National CZO Program

CRITICAL ZONE OBSERVATORIES

funded by NSF

studying the zone where rock meets life

The **Critical Zone Observatories National Office** (CZONO) was established to promote collaboration and coordination across both the individual CZOs and the diverse scientific disciplines represented by each research team. The office is staffed by Director Lou Derry (Cornell) and Coordinator Tim White (Penn State) and includes a post-doctoral scientist.

The office seeks to further develop the science of the Critical Zone by working with diverse researchers to address scientific questions that are of broad interest and relevance across the Critical Zone, and therefore can have significant intellectual and/or societal impact. Further, the CZONO seeks to facilitate and develop educational opportunities and resources to promote the study of the Critical Zone at the graduate and undergraduate level, and to integrate the Critical Zone connect into the geoscience curriculum beginning at the K-12 level.

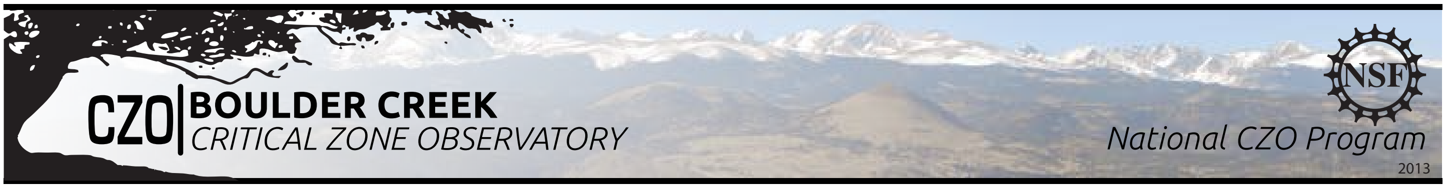
Routine activities of the CZONO that will help to accomplish these goals include: establishing regular communication among CZO PIs, organizing two national meetings annually, offering graduate/young scientists workshops, and developing electronic delivery of educational resources for Critical Zone science. The CZONO will lead the maintenance and further development of the criticalzone.org website, a key resource for the CZO and the broader scientific community. It will develop and maintain a visible presence in the scientific community at national and international meetings and via new media. The office will also seek to identify and raise funds for larger initiatives, including international summer schools in Critical Zone science and a national Critical Zone K-12 education strategy. An important function of the CZONO will be to integrate scientists and students currently outside the CZO community to take advantage of the CZO as an outstanding scientific resource.

An aspirational goal of the CZONO and U.S. CZO network is to develop a collaborative research and education network of sites, people and data that represents the diversity of environmental landscapes in North America. As arrayed in 2014, the CZOs do not cover the full range of environmental gradient space. The CZ science community must collaborate with environmental science networks, including internationally, to identify societally relevant research pursuits that can only be informed by observatory-style environmental gradient science. Thus, the NO will act as a liaison between the CZO program and other networks. Only through collaborative science, education and outreach, will CZO science begin to inform decision and policy makers to properly manage a range of natural resources threatened by climate and land-use change.

A national education component of CZO science is poised for great progress in the U.S. over the coming decade. Existing short and semester-long courses for secondary education teachers, classroom activity guides, and a recently developed semester long undergraduate course will continue to be offered through the CZONO. The CZONO-led Science Across Virtual Institutes (SAVI) program will reinvigorate the U.S. NSF CZ International Scholars program, support post-doctoral research, as well as field schools, joint field campaigns, training workshops, and cyberseminar and speaker series. All of these actions will focus on developing societally relevant cross-network science questions that use common measurements at the CZOs, and thus will build from, and support and inform science at the observatories.

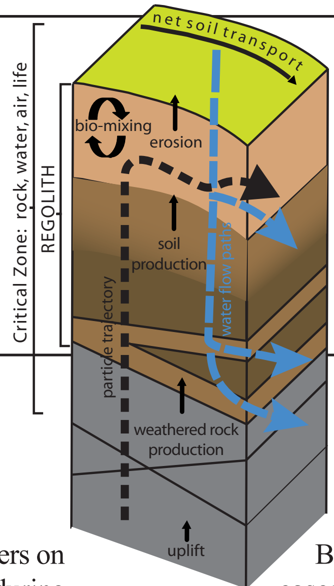
Contact: Lou Derry, lad9@cornell.edu
Tim White, tsw113@psu.edu

For more information, see http://criticalzone.org/national/infrastructure/national-office/.



Spotlight on The Boulder Creek CZO

BcCZO aims to understand how CZ architecture evolves over time, how it conditions hydrologic and biogeochemical response and ecosystem structure, and how it will respond to future changes in climate. We document critical zone architecture, and study denudation processes, weathering front advance, and hydro-biogeochemical coupling.



The BcCZO is situated in the Colorado Front Range, one of the Laramide ranges. Boulder Creek flows east, from the Continental Divide to the eastern Great Plains, crossing landscapes shaped by glaciers and permafrost, fluvial canyon incision, and exhumation of the former Cretaceous seaway on the Great Plains.

Key insights

1) Critical Zone role in exhumation of the Plains: Cosmogenic radionuclide ages of strath terrace sediment covers on the Plains suggest that terrace planation occurs during glacials, and river incision during deep interglacials. Change in sediment delivery from hillslopes thus is a key driver of river downcutting, which itself incites transient adjustment of hillslopes.

2) Multiple roles of trees: In addition to sediment transport by tree-fall, trees also stress rock and transport regolith, simply by growing and dying. Over the lifetime of a tree (order 100 years), rock and regolith are dilated and collapse--- the roots act as slow explosions, breaking and prying apart rock.

3) Water flow: Hydraulic conductivity and porosity structure of the critical zone controls water flow, with feedbacks on ecosystem and rock porosity stucture evolution. For instance the decline in porosity with depth leads to potential for threshold-like behavior in water delivery to rocks and for strong lateral flow even in the vadose zone.

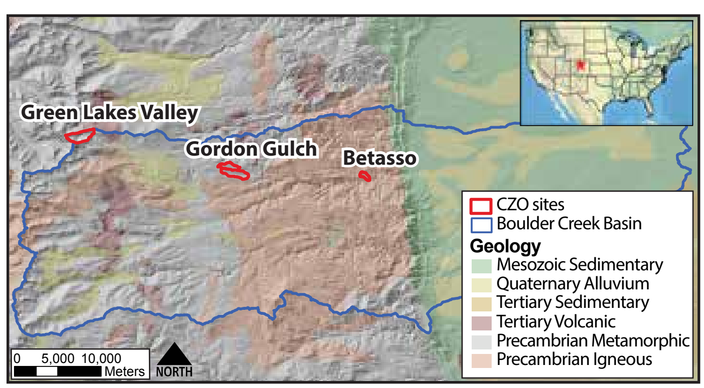
4) Slope aspect: At the rain-snow transition, aspect strongly controls snowpack presence, which controls water flow paths. Thickness of weathered rock varies with slope aspect as well, which could reflect these differences in water flow path or some other process difference over the order 10^5 year residence time in the weathered rock layers.

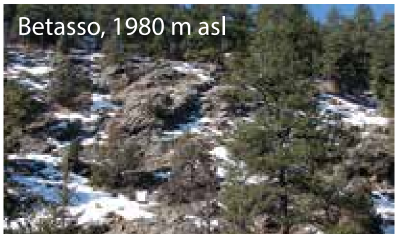
Focus catchments within Boulder Creek

Betasso (1980 m) is granodiorite in lower Boulder Canyon. Its steep ephemeral stream cascades into Boulder Canyon from a low relief upland. Vegetation is dominated by grasses and Ponderosa pine (*P. ponderosa*). MAP is 400 mm, 60% as snow.

Gordon Gulch (2590 m) is in the low relief Rocky Mountain surface, underlain by biotite gneiss. Long evolution, notably including past periglacial conditions, shaped this landscape. Different aspect slopes present contrasts in soils and vegetation: thinner, less-weathered rock with grasses and Ponderosa pine (*P. ponderosa*) on south-facing slopes, and thicker, more weathered rock with dense Lodgepole pine (*P. cortorta*) on north-facing slopes. MAP is 780 mm, 70% as snow.

Green Lakes Valley (3800 m) is a glaciated alpine watershed on biotite gneiss and granodiorite. As part of the Niwot Ridge LTER, monitoring data extends back several decades. MAP is 1190 mm, 85% as snow.




Betasso, 1980 m asl


Gordon Gulch, 2590 m asl


Green Lakes Valley, 3800 m asl

Current infrastructure at the BcCZO


Snow poles, automated camera, and soil water sampling sites.

- Meteorological tower (Betasso, Gordon Gulch)
- Continuously recording soil temperature and soil water content probes at multiple depths within the soil profile (all locations)
- Arrays of soil water samplers (zero tension, ceramic and fused quartz suction lysimeters) (Gordon Gulch)
- Snow depth sensors (automated) (all locations)
- Time-lapse cameras (Gordon Gulch, Green Lakes Valley)
- Stream gauges (all locations)
- Automated stream water samplers (Gordon Gulch)
- Manual surface water and snow sampling program (all locations)
- Groundwater wells (Betasso, Gordon Gulch)

Nearby infrastructure

- Meterological monitoring at Niwot Ridge and Sugarloaf including Ameriflux, SNOWTEL, and NADP sites
- USGS maintained stream gages on Boulder Creek and Fourmile Creek
- Niwot Ridge LTER

Beyond the Science

Community Outreach *& Education*
BcCZO partners with CU's Science Discovery to bring Critical Zone science to K-12

Summer classes "Go with the Flow", "Fire and Ice".

