hills a lot. While at Garner Run, it is more controlled by seasonal difference. In the end, the "memory" difference between these two sites might indicate the 'self-organization' characteristic of the soil moisture behavior.

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Poster Session II Rm. 6 #30

TANG, Qicheng - *Pennsylvania State University; Susquehanna Shale Hills CZO*

## Comparison of soil moisture dynamics and preferential flow occurrence between two forested catchments with contrasting geology and soils

Qicheng Tang and Henry Lin

By moving from a small focus area (Shale Hills, 0.08km2) to a larger area (Shavers Creek Watershed, 164km2), the SSHCZO team set up a new site at Garner Run, which has a totally different lithological condition compared with Shale Hills. Thus the cross-

than did Alanine. Finally, the abundance of Fe-reducing bacteria limited Fe reduction potential in almost all of these soils, particularly the pine soils.

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THOMPSON, Aaron - *University of Georgia; Calhoun CZO, Luquillo CZO*

## The potential for iron reduction in upland soils in Calhoun Critical Zone Observatory

Chunmei Chen, Nadia Noor, Diego Barcellos, Caitlin Hodges, and Aaron Thompson

Fe redox cycling plays an important role in organic matter preservation and degradation, and the fate of nutrients and contaminants. Despite its importance, Fe redox cycling in non-flooded upland soils has been underappreciated, although many upland terrestrial ecosystems have episodes of low redox events and an abundance of anoxic microsites. Soil Fe reduction is generally constrained by C availability, the reactivity of Fe(III) oxyhydroxides, and the abundance of Fe reducing bacteria. The goal of this study was to determine the potential for Fe reduction in upland soils under varying land-uses (Hardwood, Pine and Cultivated soils) from Calhoun Critical Zone Observatory. Fresh field soils from multiple depths were incubated in the lab without amendments under anoxic conditions for 3 weeks to determine the native potential for soil Fe reduction and to assess the limiting factors, the soils were amended with factorial mixtures of the following: (1) organic substrates (glucose and alanine); (2) bioavailable Fe (ferrihydrite); and (3) Fe reducing bacteria (Shewanella oneidensis strain MR-1). Results showed that Fe reduction potential generally decreased with soil depth. Fe reduction potential is very minimal below ~1m of soil profile. The availability of Fe(III) minerals did not constrain pine and hardwood soil Fe reduction potential. Fe(III) availability only slightly limited the potential for Fe reduction the cultivated soils, which have the lowest extractable Fe by ascorbate-citrate. Labile C constrained Fe reduction in the hardwood and cultivated soils, but not in the pine soils, which had the highest extractable C by K2SO4. In addition, we found the more energetic C source (glucose) facilitated more Fe reduction in the subsurface soil

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VAN DER MEIJ, Marijn - *Wageningen University & Research; Susquehanna Shale Hills CZO*

## Geophysical techniques for revealing subsurface structure and processes in the Critical Zone

Li Guo and Henry Lin

Insights into subsurface structure and processes, including soil depth, soil layering, soil-bedrock interface, root system, subsurface flow pathways, and dynamic changes in water, salts, and other elements belowground can significantly enhance the understanding of Critical Zone functions and services. Traditional sampling and observation methods have encountered challenges for gaining such insights as many of them are costly, time consuming, and even infeasible especially when spatial scale involved is large or when temporal dimension involved requires repeated measurements. Geophysical methods provide an alternative or complement to traditional techniques to characterize spatial heterogeneity and temporal dynamics in the subsurface. Using ground-penetrating radar, we have been able to successfully delineate soil-bedrock interface and soil layering patterns, estimate coarse root biomass, reconstruct root system architecture, monitor soil water dynamics, and detect subsurface preferential flow networks. We have applied time-lapse electromagnetic induction surveys to reveal the drying-wetting cycle at the catchment scale and identify potential subsurface flow pathways. We have also used electrical resistivity tomography to monitor infiltration process after introducing water into soils. Recent advances in thermal imaging create opportunities to map the network of surface runoff and subsurface lateral flow. Our results highlight the promising potential of geophysical techniques as a minimally invasive, repeatable, and scalable

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approach to explore subsurface structure and processes in the Critical Zone across multiple spatial-temporal scales. The advancement of Critical Zone science depends, to a significant degree, on the continued improvements of geophysical techniques for revealing subsurface structure and processes, and the establishment of Critical Zone Observatories provides necessary platforms for testing and improving various geophysical techniques.

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VISSER, Ate - *Lawrence Livermore National Lab*

## Tracking water through the Critical Zone: Models and isotope tracers at the Southern Sierra CZO

Ate Visser, Melissa Thaw, Amanda Deinhart, Richard Bibby, Ype van der Velde, Brad Esser, and Martha Conklin

The ability to track water through the Critical Zone, using chemical and isotopic tracers and models, has greatly enhanced our understanding of the hydrological system and improved vulnerability assessments of water supply. A combination isotopic tracers and particle tracking tools were applied at the Southern Sierra Critical Zone Observatory (California), to study the origin, residence time and fate of water. Providence Creek drains a small (4.6 km2) sub-alpine (1660-2117 m) catchment in a Mediterranean climate (8 °C, 1200 mm/yr) that is recovering from a severe 4-year drought (2012-2015).

The origin of precipitation at the SS-CZO was analyzed by means of NOAA HySplit air mass trajectory analyses with post-processing to accommodate atmospheric water transport. Higher latitude or inland sources bring higher tritium levels in precipitation than precipitation originating in the lower latitude Pacific Ocean. Precipitation sources explain 79% of observed variation in tritium in precipitation, improving stream flow residence time estimates.

Monthly samples of naturally occurring cosmogenic radioactive isotopes are analyzed to study how stream travel times vary with stream flow. Detections of sodium-22 (t_ = 2.6 years) are evidence of a small fraction of young (< 5 years) water. Low concentrations of sulfur-35 (t_ = 87 days) suggest very small contributions of same-year snowmelt or precipitation. Results from two contrasting years (severe drought in 2015 and near-normal conditions in 2016) illustrate travel time responses to hydrological conditions and further constrain subsurface storage in the catchment. Tracer-based residence time analyses are also compared to particle tracking through a ParFlow.CLM model of the catchment. Combining three cosmogenic tracers with model results provides a unique insight into the hydrological response of a catchment.

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WACHA, Ken - *USDA ARS; Intensively Managed Landscapes (IML) CZO*

## Big whorls have little whorls which feed into the runoff velocity all of which affect Aggregate Stability:   The break - up of macroaggregates to microaggregates

Kenneth Wacha, Thanos Papanicolaou, Benjamin Abban, Christopher Wilson, Jerry Hatfield, Timothy Filley, and Tingyu Hou

This study provides a systematic examination of the role of management practices on the functionality of aggregate size distribution and stability at the hillslope scale in managed landscapes. Soil samples were collected along the downslope flow pathways of representative hillslopes within conservation and conventionally managed fields as well as a restored prairie. Dual-level aggregate testing includes the determination of aggregate size distribution to reflect the degree of mechanized breakdown through various intensities of tillage, and rainfall simulators used to assess the stability of aggregates

against the fluvial process of raindrop impact. The focus is on the small macroaggregates as they best reflect the role of management on the aggregate size distribution and stability. Increased tillage perturbations were found to preferentially skew aggregate size distributions towards finer fractions as well as decrease stability. Conservation sites were shown to have comparable stability values as restored grassland sites, due to dampened perturbations to the soil and promotion of aggregate stabilization. The stability of aggregates due to raindrop and water impact may also provide some key insight on available size fractions preferentially entrained in various flow conditions.

Poster Session II Rm. 3 #3

WARD, Adam - *Indiana University; Intensively Managed Landscapes (IML) CZO*

## Nutrient export from intensively managed landscapes integrates human and natural forcing

Adam Ward, Scott Spak, Tyler Balson, Yuwei Li, and Kajsa Dalrymple

The modern food and energy systems are heavily reliant upon artificial fertilizer application to maintain crop yields. One highly visible consequence of humans altering this biogeochemical cycle is the export of nutrients from intensively managed landscapes to nearby waterways. These exports are exacerbated by changes in weather patterns and climate, where increasingly frequent droughts and floods alter the timing and magnitude of human-derived nutrients from the landscape. The results of excessive nutrient loads to waterways include harmful algal blooms and the development of hypoxic (or "dead") zones in gulfs and bays around the world.

A common assumption is that increasing nutrient exports from the landscape to waterways can be directly attributed to increasing fertilizer use in intensively managed landscapes. However, the last 20 years have seen increased focus on landscape

conservation, management of fertilizer losses, and increasingly efficient farming techniques (commonly "precision agriculture"). Given these advances in agricultural production, it would be reasonable to expect decreasing nutrient exports. Instead, empirical data suggest nutrient loads are generally constant or still increasing. Here, we consider the changes in climate that have occurred during the past 70 years as a possible explanatory variable for these nutrient export observations. Using agro-ecosystem models, we isolate the role of nitrogen fertilizer rate from that of changing climate to attribute nutrient export to a combination of management strategies and climate change. As a result, we demonstrate the interactions between human and natural systems in generating nutrient exports from intensively managed landscapes. Results of this work are useful to natural resource managers and regulators, as well and farmers and land managers, to efficiently and effectively manage nitrogen in the face of future change.