Middle School "Science Explorers" workshops

High School mountain research experience.
Colorado Teachers professional development field course.
http://www.colorado.edu/sciencedisovery/

Talk with BcCZO scientists

Suzanne Anderson (PI) University of Colorado, Boulder
Robert Anderson, University of Colorado, Boulder
Dave Barnard (post-doc) University of Colorado, Boulder
Holly Barnard, University of Colorad of Boulder
Dan Doak, University of Colorado, Boulder
Noah Fierer, University of Colorado, Boulder
Adrian Harpold, University of Colorado, Boulder
Clayton Jensen (research staff)
Diane McKnight, University of Colorado, Boulder
Noah Molotch, University of Colorado, Boulder
Sheila Murphy, U.S. Geological Survey
Hari Rajaram, University of Colorado, Boulder
Nate Rock (research staff)
Anne Sheehan, University of Colorado, Boulder
Kamini Singha, Colorado School of Mines
Alexis Templeton, University of Colorado, Boulder
Gregory Tucker, University of Colorado, Boulder

What can you do? How to Get Involved

The BcCZO welcomes research by investigators from across the earth and environmental sciences. ***Projects that integrate datasets from or ask questions across multiple CZOs are particularly encouraged***.

For more informationBcCZO website:
http://criticalzone.org/boulder/
Data: http://criticalzone.org/boulder/data/
Email Data Manager Jeri Tebbetts: bcczodata@colorado.edu
Email Suzanne Anderson (BcCZO PI): suzanne.anderson@colorado.edu

CZO | CALHOUN
CRITICAL ZONE OBSERVATORY

NATIONAL CZO PROGRAM

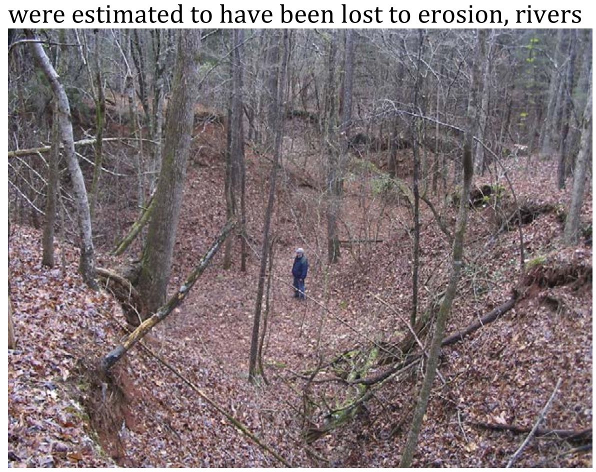
An observatory that integrates human and natural forcings of Earth's Critical Zones and the sciences of water, mineral, and organic matter cycles

A new CZO. The Calhoun CZO seeks to understand how Earth's Critical Zones (CZ) respond to severe soil erosion and land degradation. Re-instrumented catchments measure and help model changes in ecohydrology and biogeochemistry of interfluves, hill slopes, and terraces that were historically subject to accelerated erosion and deposition. Because CZs are integrated systems from upper plant-canopies to water in deep aquifers, research focuses on how land use stresses networks and processes that connect the CZ's surface and subsurface subsystems. Researchers will use historic and contemporary data of vegetation, soil, catchments, and sensor networks to help hindcast and forecast CZ dynamics and evolution across temporal and spatial scales.

USDA Forest Service Calhoun Experimental Forest Photo: ~1948

Location and Current Investigators. The Calhoun CZO is located in the USA's Southern Piedmont that extends from Virginia to Alabama. The new Calhoun CZO leverages more than 60 years of USDA Forest Service and Duke University research on land and water degradation and soil change based at the Forest Service's Calhoun Experimental Forest in the Sumter National Forest. The CZO investigators include researchers and educators from Duke University, University of Georgia, Georgia Tech, University of Kansas, Mississippi State University, Roanoke College, as well as the USDA Forest Service.

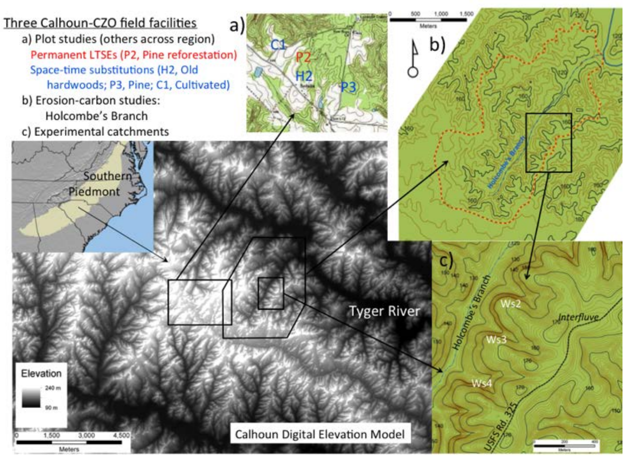
Critical Zone Evolution on the Piedmont. The Calhoun CZO aims to improve understanding of the dynamics and evolution of biota, landforms, soils, saprolites, hillslope hydrology, stream channels, and sediments that comprise CZs with belowground systems that are ancient (>10^6 y), deep (~30 m on interfluves), and of advanced-weathering stage, often with no weatherable primary minerals for many meters in depth. These attributes suggest CZs that are highly vulnerable to human alteration, and indeed, much of the Southern Piedmont including the Calhoun Experimental Forest has a history that involves some of the most serious agricultural land and water degradation in the nation. By the mid-20th century, nearly 18-cm of soil over more than 10 million ha were estimated to have been lost to erosion, rivers



Calhoun Experimental Forest photo, ~2006 James et al. Catena

carried enormous sediment yields, cultivation-based crops were no longer viable, and large numbers of farmers had abandoned the land. Remarkably, by the late 20th century, the eroded and often abandoned Piedmont farmland had been extensively reforested, motivating many to adopt the perspective that the degraded land had been restored in a matter of decades by a process known as "old-field succession." *Our team has a more critical perspective, and is guided by a hypothesis that the impressive reforestation masks fundamental alterations in CZ hydrology, geomorphology, biology, and biogeochemistry and that post-disturbance CZ evolution may not so much recover as restabilize in altered states*. Given all this, the Calhoun-CZO provides an important opportunity for meeting the growing need to understand CZs "in the face of land use change … to inform strategies for sustaining a wide range of human activities" (from NSF's CZO Program Solicitation, NSF 12-575).

Critical Zone Science at the Calhoun CZO. We live in a time in which over half of the Earth's CZs are affected by natural *and* human forcings, and a key objective of the Calhoun-CZO is to help integrate humanity into CZ science. To that end, we see Calhoun CZ science to be transformational in exploring the CZ's lower boundary conditions and processes, and the CZ's evolution following land degradation. The CZO is organized by research questions motivated by the concept that natural CZs are integrated systems from upper plant-canopy boundary layer to the water in the deepest aquifers and that human forcings typically accelerate CZ processes associated with vegetation, atmosphere, and surface hydrology and soils, thus stressing temporal and spatial networks that connect surface and deep subsurface components of the CZ.



Three Calhoun CZO field facilities located on topo and DEM maps..

The questions that organize Calhoun CZO research build directly on past research at the site and span multiple scales of time and space:

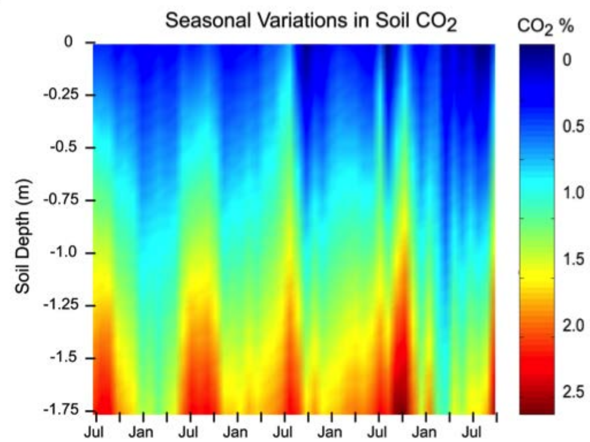
1) Do land-use change, land degradation, and erosion decouple upper and lower CZ systems, by destroying macroporosity networks that are conduits of gas and water exchange? How rapidly can re-forestation recover CZ porosity and re-network the CZ into an integrated system?

2) How has the legacy of severe erosion redistributed and altered organic carbon dynamics on both eroded uplands and in anoxic alluvium filled with historic sediment?

3) How do human-forced changes in the CZ interact with human livelihoods, adaptation, and governance?

4) Can human-forced CZs enter new steady states, complete with positive feedbacks and attractors that resist recovery?

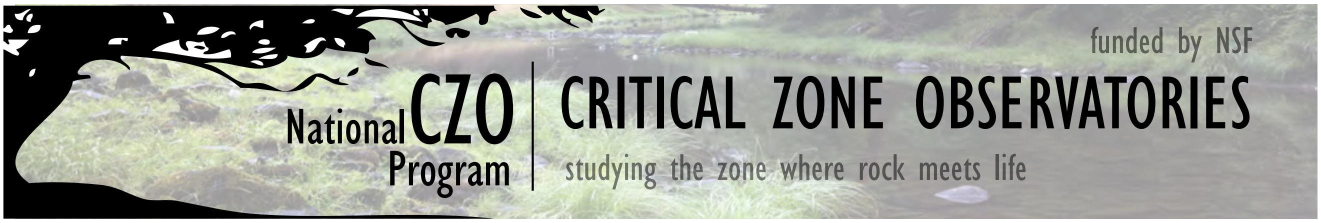
Re- and up-instrumented catchments, first instrumented by hydrologists in the late 1940s, will allow investigators to measure, experiment, and model ecohydrologic and biogeochemical dynamics from interfluves to a variety of hill slopes to toe slopes and terraces, all across multiple temporal and spatial scales. Sensors connected by wireless networks and samplers of gases and water will be co-located along transects and in depth-dependent arrangements to examine the recovery of integration in the degraded Critical Zone systems. Interdisciplinary models are being coupled with radiocarbon and stable isotope analyses to hindcast and forecast system hydrology, soil properties and processes, and overall CZ biogeochemistry.



Deep CO_2, soil solid and solution data will be greatly expanded in Calhoun-specific and Cross-CZO studies.