Poster Session I Rm. 3 #10

WAYMAN, Callum - *Pennsylvania State University; Susquehanna Shale Hills CZO*

## Modeling water and solute transport in a watershed with diverse landuses and lithologies

Callum Wayman, Tess Russo, Susan Brantley, Li Li, Brandon Forsythe, and Beth Hoagland

Developing simulations of water and nutrient transport that accurately reflect field observations is difficult in areas with complex subsurface heterogeneity. However, there is a need for watershed-scale nutrient and water transport models in watersheds containing varied lithology and landuses. RT-Flux-PIHM will be used to simulate water and solute transport within the Shaver's Creek watershed in central PA. RT-Flux-PIHM is a 3D numerical model that integrates a reactive transport (RT) module into a combined land surface and shallow groundwater/surface water model. As part of the Susquehanna Shale Hills Critical Zone

Observatory project, we have collected geochemical and hydrological data throughout Shaver's Creek watershed. The model will be applied and evaluated first within a small catchment on agriculturally developed land. Following successful simulation, the model will be expanded to encompass the Shaver's Creek watershed (163 km2), which includes both agricultural and forested land-types, and multiple lithologies. The primary inputs for both models include soil parameters, vegetation parameters, and meteorological forcing time series data. Calibration data will include measured stream discharge and nutrient concentration time series records, and remote sensing data for evapotranspiration (ET) rates across the watershed. Initially, Landsat 7 and 8 thermal imagery will be used to estimate ET, but other products may be used in the future if there is a call for data that Landsat cannot provide. Developing these models is important because they will improve our understanding of the effects of land development and bedrock geology on fluid and solute transport. Agriculturally developed land has distinctly different soil and land cover properties from those found in forested landscapes. This type of model could be applied in other watersheds to understand how changing land use could affect the physical hydrology and well as the geochemistry of those watersheds.

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WELTY, Claire - *University of Maryland, Baltimore County*

## Spatial and temporal variability of nitrate loads from groundwater in nested urban watersheds

Erin Stapleton, Claire Welty, John Kemper, and Jon Duncan

The Baltimore Ecosystem Study LTER maintains a network of SUNA v1 sensors recording stream nitrate concentrations every 30 minutes at six USGS stream gaging stations. The observation stations are situated in a nested watershed design within the 14.1 sq km urbanized Dead Run watershed, which ultimately drains to Baltimore Harbor and the Chesapeake Bay. Quantification of nitrogen delivery to the Chesapeake Bay is critical in carrying out local watershed implementation plans aimed at achieving nutrient reductions to comply with total maximum daily load regulations. Nitrate loads from groundwater and surface runoff in Dead Run were estimated using the method of Miller et al. (WRR 2016), which requires use of stream hydrograph base flow separation and high-frequency stream nitrate data. Partitioning of observed stream nitrate loads was carried out spatially across the subwatersheds and temporally over three years (December 2012 to December 2015). The calculated fraction of groundwater contribution to the total stream nitrate load ranged from 13% to 54%, varied across subwatersheds, and was generally greatest in the wet year of 2014 at all stations, when base flow was higher than normal. Annual first-order watershed-scale reaction rate constants for nitrate loss were determined for each site for each of the three years of data evaluated. Reaction rates generally ranged from about 0.10 to 0.60 d^-1, and varied spatially across subwatersheds and temporally across seasons. At some sites, this reaction rate was found to be negative, implying net export of nitrate. Known anthropogenic perturbations to the stream network from potable water leaks and sewer leaks contribute to the complexity of the observed results, demonstrating the need to incorporate water infrastructure data for enhanced understanding of the critical zone in urban watersheds.

WEN, Hang - *Pennsylvania State University*

## Scaling Magnesite Dissolution Rates Versus Time in Heterogeneous Porous Media

Hang Wen and Li Li

Mineral dissolution is a dominant control on water chemistry and global element cycles. Although extensive literature has documented the dependence of mineral dissolution on time and spatial scales in natural systems, a general rate law in heterogeneous media across scales remains elusive. Here we fill this gap by answering three questions: 1) How does the relative importance of transport (advection and diffusion) and reactions change across scales? 2) How and to what extent does the effects of spatial heterogeneity change as scales change? 3) What is the form of an upscaled rate law in heterogeneous media that integrate the effects of time and spatial scales? With data constraints from experimental work, we carried out 640 Monte-Carlo numerical experiments of magnesite dissolution within quartz matrix with spatial distributions characterized by permeability variance and correlation length under a wide range of flow velocity and domain length. We found that the relative strength between reaction, advection, and diffusion in the magnesite zones controls the significance of spatial heterogeneity on dissolution rates. Long residence times at small flow velocities and long domain lengths promotes the importance of diffusive transport that homogenize the spatial profiles, therefore leading to less heterogeneous impacts. An upscaled rate law was derived to quantify effective dissolution rates across scales based on kinetic rate constant measured under well-mixed conditions, and timescales of transport in the reactive zones and domain scale. This work provides a potential approach to predict the effect of spatial heterogeneity on mineral dissolution / chemical weathering in the Critical Zone.