Broader Impacts of CZO Science. The Calhoun-CZO is a center for research *and* education. The CZO is linked to a Duke University IGERT-training center on intelligent sensor networks, annual CZO science meetings will have oral and poster presentations, discussions, and training sessions that involve scientists and students as fundamental members of the CZO team. We plan a range of outreach efforts to local, regional, and national publics with multi-media science, history, and community-based components, using field days, hardcover books, op-eds, Facebook, and Twitter. An important focus of the CZO is on undergraduate research and education, and we are developing a set of classroom-tested, web-based laboratory and classroom activities for undergraduates and advanced high school students based, in part, on real-time and historic data from the Calhoun CZO.

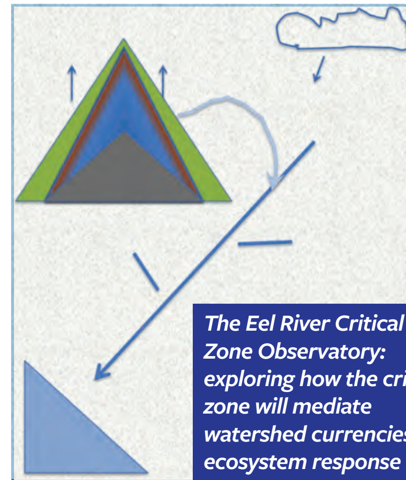
For further information contact the PIs at Duke University, Daniel Richter, Amilcare Porporato, Brian McGlynn, Mukesh Kumar, or Sari Palmroth; at University of Georgia, Daniel Markewitz, Paul Schroader, Aaron Thompson, Don Nelson, or Alex Cherkinsky; at Georgia Tech, Rafael Bras or Jingfeng Wang; University of Kansas, Sharon Billings; Mississippi State, James Giessen; and Roanoke College, Katherine O'Neill.



The Eel River Critical Zone Observatory

Research Focus: Watershed Currencies & the Critical Zone

The Eel River CZO follows watershed currencies including **water, solutes, gases, sediment, biota, energy and momentum** through intensive field monitoring. These currencies move through the subsurface physical environment and microbial ecosystem into the terrestrial ecosystem, up into the atmosphere, and out through diverse drainage channel networks, which mediate the delivery of nutrients to coastal ecosystems at the river mouth.

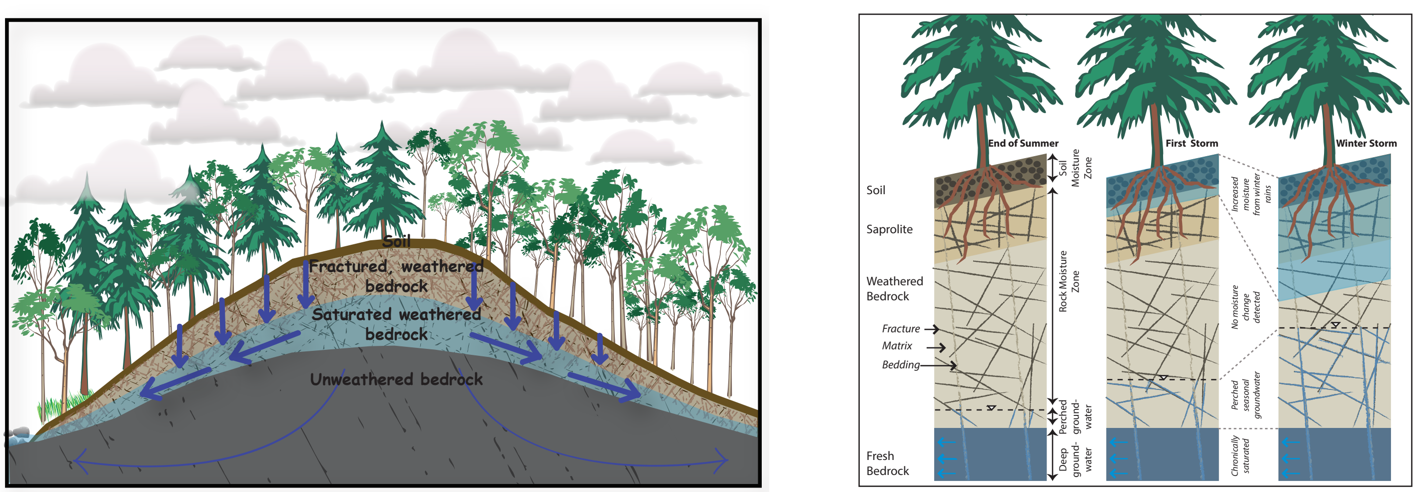


The Eel River Critical Zone Observatory: exploring how the critical zone will mediate watershed currencies and ecosystem response in a changing environment.

The critical zone of vegetation (green), soil and weathered bedrock with perched water table (red to blue), overlying fresh bedrock (grey) that exchange currencies (arrows) with atmosphere (cloud) and mediates effluents (curved arrow) to a channel network (lines) which drain to ocean (blue triangle).

Research Questions

1) Does lithology control rock moisture availability to plants and therefore overall resilience of vegetation to climate change in seasonally dry environments?
2) How are solute and gas effluents from hillslopes influenced by biota in changing moisture regimes?
3) What controls the spatial extent of wetted channels in the channel networks of seasonally dry environments?
4) Will changes in critical zone currencies induced by climate or land use change lead to threshold-type switches in river and coastal ecosystems?



Idealized cross-section through the hillslope (left) and profiles (right) showing vertical structure and seasonal rapid injection of winter rain via fracture flow to a perched water table as soil and saprolite and weathered bedrock more slowly gain moisture (Salve, et al., 2012).

Modeling Framework

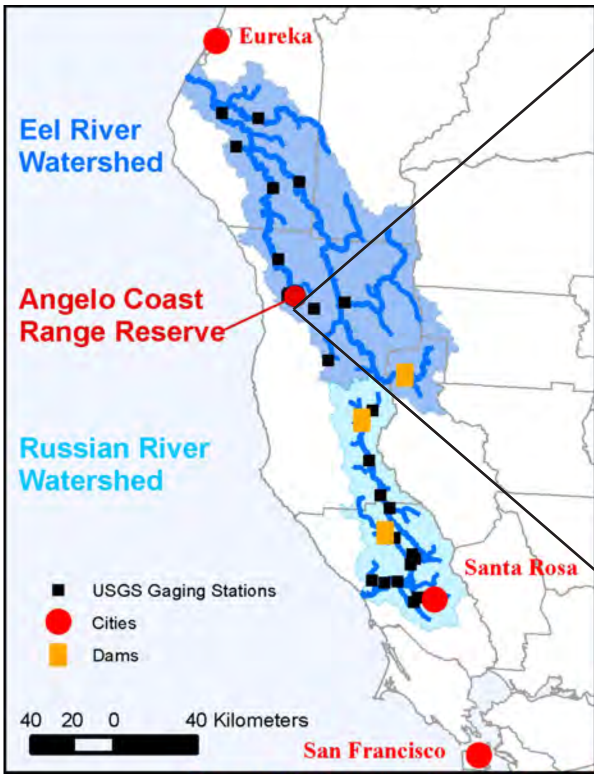
AWESOM - Atmosphere, Watershed, Ecology, Stream, and Ocean Model

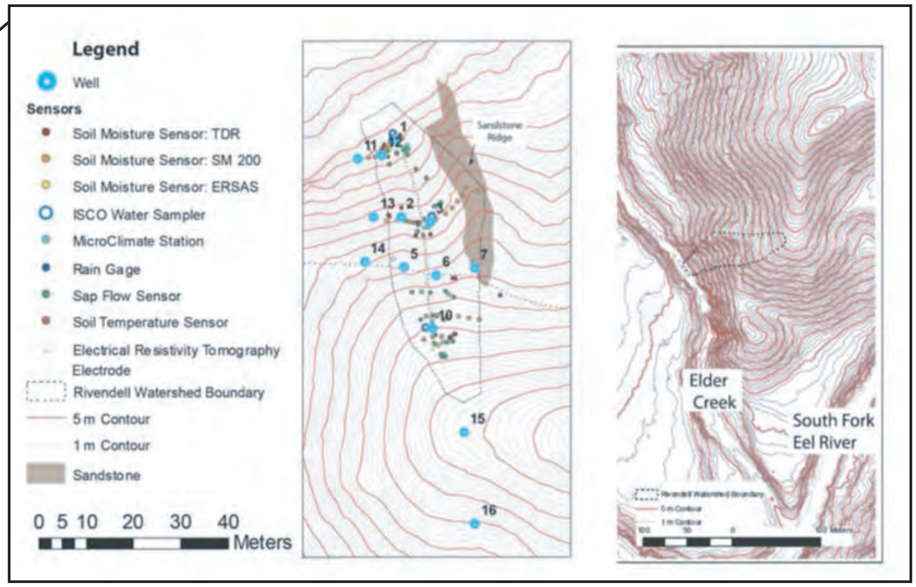
AWESOM is being developed to predict watershed currency dynamics as mediated by the critical zone and link them to climate and four distinct ecosystems: forests, subsurface (soil surface to the base of the weathered bedrock), streams, and coastal oceans. AWESOM builds upon existing models to explicitly explore critical zone influence on watershed currencies and link their dynamics to ecosystem fates in a changing world.

Northern California Study Sites

The Eel River watershed (9540 km^2) and its southern neighbor, the Russian River watershed (4260 km^2) offer an ideal opportunity to conduct fine scale research within the critical zone, follow currencies to the atmosphere, streams and ocean as they drive and are altered by a succession of ecosystems, and explore the consequences for management practices caused by changing climate and land use.

Our Critical Zone Workshop at Angelo Coast Range Reserve (Rivendell)





We have been intensively monitoring a ~4000 m^2 densely forested hillslope underlain primarily by mudstone adjacent to Elder Creek in the South Fork Eel River watershed since 2007. We recently expanded our intensive monitoring to hillslopes 20 km to the southeast in landscapes underlain by mélange and covered in grass and scattered hardwood trees to explore how lithology drives ecohydrology.

Eel River CZO website: http://angelo.berkeley.edu
Keck Hydrowatch Data: http://sensor.berkeley.edu

Director: William E. Dietrich
Deputy Director: Sally Thompson
Project Coordinator: Jen Hunter
Data Manager: Collin Bode
Co-PIs and Senior Personnel at UC Berkeley:
Jill Banfield, James Bishop, Stephanie Carlson, Todd Dawson,
Mary Firestone, Inez Fung, & Mary Power

CZO National Program: http://criticalzone.org/national

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INTENSIVELY MANAGED LANDSCAPES Critical Zone Observatory (IML-CZO)

Upper Sangamon Basin, Illinois • Clear Creek Watershed, Iowa • Minnesota River Basin, Minnesota

Artificial surface and subsurface drainage systems in the agricultural Midwest have altered the natural patterns of water storage and residence times and the magnitudes of water flow.

Loess underlain by glacial outwash provides a rich, productive soil in the region.

Intensively managed landscapes encompass agricultural, urban, and natural environments where human modifications of the landscapes intersect with the natural legacies of the land.

Overview. Intensively managed landscapes, regions of significant land use change, serve as sources of economic prosperity. However, the intensity of land use change is responsible for unintended deterioration of our land and water environments. The Intensively Managed Landscapes-Critical Zone Observatory (IML-CZO) aims to understand the present-day dynamics of this change in the context of long-term natural coevolution of the landscape, soil, and biota. The CZO will enable us to assess the short- and long-term resilience of the crucial ecological, hydrological, and climatic "services" provided by the Critical Zone, the "skin" of the earth that extends from the treetops to the bedrock. An observational network of three sites in Illinois, Iowa, and Minnesota that capture the geological diversity of the low-relief, glaciated, and tile-drained landscape will allow for novel scientific and technological advances in understanding the Critical Zone. The IML-CZO will also provide leadership in developing the next generation of scientists and practitioners and in advancing management strategies aimed at reducing the vulnerability of the system to present and emerging trends in human activities.

Study Sites. The IML-CZO includes two core sites—the 3,690-km^2 Upper Sangamon River Basin in Illinois and the 270-km^2 Clear Creek Watershed in Iowa—and a third participating site, the 44,000-km^2 Minnesota River Basin. These three sites, all characterized by low-relief landscapes with poorly drained soils, represent the broad range of physiographic variations found throughout the glaciated Midwest, and thereby provide an opportunity to advance understanding of the Critical Zone in this important region.

Focal Science Questions.

Through novel measurements, analysis, and modeling, the IML-CZO Program aims to address the following questions:

- How do different time scales of geologic evolution and anthropogenic (human) influence interact to determine the trajectory of Critical Zone structure and function?
- How is the coevolution of biota (both vegetation and microbes) and the soil affected by intensive management?
- How have the natural dynamic patterns of heterogeneity and connectivity across transition zones been changed by anthropogenic impacts?
- How do these changes affect the residence times and aggregate fluxes of water, carbon, nutrients, and sediment?

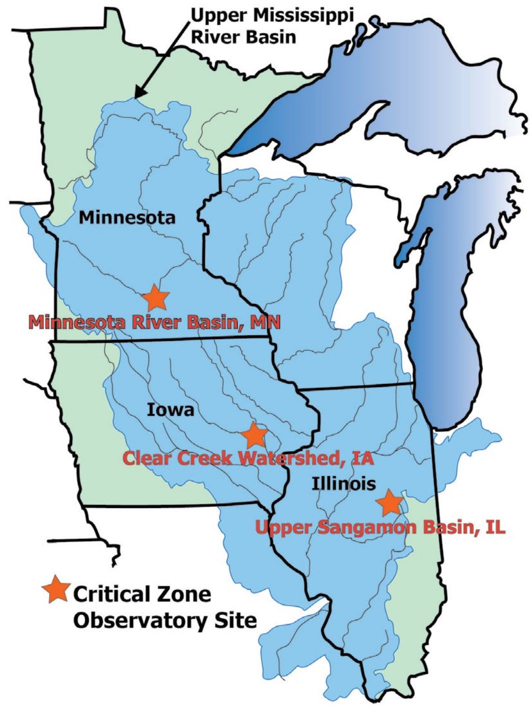
Facilities such as the Watershed Experimental Station in Amana, Iowa, operated by researchers from the University of Iowa, provide unique opportunities for Critical Zone studies.

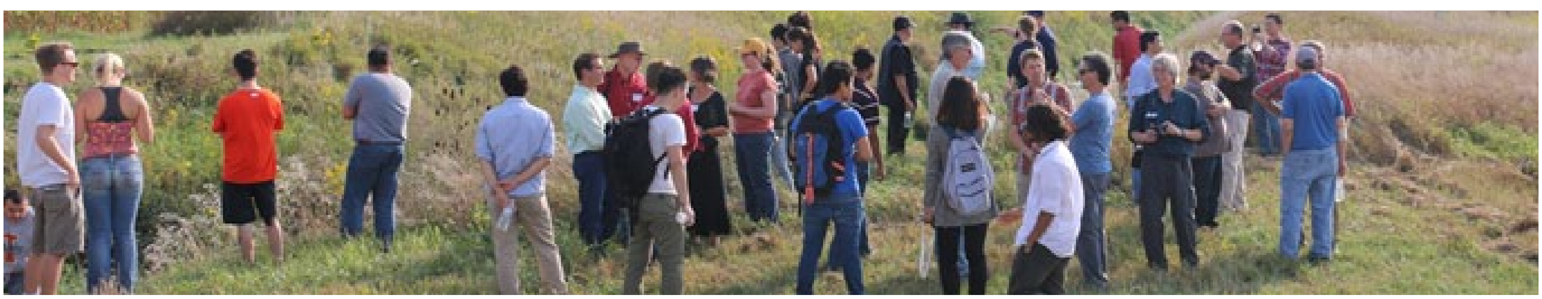
Observations.

Members of the IML-CZO team will use historical data, existing observational networks, new instrumentation, remote sensing, sampling and laboratory analyses, and novel sensing technologies (e.g., open source hardware and unmanned vehicles) to study a number of variables related to climate and weather, hydrology, geology, geomorphology, soils, water chemistry, biogeochemistry, ecology, and land management.

Education and Public Engagement.

A primary aim of the IML-CZO project is to engage a broad spectrum of students at the elementary, middle school, high school, and college levels and the general public. These aims will be accomplished through educational programs, student internships, professional development programs, field tours and exhibitions, speaking opportunities at public events and gatherings, and partnerships with volunteer groups and nongovernmental organizations. Partners in this effort include several state agencies in Illinois, Iowa, and Minnesota, including the National Great Rivers Research and Education Center (East Alton, IL), the Partnership for River Restoration and Science in the Upper Midwest, the Science Museum of Minnesota (St. Paul, MN), and the Agricultural Watershed Institute (Decatur, IL).





Partnership.

The IML-CZO Program is a joint effort by a growing team of faculty and scientists from several institutions, including the University of Illinois at Urbana-Champaign, the University of Iowa, Purdue University, Northwestern University, Pennsylvania State University, the University of Minnesota, Utah State University, the University of Tennessee, the Illinois State Water Survey, the Illinois State Geological Survey, and the U.S. Geological Survey.

National CZO Program

NSF

For further information please contact

Professor Praveen Kumar (Director), Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign (e-mail: kumar1@illinois.edu; phone: +1-217-333-4688)

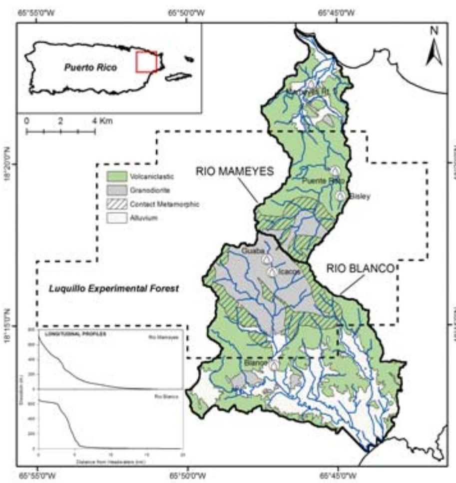
Professor Thanos Papanicolaou (Co-director), currently at the Department of Civil and Environmental Engineering, University of Iowa; moving to the Department of Civil and Environmental Engineering, University of Tennessee (e-mail: tpapanic@utk.edu; phone: +1-865-974-7836)

Research focus: The Luquillo Critical Zone Observatory (LCZO) is one of 9 NSF supported observatories designed to provide an integrated platform for collaborative studies in Critical Zone Processes. *The role of hot spots and hot moments in tropical landscape evolution and critical zone function* is the overarching focus of the LCZO. Our infrastructure, sampling strategy, and data management system are designed to address this question in watersheds underlain by granodiorite (GD) and volcaniclastic (VC) bedrock in the natural laboratory of the Luquillo Mountains, Puerto Rico.

Funding: The LCZO is supported by NSF's Earth Science Division, and is a collaboration among nine academic institutions, the USFS International Institute of Tropical Forestry, and the USGS-WEBB program.

Focal Science Questions: LCZO research is centered on four inter-related focal areas: 1) the importance of knickpoints and different landscape positions as hot spots for weathering, soil development, and biogeochemical cycling; 2) the role of hot spots and hot moments in redox cycling, and their effects on weathering as well as the storage and loss of carbon and nutrients in soils over a range of spatial and temporal scales; 3) the role of hot moments in the transport of sediment, C, and nutrients in stream flow, and hot spots that determine the distribution of material across the landscape; 4) scaling up hot spots and hot moments in time and space using climate and hydrologic modeling, and assessing the role of rain, cloud water, and dust inputs on landscape evolution and critical zone function. Overall, the research proposed LCZO research program will provide a well-integrated assessment of critical zone properties and processes that scale from microsites to catenas, watersheds, landscapes, and the region, and from minutes to hours, days, months, and years.

Geography: The LCZO is located in NE Puerto Rico, in one of the wettest regions of the Caribbean. Over a distance of 10 to 20 km, the mountains rise from sea level to an elevation of 1075 meters while precipitation increases from < 1000 mm/yr to > 5000 mm/y.