WEST, Nicole - *Central Michigan University; Susquehanna Shale Hills CZO*

## Microclimate controls on the evolution of critical zone architecture in the Susquehanna Shale Hills Critical Zone Observatory

Nicole West, Eric Kirby, Andy Nyblade, and Susan Brantley

The functioning and structure of the critical zone is largely controlled by the formation of regolith. Therefore, understanding how regolith production and transport respond to perturbations in climate and/or tectonic forcing remains a first-order question in critical zone science. The Susquehanna Shale Hills Critical Zone Observatory (SSHO) is characterized by a systematic asymmetry in hillslope gradient and mobile regolith thicknesses; both are greater on north-facing hillslopes. Hydrologic and geochemical studies of the SSHO suggest asymmetric sediment transport, fluid flow, and mineral weathering with respect to hillslope aspect. We combine shallow seismic surveys completed along 4 hillslope transects (2 north-facing and 2-south facing), 2 ridgetops transects, and subsurface observations in boreholes to investigate the role of climate in inducing fracturing and priming the development of the observed asymmetry. Comparisons of shallow p-wave velocities with borehole and pit observations suggest the presence of three distinct layers at SSHO: 1) a deep, high velocity layer that is consistent with largely unweathered shale bedrock immediately overlain by 2) an intermediate velocity layer that is consistent with fractured and chemically altered bedrock, and 3) a shallow, slow velocity layer that is consistent with mobile material or shallow soil. Shallow p-wave velocity profiles suggest differences in thickness for both the mobile and immobile regolith material with respect to aspect. Patterns of p-wave velocities with depth are consistent with patterns of fracture densities observed in boreholes and with predictive cracking intensity models related to frost action.

Similarly, p-wave velocity profiles correspond with chemical depletion profiles measured in the SSHO subsurface. These data suggest that the feedbacks between chemical weathering and the physical structure of the critical zone at SSHO may be driven by microclimate asymmetry over geologic time.

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WHITE, Alissa - *University of Arizona; Catalina-Jemez CZO*

## Uranium and strontium isotope tracers of water rock interactions and biogeochemical processes in the critical zone

Alissa White, Lin Ma, Bryan Moravec, Jennifer McIntosh, and Jon Chorover

In the Jemez River Basin Critical Zone Observatory (JRB-CZO) in a remote NM headwater catchment, stable water isotopes and solute chemistry have shown that snowmelt infiltrates and is stored before later discharging into springs and streams via subsurface flowpaths that vary seasonally. Therefore, water transit times (WTT) and water-rock interactions are expected to also change with season as hydrologic flowpaths pass water through different biogeochemical conditions, rock types and porous structures. Uranium-series isotopes have recently been shown to be a novel tracer of water-rock reactions and source water contributions; therefore, this study seeks to understand how U isotope signatures evolve through the critical zone. More specifically, this work examines the relationship between seasonality, WTT, and U-series isotopes in several catchments within the JRB-CZO.

Samples from ten springs, for which WTT are already known, were collected and analyzed for U and strontium isotopes to determine the effect of WTT on the isotopic composition of natural waters. Preliminary results suggest that WTT cannot explain the variability of U and Sr isotope composition in springs throughout the JRB-CZO. Stream samples were also collected across two water years to establish how seasonality controls surface water isotopic composition. U and Sr isotope values vary with season; however, those changes are not consistent between catchments suggesting that differences in the mineralogy and structure of the deep critical zone, and partitioning of water along deep versus surficial flow paths, likely also control isotopic variability. Ongoing work investigating the distribution of U-series isotopes in solid phase core samples with depth beneath the surface show distinct weathering profiles with high $^{234}U/^{238}U$ corresponding to areas with high clay content. Such data will be vital for the characterization of hydrogeologic controls on isotopic composition in this complex lithologic terrain.

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WHITE, Tim - *Pennsylvania State University; National Office*

## Arborturbation rates in the Appalachian Mountains

Tim White, Ashlee Dere, and Sarah Sharkey

Arborturbation, or tree throw, the upheaval of soil and sometimes bedrock in the root mass of a fallen tree, has been suggested to be a major process in the overturn and downslope transport of soil and shallow bedrock in mountainous regions. Reported here is a quantification of tree throw effects along a climosequence of sites in the Appalachian Mountains from New York to Alabama. The study included field measurements of individual tree throws within a 120-meter diameter search area centered on shale ridge tops including: GPS location, tree girth, relative tree age, tree type, pit dimensions, azimuth of fall, and slope and azimuth of maximum slope; allowing quantification of volume and distance of transport of sediment per event, and the number of events/area/time.

The total number of tree throws decreases while sediment flux by tree throw generally increases from north to south along the study transect. Larger trees evacuate larger pits, but there is no observed

increase in average tree girth in the study area to account for the discrepancy between number of tree throws and sediment flux. The depth to a root limiting layer and the distance from the center of a root wad to the center of an excavated pit increases from north to south – deeper roots excavate more soil and deeper soils generally exist in warmer climates.

The measurements of tree throw were made as part of a broader effort to quantify erosion rates on shale slopes, information that is applicable to understanding the evolution of topography and regolith thickness on shale landscapes. The sediment fluxes reported here range from 1.8 X 10-5 m2/m/y to 2.1 X 10-4 m2/m/y. The observations double in number and verify formulations of sediment flux due to tree throw cited in the literature. Our values are comparable to the flux rates reported in the literature and exceed by several orders of magnitude values for sediment flux rate by soil creep on slopes.

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Poster Session II Rm. 6 #27

WILLENBRING, Jane - *University of California, San Diego; Luquillo CZO*

## Life in the slow lane - Tectonic controls on soils, nutrients, and tree canopies

Jane K. Willenbring, Gilles Y. Brocard, and Emma J. Harrison

Forest succession theory maintains that trees drape existing landscapes as passive niche optimizers, but in the Luquillo Mountains in Puerto Rico, the forest exerts a powerful control on erosion. The Luquillo Critical Zone observatory is set in the Luquillo Mountains, an isolated massif at the northeastern tip of Puerto Rico Island that receives up to five meters of rainfall annually. Physical erosion is kept low, occurring in the form of infrequent shallow landslides, thus increasing the residence time of minerals in the near-surface environment. The extensive chemical alteration of minerals generates a thick saprolite covered by fine-grained soil. Soils above the saprolite formed from quartz diorite

bedrock are nutrient-poor, forcing the rainforest to retrieve its nutrients from atmospheric fluxes, such as Saharan dust and marine aerosols. These atmospheric inputs are thus indirectly essential for the forest to be able to maintain slow erosion rates over the mountains. At lower elevation, using cosmogenic nuclide-derived denudation rates, we identified a wave of incision which has been propagating upstream over the past 4 My in the form of very steep and slowly migrating knickpoints. Bedrock abrasion and plucking are infrequent along the knickpoint faces, because the bedrock is massive and because rivers are bedload-starved. This situation is due to the highly weathered upland soils and slow erosion rates and high weathering rate upstream, which acts to reduce bedload grain size and limits bedload fluxes to the knickpoint, respectively. The soils change radically where the wave of erosion has passed and has increased erosion rates. There, nutrient-rich minerals make their way up into the soils, providing available cations to the forest. The knickpoints also mark a break in forest biomass patterns and on forest species composition.

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Poster Session I Rm. 4 #41

WILLIAMS, Jennifer Z - *Pennsylvania State University; Susquehanna Shale Hills CZO*

## TeenShale Network: Combining hands-on field experience with data-driven hydrology education tools

Jennifer Z. Williams, Sharon Dykhoff, Liza Brazil, Jon Pollak, Eugene Ruocchio, Yvonne Pickering, and Susan L. Brantley

TeenShale Network: Combining Hands-on Field Experience with Data-Driven Hydrology Education Tools
When high school students slip their feet into waders and step into a cold Pennsylvania stream to retrieve a data sensor, their learning leaps out of the textbook and beyond the classroom.  Data-driven, place-based education connects students to real-world issues in their local communities through

experiential learning that actively engages them with authentic scientific data.  In the field, students learn to quantify their observations as they use standard instruments to collect data first-hand.  As they share data and interact with researchers, they expand their knowledge, following the practice of scientists who collaborate with each other to understand complex systems.

The TeenShale Network is a multi-year project that focuses on two primary objectives: first, to monitor the quality of water in the Black Moshannon Creek in central Pennsylvania, located in close proximity to active hydraulic fracturing sites, and second, to engage students in authentic field research in collaboration with experts.  Students practice water quality monitoring techniques used by academics and government agencies, communicate their research in the news and scientific meetings, and use CUAHSI hydrology tools for analysis and visualization of datasets, large and small.  Using CUAHSI tools, students experience the complete lifecycle of data, from creation to publication to analysis to reuse.

This study seeks to understand the perceived impact of outdoor classroom projects by asking "How does working with authentic data in place-based scientific inquiry affect student perception about their role in scientific research?"  Research indicates that data-driven, place-based learning builds enthusiasm for scientific endeavors as it equips students to join the conversation about local environmental issues.  In the process, they become more active citizens, better stewards of the natural world, and perhaps even scientists themselves.

WILSON, Christopher G. - *The University of Tennessee; Intensively Managed Landscapes (IML) CZO*

## Dynamic assessment of current management in an intensively managed agroecosystem

Christopher G. Wilson, Kenneth M. Wacha, Thanos Papanicolaou, Heather A. Sander, Violet B. Freudenberg, and Benjamin K.B. Abban