Geology and soils: The two main study watersheds, the Río Mameyes and the Río Blanco, have similar climates and environmental histories but differing lithology (Figure 1). The Mameyes watershed is primarily underlain by volcaniclastic bedrock that weathers to produce clays and boulders. The Río Blanco watershed is underlain by granodiorite that weathers into a saprolite comprised of sand and large corestones. These differences in weathering patterns have a profound influence on forest composition, landslide frequency, chemical denudation, and the morphology of streams and hillslopes.

Climate and meteorology: The Observatory has a subtropical, humid, maritime climate that is influenced by both orographic and global-scale synoptic weather systems. Rainfall occurs throughout the year and exceeds 5000 mm/yr at the highest elevations. Rainfall events at mid-elevations are generally small (median daily rainfall 3 mm/day) but numerous (267 rain days per year) and of relatively low intensity (< 5mm/hr). Nevertheless, individual storms with greater than 125 mm/day occur annually, and daily rainfalls greater than 600 mm have been recorded.

Vegetation and Land Use: Six Holdridge life zones occur in the Luquillo Mountains and surrounding areas: lower montane wet, lower montane rain, subtropical moist, wet, rain, and dry. Luquillo forests are classified into main four types: "tabonuco forest", so named for the dominant tree *Dacryodes excelsa*, which covers lower elevations up to about 600 m and harbors about 168 tree species. The "colorado forest", named for *Cyrilla racemiflora* trees, occurs above the tabonuco forest and extends to about 900 m. This forest type is a montane cloud forest that has a canopy of about 15 m and harbors 53 tree species. At this same elevation, and in especially steep and wet areas, is the third forest type: the "palm forest", which is dominated by *Prestoea acuminata*. On the highest peaks is the "elfin forest", a dense, short-statured cloud forest with abundant epiphytes and a canopy that can be less than 3 m.

Two striking features of the region's disturbance regime are the long history of natural hurricanes and the recent history of human disturbance and recovery. In addition to hurricanes, other natural disturbances include landslides, treefalls, floods, and droughts. Human disturbances are most common at lower elevations and include historic clearing for pasture, crops, and coffee plantations, logging, road construction, and water diversions.

Instrumentation: Researchers have access to 11 stream gages, 2 walk-up canopy towers, 4 meteorological stations, three deep observation wells, lysimeter nests, an extensive GIS system and numerous long-term vegetation plots at the site.

Signature Data Sets: Because the Luquillo Mountains have been a center for research on tropical forests for over a century, many long-term environmental data sets exist. For references and online access see the LCZO data page (https://www.sas.upenn.edu/lczodata), the Luquillo LTER (http://luq.lternet.edu/) and the USGS-WEBB (http://water.usgs.gov/webb/), Signature data sets include:

Micrometeorology and Hydrology: Hourly and daily measurement of radiation, air pressure, temperature, relative humidity, precipitation, wind speed, and wind direction (4 stations maintained by USFS-IITF). The world's longest known record of weekly rainfall and throughfall and associated chemistry is maintained at the site and available online. Eight stream gages are maintained by the USGS, and the USFS-IITF maintains three stream gages in the Bisley Watershed.

Geochemistry and Biogeochemistry: The LCZO is developing an extensive data set of Luquillo soils and bedrock geochemistry. The chemistry of weekly rainfall, throughfall, and streamflow is maintained and available from the LCZO and Luquillo LTER web pages. Additional data are available on plant species composition, allometry, and chemistry.

Spatial Data Sets: A 10 m DEM and associated spatial data sets are also available for the upper Luquillo Mountains.

Contact for joining the LCZO Community:
Email: Luquillo-CZO@sas.upenn.edu: Web: http://www.sas.upenn.edu/lczo

REYNOLDS CREEK
CRITICAL ZONE OBSERVATORY

Spotlight on the Reynolds Creek CZO

Reynolds Creek Critical Zone Observatory (RC CZO) is focused on the quantification of soil carbon and the critical zone processes governing it. Most of the world's terrestrial carbon is found in the critical zone, where it is predominantly stored as soil carbon and sensitive to climate change and land management. Despite its importance, soil carbon remains a large source of uncertainty in both carbon cycling and global climate models. The RC CZO will address the grand challenges of improving prediction of soil carbon storage and flux from the pedon to landscape scale.

Goals of the RC CZO:

1) Determine the relationship between measured soil carbon storage and the soil environment at high spatial resolution across a broad, regionally significant environmental gradient

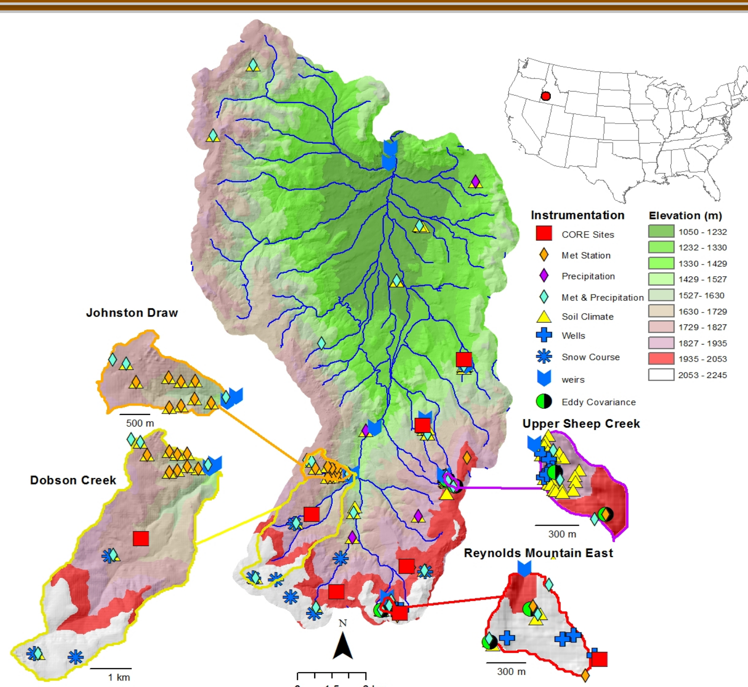
2) Measure net carbon flux in conjunction with components of the soil carbon cycle (soil respiration, litter decomposition, soil carbon characteristics) at the pedon to landscape scale.

3) Evaluate soil carbon model performance in terms of a) soil carbon distribution across the landscape and b) representation of critical carbon fluxes at the pedon to landscape scale.

4) Be a community resource and magnet for global climate modeling and carbon cycle research

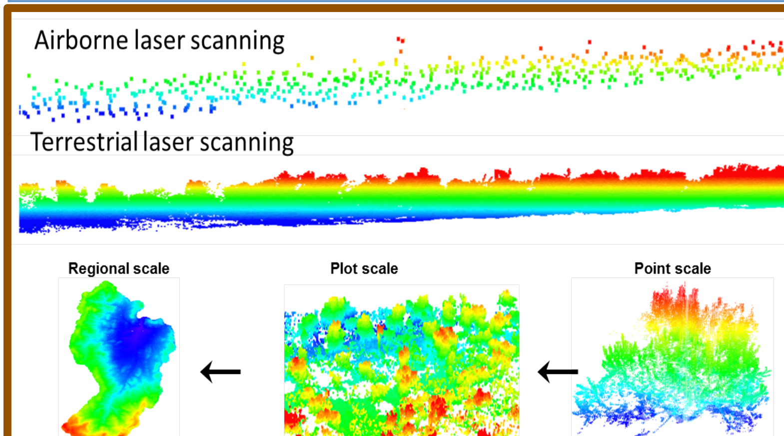
RC CZO location

The RC CZO is situated in southwestern Idaho at the Reynolds Creek Experimental Watershed (RCEW) (239 km^2). The RC CZO extends over a steep elevation-climatic gradient (mean annual precipitation 250 - 1100 mm/yr, mean annual temperature 5.5 °C to 11°C). The precipitation gradient produces a dramatic change in the importance of soil inorganic carbon at lower elevations to soil organic carbon at higher elevations. This new CZO is supported by unique long-term, spatially-extensive, meteorological, soil monitoring, and atmospheric datasets that will both inform and constrain conceptual and numerical models of soil carbon behavior.



Existing infrastructure

Parameter:	# of Stations	Years of Record:	Data Interval:
Precipitation	28 26	1962-2012 1962-2012	Breakpoint (bp),[1] 15 min
Snow measurements	8 2 32	1961-2012 1961-2012 1994-2012	bi-weekly 15 min 15 min
Daily Climate (evap- summer only)	32 1	1964-2012 1974-2006	Daily Summer
Weather	38	1981-2012	15 min
Eddy Correlation	5	2002-2012	10 Hz & 30 min avg
Sap Flux	12	2010-2011	Hourly
Soil Lysimeter		1976-1991	Hourly
Snowmelt lysimeter	6	1982-2012	Hourly
Neutron Probe	35	1970-2012	bi-weekly
Soil Moisture	32	2000-2012	Hourly
Soil Temperature	32	1981-2012	Hourly
DTS Snow & Soil Temperature	2 km	2010-2011	Hourly
Ground Water	9	1968-2012	Hourly
Discharge & Sediment	10 9	1963-2012 1965-2012	bp,[2] 15 min event-based
Stream Temperature	4	2000-2012	Hourly
Vegetation LiDAR TLS	3	2009-2012 2007 2009-2011	Semiannually once (x pt/m2) annually



Making the CZO a community resource

Community Outreach & Education

- Land managers
- Building sustainability through partnerships with USDA ARS and other agencies
- Developing soil carbon curriculum for K-12

***Undergraduate and graduate courses* on Earth's CZ**

- Field & laboratory
- Widely distributed & shared

Research community

- Spatially and temporally extensive data
- Landscape level soil data
- Leaders in laser scanning and hyperspectral analysis

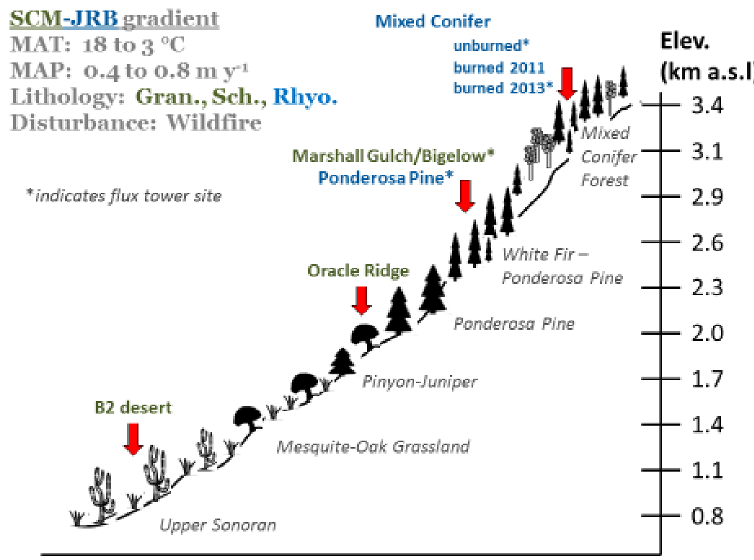
How do you get involved? Talk to RC CZO scientists

Kathleen Lohse (RC PI, klohse@isu.edu), Mark Seyfried (RC co-PI, site lead, USDAARS-Mark.Seyfried@ars.usda.gov), Shawn Benner (BSU), Nancy Glenn (BSU), Lejo Flores (BSU), Colden Baxter (ISU), Bruce Finney (ISU), Sarah Godsey (ISU), Keith Reinhardt (ISU), Marie Anne de Graaf (BSU), Kevin Feris (BSU), Ben Crosby (ISU), Jen Pierce (BSU), Jim McNamara (BSU), Gerald Flerchinger (UDSA ARS), Danny Marks (USDA ARS), Jim McNamara, Fred Pierson (USDA ARS)

Visit our website at the National Critical Zone Observatory (www.criticalzone.org)

Santa Catalina Mountains – Jemez River Basin CZO

Research focus. The Santa Catalina Mountains – Jemez River Basin Critical Zone Observatory (SCM-JRB CZO) was established in 2009 as part of the National CZO Program funded by NSF. It comprises an elevation gradient that begins with a granite-schist "sky island" mountain range rising out of Sonoran desert scrub in southern Arizona (SCM) and extends into a rhyolitic montane caldera in northern New Mexico (JRB). By including both sites in the observatory design, researchers can explore a wider range of CZ-forcing parameter space than would be possible with either site alone. The CZO includes lithologic, climatic and disturbance variation characteristic of much of the southwestern US.

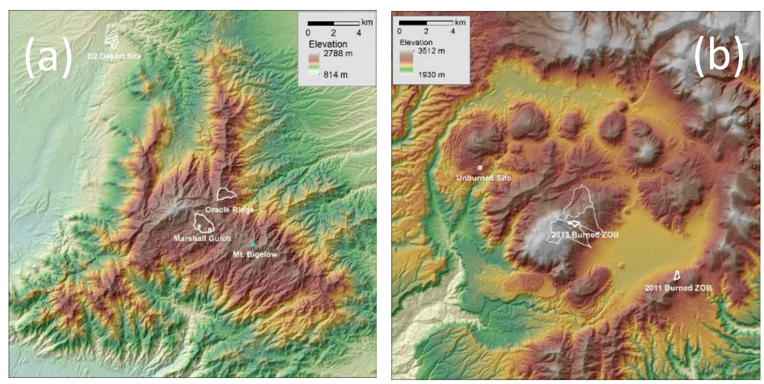


Our focus is on understanding how variability in climate, lithology and disturbance influence CZ structure and function over both short (e.g., hydrologic event) and long (e.g., landscape evolution) time scales. We are addressing this issue using a theoretical framework that quantifies system inputs in terms of effective energy and mass transfer (EEMT, MJ m^{-2} yr^{-1}).

Science questions being addressed in this phase of CZO research include:

- *How do long-term drivers of CZ structure and function (EEMT and tectonics) interact with parent material to control current CZ structure and response to perturbation?*
- *How is long-term CZ evolution affected by ecosystem process controls?*
- *What is the impact of CZ structure on buffering climate- and disturbance-driven variability in water, soil, and vegetation resources, and how does this translate into changes in CZ services?*

Land use/vegetation. Instrumented zero order basins (ZOBs) are in Upper Sonoran Desert, Desert Woodland-Grassland, Ponderosa Pine, and Mixed Conifer forest ecosystems that have been managed for multiple use. Both SCM and JRB have been subjected to regular wildfires, including two in 2011 and 2013 in the Valles Caldera National Preserve (VCNP, JRB) that provide a chronosequence of mixed conifer forest disturbance.



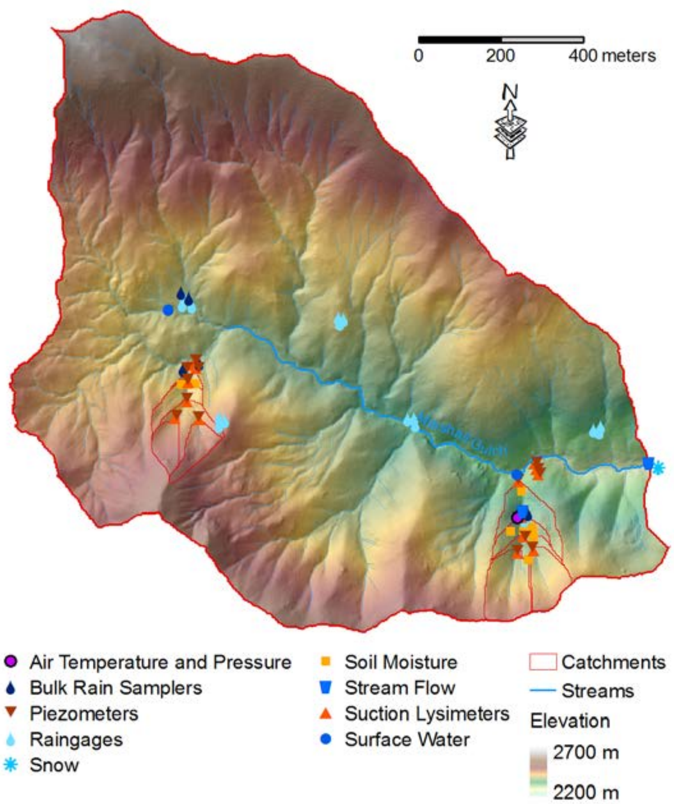
Digital elevation maps of the SCM (a) and JRB (b) showing locations of instrumented catchment sites.

Geology and soils. SCM bedrock is dominated by pre-Cambrian and Tertiary aged granites and granodiorite, in combination with Paleozoic aged metamorphic rocks such as schist and quartzite. Terrain is steep and rugged. Soils are shallow at low elevation (< 25 to 50 cm depending on landscape position) where weathering depth is limited by hot, dry climate conditions and deeper (ca. 50-100 cm) at high elevation where cool, wet conditions prevail. Schist soils are more deeply weathered, finer in texture, and contain more organic matter than granite soils.

JRB bedrock is dominated by silica-rich extrusive volcanic rocks: rhyolitic tuff, rhyolite, andesite, dacite, and silica-rich volcanic ash. Instrumented catchments in JRB are located primarily on rhyolitic tuff, which facilitates formation of deep soils (70 to > 200 cm depending on landscape position). The thick soil cover corresponds with a relatively diffuse landscape structure. Tuff-derived soils exhibit substantial clay accumulation in the subsurface. Upper soil horizons contain appreciable volcanic glass and kaolin, whereas subsurface horizons have less glass and more smectite.

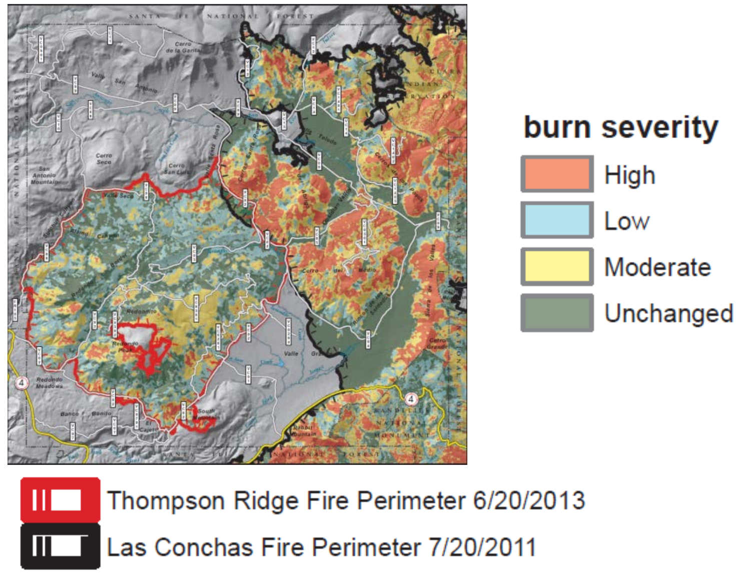
SCM-JRB climate covers much of the SW US. Precipitation and temperature throughout the southwestern US is highly dependent on elevation. Most of the water sustaining urban populations in semi-arid basins of the SW US (e.g., Tucson, Phoenix, Albuquerque, El Paso) derives from montane precipitation regimes (dominantly snowpack at higher elevation). The SCM-JRB CZO seeks to better resolve the water, carbon and weathering dynamics of high elevation receiving catchments, including their resilience to climatic variation and associated disturbances such as wildfire.

ZOBs nested within catchments are an integrating unit of study. The SCM-JRB has instrumented zero order basins (ZOBs) nested within catchments as depicted for the Marshall Gulch (SCM) Catchment (below, 1.54 km^2). The MG catchment, southeast of Mount Lemmon peak (32°25'45"N 110°46'0"W) contains a weir for integrated response and instrumented ZOBs as shown below. Two V-shaped ZOBs (schist (SC) and granite (GC)) lie within the Marshall Gulch catchment. Both are north oriented with relatively steep slopes (3.2 – 56.4 degrees).