A modeling framework is developed to assess management impacts on the functionality of intensively managed agroecosystems. The framework is equipped with dynamic, data-informed indicators and indices to illuminate the factors influencing sustainability.  The proposed dynamic indices consider natural and human aspects of an agroecosystem such as erosion, biogeochemistry, and economics. Most current indicators are static, or slow-changing, soil characterization parameters that reflect better long-term interactions between landscape features, climate, and biology. However, the ever-changing land management and climate necessitates the use of dynamic parameters that reflect agroecosystem responses to different land management on similar timescales. Our framework examines the performance of different ecosystem services including crop productivity, carbon storage, and net income under three different strategies with varying degrees of tillage intensity. The strategy with the highest intensity produced the highest yields, but also had the highest production costs. The second most intense strategy also had high yields, as well as the highest net income. However, these two strategies produced high erosion rates, which depleted the recalcitrant soil carbon, a critical component of system productivity and health. The study found that the more intense strategies were not sustainable despite their high short-term productivity or profitability. The least intense strategy had the lowest Soil Organic Carbon (SOC) depletion through erosion. Our study shows that to

augment SOC storage, it important not only to increase the overall organic matter input, but also increase the amount of recalcitrant carbon in the soil and the longevity of all soil carbon through aggregate formation.

WOO, Dong Kook  - *University of Illinois at Urbana–Champaign; Intensively Managed Landscapes (IML) CZO*

## Impact of subsurface tile drainage on distribution of concentration and age of inorganic soil nitrogen

Dong K. Woo and Praveen Kumar

While strategies to reduce inorganic nitrogen loading from drained agricultural lands have been widely studied, changes in the dynamics of the ``age'' of inorganic nitrogen in the soil due to tile drain systems have not been well investigated, limiting our ability to develop an adaptive management due to the time legacy of nitrogen. The objective of this study is to explore the impacts of tile drains on the age dynamics of nitrate, immobile ammonium, mobile ammonia/um, and nonreactive tracer (such as chloride) by developing a three-dimensional tile drain model. We applied this model to an agricultural farm supporting a corn-soybean rotation in the Midwestern United States. There is a common knowledge that the installation of tile drains will decrease the age of soil nutrient due to nutrient losses through tile drainage. However, an increase in the age of mobile ammonia/um is observed in contrast to the cases for nitrate, immobile ammonium, and nonreactive tracer. These results arise because the depletion of mobile ammonia/um due to tile drainage causes a high mobility flux from immobile ammonium to mobile ammonia/um, which also carries a considerable amount of relatively old age of immobile ammonium to mobile ammonia/um. In addition, the ages of nitrate and mobile ammonia/um in tile drainage range from 1 to 3 years, and less than a year, respectively, implying that not considering age transformations between

nitrogen species would result in substantial underestimation of nitrogen ages, possibly leading to an erroneous conclusion.

WYMORE, Adam - *University of New Hampshire; Luquillo CZO*

## Critical zone structure controls concentration-discharge relationships and solute generation in forested tropical montane watersheds

Adam Wymore, Daniel Ibarra, Richard Brereton, Kate Maher, and William McDowell

Concentration-discharge (C-Q) relationships are poorly known for tropical watersheds, even though the tropics contribute a disproportionate amount of solutes to the global ocean. The Luquillo Critical Zone Observatory in Puerto Rico offers an ideal environment to examine C-Q relationships across a heterogeneous tropical montane landscape. We use 10-30 years of weekly stream chemistry data across ten watersheds to examine C-Q relationships for weathering products ($SiO_2(aq)$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$) and biologically-controlled solutes (dissolved organic carbon [DOC], $NH_4^+$, $NO_3^-$, $PO_4^{3-}$, $K^+$, $SO_4^{2-}$). We analyze C-Q relationships using power-law equations and a solute production model, and use Principal Component Analysis to test hypotheses regarding how the structure of the Critical Zone controls solute generation. Volcaniclastic watersheds had higher concentrations of weathering solutes and smaller tributaries were approximately 3-fold more efficient at generating these solutes than larger rivers. Lithology and vegetation explained a significant amount of variation in the theoretical maximum concentrations of weathering solutes and in the C-Q relationships of $PO_4^{3-}$ and $SiO_2(aq)$. However, the direction and magnitude of these relationships varied. Across watersheds various forms of N and P displayed variable C-Q relationships, while DOC was consistently enriched with increasing discharge. Results suggest that $PO_4^{3-}$ may be a useful indicator of watershed function. Relationships between C-Q

and landscape characteristics indicate the extent to which the structure and function of the critical zone controls watershed solute fluxes.

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XIAO, Dacheng - *Pennsylvania State University; Susquehanna Shale Hills CZO*

## Understanding controls of hydrologic processes across two monolithological catchments using model–data synthesis

Dacheng Xiao, Yuning Shi, and Li Li

Field measurements are important to understand the fluxes of water, energy, sediment, and solute in the Critical Zone however are expensive in time, money, and labor. This study aims to assess the model predictability of hydrological processes in a watershed using information from another intensively measured watershed and understand controls of hydrologic processes across two watersheds. We compare two watersheds of different lithology using national datasets, field measurements, and physics–based model, Flux–PIHM. We focus on two monolithological, forested watersheds under the same climate in the Shale Hills Susquehanna CZO in central Pennsylvania: the Shale–based Shale Hills (SSH, 0.08 km2) and the sandstone–based Garner Run (GR, 1.34 km2). We firstly tested the transferability of calibration coefficients from SSH to GR. We found that without any calibration the model can successfully predict seasonal average soil moisture and discharge which shows the advantage of a physics–based model, however, cannot precisely capture some peaks or the runoff in the dry condition. The model reproduces the GR field data with high performance after calibrating the soil related parameters with the HSY algorithm and the Latin Hypercube Sampling method. The parameter difference between two watersheds shows that the sandstone has larger pore diameter, larger water storage created by porosity, lower water retention ability, shallower soil layer depth, and larger preferential flow. The water budget calculation reflects a gentle slope region can

act as a buffer zone which influences the contributions to stream discharge and the water balance. A field measured boulder map helps to estimate parameter close to physical meanings and reproduce a better spatial distribution of water variables. This work also provides an approach of model-data synthesis can be applied to other watershed comparison cases with different vegetation or climate condition.

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YAN, Qina - *University of Illinois at Urbana-Champaign; Intensively Managed Landscapes (IML) CZO*

## Soil organic carbon dynamics in intensively management landscapes

Qina Yan and Praveen Kumar

In agricultural areas, soil is the largest reservoir of carbon in the biosphere but is going through rapid erosion due to crop harvest, tillage, and tile drainage. For example, in the U.S. Midwest, massive land is intensively managed for agriculture practices. Identifying whether the production of soil organic carbon (SOC) can compensate for the loss due to erosion is critical to ensure our food security and adjust to climate shift.

This work focuses on the soil organic carbon dynamics in agricultural fields. We build a model that couples landscape evolution, surface water runoff, organic matter transformation, and soil moisture dynamics to understand organic carbon gain and loss due to nature forcing and farming practices, such as fertilizer and tillage. Our results show that both LE and farming practices play dominant roles in soil organic carbon (SOC) both above- and below-ground. Contrary to a common assumption that a vertical profile of SOC concentration decreases exponentially, we find that in many situations SOC concentration below-ground could be higher than the one at surface. Tillage plays a very complicated role in organic matter dynamics. How tillage affects carbon storage depends on the way of tilling

practices and climate forcing. In general, our model shows that tillage changes the C-N oscillation cycle and hence increase the time to reach a dynamic equilibrium. The SOC measured in the field site of Intensively Managed Landscapes Critical Zone Observatory (IMLCZO) is consistent with our model results.

This model framework bridges the gaps between the landscape evolution, below- and above-ground hydro cycle, and biogeochemical processes. This study not only helps us understand the natural carbon-nitrogen cycle, but also serve as an instrument to develop practical means for reducing soil erosion and carbon loss when the landscape is affected by human activities.

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Poster Session II Rm. 6 #25

ZHANG, Yu - *Duke University; Susquehanna Shale Hills CZO*

## Water-regolith-energy interaction in landscape evolution and its influence on forming asymmetric landscape: model development and application in the Shale Hills CZO

Yu Zhang, Rudy Slingerland, Tim White, Yuning Shi, Christopher Duffy, Ashlee Dere, and Henry Lin

With relative homogeneous bedrock, regolith, and tectonic uplift, a 0.08 km2 first order catchment (Shale Hills Critical Zone Observatory, SSHCZO) shows asymmetric slope and thickness of regolith on the north- and south-facing hillslopes. What are the possible factors causing these differences, and what are the differences of spatial distribution of regolith transport fluxes on both sides of hillslopes? With the support of multi-spatial and temporal scale data for model parametrization, calibration and validation, this study utilized a hydrological-morphodynamic model (LE-PIHM) which links bedrock, soil, surface and subsurface water flow, plant, energy, and seasonal climate to estimate the regolith transport and explore the possible factors that cause the

topographic asymmetry of SSHCZO. Two non-dimensional parameters were used to explore the competitive relationship between regolith diffusion and advection towards steady state. Model simulation under seasonal meteorological forcing shows obvious spatial variations of hillslope sediment fluxes. The region of highest diffusion rate locates at the planar of the south-facing slope and the minimum rate comes from the planar of the north-facing slope, which indicates that the transport efficiency estimated from the previous field measurement overestimates the difference of sediment transport efficiency on the two hillslopes. The largest regolith transport rate by overland flow happens at the junctions of main channel and swales. Especially, the model simulation indicates that different solar insolation which affects freeze-thaw frequency is the major factor that causes asymmetric sediment diffusivity, thereby causing asymmetric hillslope profiles. This study estimated regolith transport at watershed scale and highlights the critical transition zone where additional measurement or observation should be conducted in order to support a better estimation at watershed scale.