Signature data types. All level 2 time series, sample and spatially distributed data can be accessed at http://criticalzone.org/jemez-catalina/. The most current level 1 data are available by request. Investigator-specific data are available as per the NSF data policy.

Wildfire is a principal CZ disturbance in the western US. The Jemez River Basin is located in the transition zone between the SW desert and the Rocky Mountains. Within the Valles Caldera National Preserve (VCNP) the Las Conchas wildfire (summer 2011) and Thompson Ridge Wildfire (summer 2013) together burned a large fraction of the forested terrain.



Fire-impacted sites represent a chronosequence of CZ recovery. Two ZOBs are instrumented for measuring post-fire recovery in the JRB. The La Jara ZOB (instrumented 8/10), in mixed conifer forest on the east slope of Redondo Peak, the dome in the center of Valles caldera, was burned severely in the 2013 Thompson Ridge fire. The East Rabbit ZOB (instrumented 10/11) is located on a north-facing slope of Rabbit Mountain in mixed conifer forest, and was burned in the 2011 Las Conchas wildfire. The two instrumented ZOBs are coupled with a newly installed unburned control.

Sensor and sampler networks for continuous observation. At each location (JRB and SCM) field equipment deployed in ZOBs provide continuous or periodic measures of water, carbon and energy stores and fluxes across the CZ. Instrumentation includes eddy covariance flux towers, sap flow sensors, phenocams, weather stations, rain gauges, rain water samplers, streamflow flumes, snow depth sensors, snow melt lysimeters, shallow groundwater piezometers, soil moisture and soil temperature probes, soil water tensiometers, soil gas sensors, and soil water solution samplers.

Research highlights. Isotope hydrology, trace element geochemistry, pedogenic studies, and landscape evolution modeling show that weathering trajectories at the pedon and ZOB scale exhibit strong dependence on landscape position and lithology in similar water/energy (EEMT) regimes. CZ evolution occurs episodically; landscape disturbance events, such as wildfire, disproportionately affect long-term rates.

Contact. The Jemez River Basin and Santa Catalina Mountains CZO PIs and theme leaders are:

Jon Chorover, chorover@email.arizona.edu
Jon Pelletier, jdpellet@email.arizona.edu
David Breshears, daveb@email.arizona.edu
Jennifer McIntosh, jenmc@email.arizona.edu
Craig Rasmussen, crasmuss@cals.arizona.edu

For more information, see criticalzone.org/jemez-catalina/
The SCM-JRB CZO invites co-investigators, collaborators, students and postdocs interested in conducting interdisciplinary earth surface science research. **To join the CZO community, contact one of the PIs or Tim White (CZO coordinator):** tsw113@psu.edu

National CZO Program | Susquehanna Shale Hills CZO

Research focus: We are quantifying the rates of formation and evolution of the structure and function of the Critical Zone, focusing on the fluxes of water, energy, gas, solutes, and sediments (WEGSS) in a temperate, forested landscape on sedimentary rock in Pennsylvania. Our interdisciplinary team works collaboratively to advance methods for characterizing regolith and WEGSS fluxes and to provide models to predict the distribution and character of regolith and WEGSS fluxes across the landscape.

Science focal areas are integrated into nine hypotheses that focus on the effects of fractures on water flow and regolith formation; the imprint of biota on weathering; the importance of tree roots on carbon cycling and soil formation; the importance of soil macropores; the development of regolith-formation models; the controls on solute concentrations versus stream discharge; the controls on land-air-ecosystem coupling; water-data integration techniques for upscaling; and an effort to project earth surface processes into the future (earth casting).

Overarching Hypothesis

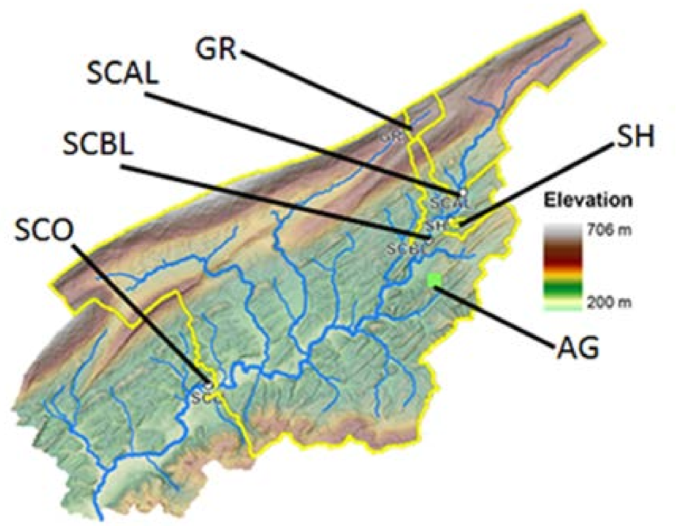
To project Critical Zone evolution into the future requires knowledge of the geological history, observations of Critical Zone processes today, and scenarios of human activities tomorrow.

Research Highlights

Geography: The SSHCZO includes the Shale Hills watershed (SH outlined in yellow in figure to right), an 8 hectare catchment which lies within the Valley and Ridge Physiographic Province of the central Appalachian Mountains in Huntingdon County, Pennsylvania (40º39’52. 39”N 77º54’24.23”W). It is a first order, V-shaped basin characterized by relatively steep slopes (25-35%) and narrow ridges. The stream is a tributary of Shaver’s Creek that eventually debauches into the Juniata River, a part of the Susquehanna River Basin. In 2013, the focus of SSHCZO grew to include most the Shaver’s Creek watershed. The team now monitors the main channel of the stream (SCAL, SCBL, and SCO in figure), and has begun a study on a subcatchment on sandstone, Garner Run (GR), in parallel to Shale Hills. GR is a small, forested catchment (GR outlined in yellow in figure). In 2016, a similarly sized agricultural subcatchment on calcareous shale (AG, green symbol in figure) will be added. The subcatchments are studied as a step toward scaling up to the entire Shavers Creek.

Geology: The Shale Hills subcatchment is underlain by Silurian Rose Hill Formation shale whereas Shaver’s creek includes sandstone, calcareous shale, and limestone. The Garner Run subcatchment is underlain by Silurian Tuscarora quartzose sandstone. The folded and faulted sedimentary strata were uplifted during the Alleghenian Orogeny ~300 million years ago. Pleistocene permafrost and associated solifluction occurred most recently during and shortly after the Last Glacial Maximum when the area experienced periglacial conditions.

Soils: Shallow to moderately deep, gently-dipping to steep, well-drained residual shale soils occur on the ridge of Shale Hills, soils have formed on a colluvial and alluvial mantle of shale material in the valley. In GR, soils are formed from quartzite with large additions of clay material.



Shaver’s Creek Watershed Subcatchments: SH: Shale Hills (shale, forested), GR: Garner Run (sandstone, forested), AG: Agricultural Site (Location Not Final). Mainstem stream monitoring sites: SCAL: Shavers Creek Above Lake, SCBL: Shavers Creek Below Lake, SCO: Shavers Creek Outlet.

Soils are typically saturated along the stream where they exhibit redoximorphic features as a result of seasonal soil saturation. A 3 – 5 cm organic layer of decaying leaf litter overlies all soils in the watershed. Typical surface soil textures are silt loam, with the percentage of channery shale increasing with depth. Effective rooting depth (depth to bedrock) ranges from 15 cm on ridge tops to 165 cm especially near valley floor. Soil structure is moderately developed throughout the basin. Small roots penetrate fractured shale beneath the augerable soil.

Climate/Meteorology: SSHCZO is characterized by a humid continental climate. Temperatures average 9.5°C with large seasonal variations: temperature averages –5.4°C (January) and 19.0°C (July). The highest temperature recorded is 33.5°C (April 27, 2009) lowest –

24.8°C (January 17, 2009). Annual average relative humidity is 70.2%. Atmospheric deposition is pH~4).

The Shale Hills water balance for 2009-2010 is:

	2009	2010
Precipitation (mm)	1028	958
Interception (mm)	284	276
Evapotranspiration (mm)	594	586
Recharge (mm)	319	306
Runoff (mm)	509	364
Runoff Ratio (%)	49.51	38.00

Ecosystem Types: The Shale Hills forest ecosystem is dominated by oak (*Quercus*), hickory (*Carya*) and pine (*Pinus*) species. Hemlock (*Tsuga canadensis*), red maple (*Acer rubrum*), white oak (*Quercus alba*) and white pine (*Pinus strobus*) line the deep, moist soils of the stream banks, while on the drier, shallower north and south-facing slopes, red oak (*Quercus rubra*), chestnut oak (*Quercus prinus*), pignut hickory (*Carya glabra*) and mockernut hickory (*Carya tomentosa*) are dominant, with Virginia pine (*Pinus virginiana*) appearing on the southern ridge. Understory woody species include plants in the Ericaceae family (including *Vaccinium spp*.), service berry (*Amelanchier spp*.), hawthorn (*Crataegus spp*.), raspberry/blackberry (*Rubus spp*.), sugar maple (*Acer saccharum*) saplings and witch hazel *(Hamamelis virginiana*). Forest surveys at the new sites are planned.

Land Use: Historically, the region was logged for charcoal to support a 19th and 20th century iron industry. Today, Shale Hills and the sandstone forest site experience low human impact. Shale Hills is used for recreation and education and the catchment is managed for timber with set-asides for research within the Penn State Forest. The sandstone site is managed by Rothrock State Forest, PA Bureau of Forestry. The lower Shavers Creek watershed is characterized by residential and agricultural land use (row crops and pasture for dairy farms). In 2016, we will extend our research into an agricultural catchment as shown on the map.