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Poster Session II Rm. 5 #57

ZHI, Wei - *Pennsylvania State University*

## Metal transport enhanced by dissolved organic carbon (DOC) at the watershed scale

Wei Zhi, Li Li, Jason Kaye, Kenneth Williams, and Carl Steefel

Extensive lab studies have demonstrated that DOC enhances metal mobility and metal leaching from soil columns. Understanding of the DOC-metal coupling at the watershed scale has been relatively limited. This study aims to test the hypothesis that DOC facilitates metal transport and is primarily controlled by large water events at the watershed scale. We test the hypothesis at the Coal Creek, Colorado, using paired concentration-discharge (CQ) data from a USGS station at the mouth of Coal

Creek. The data exhibits contrasting CQ behaviors of geogenic species (Na, Ca, Mg) and trace metals (Fe, Al, Cu). The geogenic species shows dilution behavior where concentrations decrease as discharge increases. In contrast, trace metals that form complexes with DOC showed enrichment behaviors that are similar to those of DOC export, where concentrations increase under increasing discharges, particularly under spring snowmelt conditions.  Large discharge events (avg. 6.0 m3/s) during spring snowmelt seasons that occurred only 4.5% of time accounted for disproportionately higher fractions of 49.3%, 49.6%, 48.7%, and 50.3% for annual export of DOC, Fe, Al, and Cu, respectively. This study indicates that export of trace metals and DOC from terrestrial lands to aquatic systems are highly skewed toward hydrological "hot moments". High-elevation and snow-dominated watersheds in the remote region usually suffer from undersampling and lack of data. This study highlights the importance of understanding climate change in contaminant and nutrients export, where extreme hydrological events are expected to occur more often.

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ZHOU, Shengnan - *University of Tennessee; Intensively Managed Landscapes (IML) CZO*

## Potential carbon transport: Linking soil aggregate stability and sediment enrichment for updating the soil active layer of Intensely Managed Landscapes (IMLs)

Shengnan Zhou, Thanos Papanicolaou, Kenneth Wacha, Christos Giannopoulos, Christopher Wilson, and Benjamin Abban

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ZHU, Mike - *University of Wyoming*

## Phosphorus biogeochemical transformation and effects of aeolian dust deposition during long-term soil development in semi-arid ecosystems

Mengqiang Zhu, Chunhao Gu, and Stephen Hart

Soil phosphorus (P) is often a limiting nutrient in terrestrial ecosystems and its stock and chemical forms (speciation), accordingly its bioavailability, depends on the degree of soil development. The widely accepted Walker and Syers model, describing P biogeochemical transformation during soil development, is limited inherently as it describes changes of operationally-defined P pools by chemical extractions, not P chemical speciation. Additionally, aeolian dust input is another major source of P to soils and can alter soil properties, complicating the efforts to study P biogeochemical transformation.

Here we determined P biogeochemical transformation and the effects of dust input along a 3-million-year-old soil chronosequence in Arizona using speciation-based P K-edge X-ray absorption near-edge structure spectroscopy. Our results show that the input of alkaline calcareous aeolian dust into soils greatly alters P speciation in the old soils (750 ka – 3000 ka) by increasing calcium-bound P (Ca-P) contribution and decreasing Al- and Fe-P contributions due to the high dust mass contribution to soils. However, the effects on younger soils are weaker because of low dust input. We also observed that dust input enhances soil pH, expectedly retarding P geochemical transformation. Such interference on P speciation may not be observable in humid ecosystems because strong weathering power due to the high soil acidity. A speciation-based model is proposed to describe P transformation during soil development with or without dust input in a semi-arid ecosystem.

This work has important implications for understanding how aeolian dust deposition affects P dynamics in the critical zone and associated ecosystem properties in a semi-arid ecosystem. The results are particularly useful considering that global dust deposition has been increasing due to land use changes and increasing aridity of the dust source regions.

Combined, these case studies highlight the need for Critical Zone science to take a four-dimensional approach to studying LULC change which integrates relatively well-characterized vertical changes in the water and energy balance, with understudied lateral feedbacks and the timescales over which these processes occur.

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Poster Session II Rm. 3 #4

ZIPPER, Sam - *McGill University*

## Land use change in four dimensions: Groundwater as a vector for the lateral transmission of ecohydrological impacts

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Land use/land cover (LULC) change is a primary global change driver; however, the ecohydrological impacts of LULC change are typically studied locally, at the location where the change occurred. A key challenge for Critical Zone science to effectively guide LULC decisions is understanding how LULC change can impact both local and distant ecohydrological processes. Using examples drawn from two Long Term Ecological Research (LTER) network sites, we demonstrate that changes to the vertical water and energy balance caused by LULC change in one location can laterally propagate through the groundwater flow system to impact critical zone processes elsewhere on the landscape. In an agricultural watershed representative of south-central Wisconsin, urbanization decreases groundwater recharge relative to baseline corn ecosystems, leading to reductions in water table depth at the landscape scale and increased water stress during drought for remaining corn regions. In a permafrost-dominated setting representative of the Alaskan North Slope, fire-induced changes in LULC lead to an increase in ground temperature and active layer thickness. This contributes to enhanced groundwater flow and permafrost degradation in areas downgradient of fire-affected regions.