Signature Data Types and Supporting Research: The Shale Hills watershed has a comprehensive base of instrumentation for characterization of water, energy, stable isotopes and geochemical conditions. This includes a dense network of soil moisture observation sites at multiple depths (120), a shallow observation well network (24 wells), soil lysimeters at multiple depths (+80), a cosmic-ray soil moisture sensor, a research weather station including eddy flux measurements for latent and sensible heat flux, CO_2, and water vapor, radiation, barometric pressure, temperature, relative humidity, wind speed/direction, snow depth sensors, leaf wetness sensors, a load cell precipitation gauge. A laser precipitation monitor (LPM: rain, sleet, hail, snow, etc.) was installed in 2008, as were automated water samplers (daily) for precipitation, groundwater, and stream water. Sapflow is measured as a function of tree species. Several hillslope transects have been investigated for collection of soil porewater and gas. Stream, groundwater and precipitation samples have also been collected and analyzed over extended periods. A wireless sensor network is being deployed to allow near real-time observations of soil moisture, groundwater level, ground temperature, and electrical conductance. Data collected from sensors at Shale Hills are compiled in a database for use by all. To extend observations to the sandstone and agricultural catchments, by developing a paradigm of fewer measurements per catchment, we are targeting hillslope transects like those operating at Shale Hills. We plan an array of measurements using mobile instrumentation.

Three airborne LiDAR flights were flown over the Shavers Creek watershed. The most recent flight (0.5 m resolution) allows evaluation of micro-topography and tree species. Depth to bedrock in Shale Hills has been surveyed. Ground-based LiDAR and total-station surveys were completed for all instrument elevations. Trees > 8 in. were surveyed for species, biomass, and crown height in SH. Leaf Area Index (LAI), greenness index, distribution and CO_2 flux have been measured. Between SH and GR, 10 boreholes are available.

Key Achievements: 1) The CZO soil production roughly equals erosion at ridgetops: most of the soil creep is caused by freeze-thaw. 2) GPR has been used in Shale Hills and Garner Run subcatchments to determine regolith depth and water flow patterns. 3) The team produced a coupled land surface-atmosphere model that incorporates a module to complete geochemical reactive transport modelling (RT-FLUX-PIHM). 4) BIOME-BGC is being successfully used and coupled to PIHM to model carbon stocks in SSHCZO. 5) Every tree in the Shale Hills catchment has been surveyed. 6) The water in the trees in Shale Hills is isotopically different from the stream and draining soil waters (i.e., a two-water world). 7) The relationships between solute concentration and stream flow are well explained if connectivity, soil distribution, and cation exchange capacity are considered. 8) The imprint of the early industrial revolution is observed in the Mn and Pb concentrations in the soils. 9) The shale in Shale Hills has been completely depleted in carbonate and pyrite at the surface: nested reaction fronts for these and other reactions roughly parallel the land surface at depth.

We welcome anyone who wants to work at our CZO.

To Join the CZO Community Contact:
Susan L. Brantley (Principal Investigator) sxb7@psu.edu
Timothy White (National Coordinator) tsw113@psu.edu
For more information: https://criticalzone.org/shale-hills/

Research focus. Southern Sierra Critical Zone Observatory (SSCZO) is a community platform for research on critical-zone processes. Founded in 2007, SSCZO is based on a strategic partnership between the University of California and the Pacific Southwest Research Station (PSW) of the U.S. Forest Service. The CZO is co-located with PSW's Kings River Experimental Watersheds (KREW), a watershed-level, integrated ecosystem project established in 2002 for long-term research to inform forest management.

The conceptual science model for SSCZO is built around links between water/material fluxes and landscape/climate variability across the rain-snow transition. Ongoing research focuses on water balance, nutrient cycling and weathering across the rain-snow transition, with soil moisture as the integrating variable.

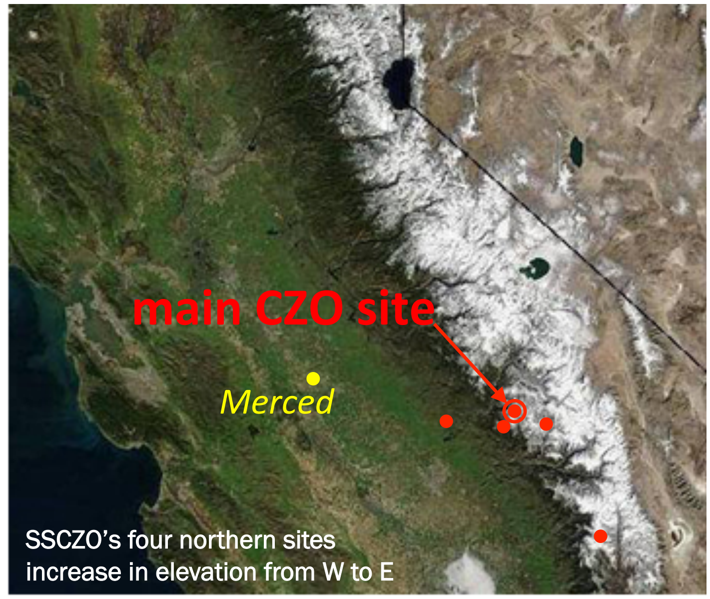
Science questions currently being addressed include:

- How do soil moisture & topographic variability interact to influence weathering and soil formation?
- How is the response of soil moisture to snowmelt & rainfall controlled by the physical, biological, and hydrological characteristics across the landscape, and how do these responses relate to streamflow & evapotranspiration (ET)?
- How does vegetation influence land-atmosphere exchange of water, energy, and CO2?
- How do soil/landscape heterogeneity and water fluxes influence nutrient cycling and retention?
- What is the role of aeolian fluxes in controlling nutrient availability and net primary productivity?


Road into SSCZO in spring

Funding. SSCZO is supported by NSF's Earth Sciences Division. KREW is supported by the USFS.

Geography. SSCZO sites span an altitudinal gradient on the western slope of the Sierra Nevada, from oak woodlands to subalpine forests (400-2700 m) and across the rain-snow transition. The main CZO site, Providence Creek, is located in a mixed-conifer forest that includes three headwater catchments with a dominant southwest aspect (37.068ºN, 119.191ºW).



SSCZO's four northern sites increase in elevation from W to E

Climate. The southern Sierra Nevada has a Mediterranean climate and experiences relatively wet winters and dry summers. As mean temperatures drop with increasing elevation, a greater fraction of precipitation falls as snow.

Site	Elevation (m)	Annual Precipitation (mm)	Min-Max Annual Temperature (°C)
SJER	400	513	9.3 - 23.5
Soaproot	1100	805	5.5 - 18.0
Providence	2100	1015	2.7 - 14.8
Shorthair	2700	1078	-1.9 - 10.2

Geology and soils. Soils at the sites developed from granite, granodiorite, and quartz diorite parent material. Soils are weakly developed as a result of parent materials' resistance to chemical weathering and cool temperatures. Upper-elevation soils are at the lower extent of late Pleistocene glaciations. The most intense soil weathering is seen at 1100-1600 m in elevation; soil profiles display subsurface horizons with clay and iron precipitate, and a deep regolith. Soils in the oak grasslands of the foothills have organic-rich surface soils from root inputs. In general, soils are shallow (< 50 cm) in areas with low tree density and many rock outcrops. Soils in more gently sloping terrain with linear or convex hillslopes are moderately deepl. Landforms with the deepest soils (>150 cm) support high tree density .

Land uses. The area has a high forest density, with canopy closures up to 90%. In recent years, PSW executed management plans that include thinning and controlled burns in two of the three headwater catchments of the main CZO site, in order to inform forest managers about impacts on ecosystem services. Five more catchments are nearby. The area has limited recreational use.


Instrumentation at CZTree-1

Research highlights. The distributed snow and soil moisture measurements show a close coupling between snowmelt and soil drying in spring/summer, with systematic variability across elevation, aspect and canopy cover. Runoff increased with elevation, corresponding to decreasing temperature, more precipitation falling as snow, decreasing vegetation density and coarser soils. ET decreased proportionally as soils dried, going from about 1 to 0.1 mm d^{-1} over the summer. However, ET continues in mid-elevation vegetation despite dry summers and freezing winter temperatures. Soil mantle patterns at a larger scale indicate bedrock nutrients are more variable than previously thought, impacting vegetation. Bedrock indicates weathering as deep as 40 m in some locations, which may be a source of water for continued summer ET. Installations and measurement across the elevational transect will be expanded in the coming years.

Signature data types. Level 1 data (cleaned, calibrated) from core field measurements are made available by water year. These include precipitation, energy balance, snow, stream flow, soil moisture, sap flow, temperatures, stream geochemistry, soil chemistry, flux tower data, meadow water levels, vegetation, and various other characterization data sets. Current-year raw (level 0) data are available by request. Investigator-specific data are available as per the NSF data policy. LIDAR coverage and a variety of other data sets, including discharge and sediment transport, are available through PSW scientists.

Discover more online at criticalzone.org/sierra. SSCZO involves Co-PIs and students or postdocs from 8 campuses, with several additional collaborators. We welcome new collaborations. To join the CZO community, contact the PI or any Co-PI. The SSCZO PI is Roger Bales, rbales@ucmerced.edu.

Main CZO site: Providence Creek Catchments

Ecosystem types. The catchments are largely Sierran mixed-conifer forest, with some mixed chaparral and rock outcrops. Dominant trees are white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*Pinus jeffreyi*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*) and black oak (*Quercus kelloggii*). Several species of shrubs are also present. Of the three perennial streams, one borders meadow over 90% of its length, one has no meadow and the third is intermediate.

Instrumentation. The Providence catchments are the most heavily instrumented of our sites. There are 2 meteorological stations, a 50-m flux tower, a 60-node wireless embedded sensor network, 215 EC-TM sensors for volumetric water content, over 110 MPS sensors for matric potential, 60 snow depth sensors, meadow piezometers and wells, sap flow sensors, stream gauges and water-quality measurements.

Forest activity & water balance. Photosynthesis persists through the winter, and soils and regolith store enough water for photosynthesis to occur all summer. As soils dry out, trees apparently extract water from the deeper soils. Annual runoff is about 15-30% of precipitation in dry years, increasing to 30-50% in wet years. The ground is snow-covered for 4-5 months each year and may experience multiple melt events during the winter and spring.