Preview of Award 1331846 - annual Project Report

< Back

- Cover |
- Accomplishments |
- Products |
- Participants/Organizations |
- Impacts |
- Changes/Problems

Cover

Federal Agency and Organization Element to Which Report is Submitted:
4900
Federal Grant or Other Identifying Number Assigned by Agency:
1331846
Project Title:
Human and Natural Forcings of Critical Zone Dynamics and Evolution at the Calhoun Critical Zone Observatory
PD/PI Name:

- Daniel D Richter, Principal Investigator
- Mukesh Kumar, Co-Principal Investigator
- Brian L McGlynn, Co-Principal Investigator
- Sari Palmroth, Co-Principal Investigator
- Amilcare Porporato, Co-Principal Investigator

Recipient Organization:
Duke University
Project/Grant Period:
12/01/2013 - 09/30/2019
Reporting Period:
12/01/2017 - 11/30/2018
Submitting Official (if other than PD\PI):

- Daniel D Richter
- Principal Investigator

Submission Date:
03/08/2019
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)
Daniel D Richter

Back to the top

Accomplishments

* What are the major goals of the project?

In 2001, Jordan *et al.* of the USA's National Research Council framed the science of Earth's critical zone as one of the most compelling and significant research projects of the Earth sciences in the 21st century. The excitement and novelty embodied in this claim spring from the need ***and*** opportunity for the Earth sciences to advance understanding of how the planet from local to global scales is being rapidly transformed by humanity. Slightly modifying a statement by Prof. Bruno Latour, the individual Earth and ecological sciences ***completely overlap*** in their scientific study of the contemporary Earth system, and ***by explicitly working together in this new critical zone science*** can accelerate scientific understanding of our dynamic planet. The overall goal of Calhoun CZO scientists is to integrate their sciences and scholarships within our observatory, among the nine USA critical zone observatories, and among the many emerging international critical zone observatories as well. The NRC in 2001 and NSF in the years that followed have not only created but have led a new and growing international movement in Earth systems science (Richter et al., 2018).

More specifically at the Calhoun CZO, our goal is to marshal the Earth and ecological sciences to understand how critical zones as structures "from tree-top to bedrock" and as dynamic fluids "from the atmosphere to the deepest aquifers" are being transformed from natural to human-natural systems (Richter and Billings, 2015). We see the Calhoun CZ to share much with the larger physiographic province of the Southern Piedmont and to have three temporal phases in its evolution: a) from the Calhoun's *ancient*, deep, and highly weathered natural systems, which on the most geomorphically stable surfaces of the Calhoun CZO have residence times of several million years (Bacon et al. 2012, St. Clair et al. 2015, Richter and Billings 2015, Calabrese et al. 2018, Holbrook et al. 2019), ancient landscape that may yet have highly surprising stories yet to tell (Richter et al. submitted); b) the *historic* human-natural CCZO system, initiated by Native Americans but greatly accelerated by severe agricultural erosion and sedimentation between about 1800 and the 1930s, mostly from cotton-based farming (Dialynas et al. 2016, Dialynas et al. 2017, Coughlan et al. 2017); and c) the *contemporary* human-natural system, marked by reforestation of many of the severely eroded soils, gullied runoff channels, and floodplains that are inundated with meters-deep historic 9legacy sediments (Richter et al. 2012, Mobley et al. 2014, Parolari et al. 2018, Chen et al., 2018, Cherkinsky et al. 2018).

Calhoun research is thus motivated by the growing need to understand and manage Earth's human-natural critical zones "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). We seek integration of the sciences and broader scholarships within the Calhoun CZO and also within all CZOs.

B. Five specific goals of Calhoun CZO

In this our fifth annual report, we continue to respond to our Virtual Site Visit Review of late 2015 and early 2016, and to suggestions made by Program Manager Yuretich from that time to reorganize our hypotheses and goals. The Calhoun CZO has done so and targets five specific goals: three of which are scientific hypotheses, the fourth to promote CZ education and outreach, and the fifth to stimulate cross-CZO science and education. Each of these is described throughout the annual reports of year three to five (2016, 2017, and 2018).

1. Hypothesis on Hydro-biogeochemical Decoupling and Regeneration of the CZ following Land Degradation. *In CZs altered by land degradation and severe erosion, hydrologic and biogeochemical processes in surficial volumes of CZs become decoupled from those at depth, with system recoveries dependent on re-establishment of macroporosity, hydrologic networks, revegetation and rooting, macroinvertebrate activity, and aggregate formation.*

2. Hypothesis on Erosion-Induced Carbon Dynamics. *Delayed oxidation of eroded soil organic carbon (SOC) buried in alluvial sediments represents a substantial fraction of erosion-induced alterations of soil C cycling.*

3. Hypothesis on Persistence of Alternative States. *CZs altered by land degradation, erosion, gullies, and reductions in infiltration, deep rooting, macroinvertebrates, and aggregate formation are impeded by self-reinforcing feedbacks in re-establishing biological productivity and environmental services.*

4. Education and Outreach Goals. *While our main focus is to facilitate research and educational opportunities for undergraduates at two- and four colleges, the Calhoun CZO actively encourages field trips and reaches out nationally and internationally via a variety of media, materials, and events.*

5. Cross-CZO Goals. *We prioritize and encourage a variety of cross-CZO relationships and participate in new and on-going projects that involve our PIs and student, and Earth, ecosystem, and environmental scientists and scholars, and that promote data- and sample-sharing and circulation of information.*

* What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?

Major Activities:

A. Activities with the five CCZO project goals

1. Hydro-biogeochemical Decoupling and Regeneration of the CZ following Land Degradation

a) Deep Geophysics and Geochemistry. A new manuscript led by Steve Holbrook of WyCEHG and Brantley of PSU was accepted for publication in 2019, coauthored with CCZO scienists, a manuscript that explicitly integrates geophysics and geochemistry using CCZO's 70-m deep borehole . The new paper directly complements St. Clair et al.

(2015) *Science* paper, and will be followed by Richter et al. (submitted) that proposes a critical zone paradigm based on G.K. Gilbert's elegant regolith production expression, being the difference of weathering and transportation. ***This latter manuscript unveils a new geologic and geomorphologic history of the Southern Piedmont, that the accepted idea that the Piedmont's regolith derives from weathering rock directly below (residual regoliths) masks a much more interesting and transport-derived landscape complete with major volumes of colluvium.***

CCZO geochemistry has several working groups within the CCZO. The entire Calhoun CZO team of researchers is especially proud of PI Paul Schroeder of UGA who in August 2018, published a Cambridge University Press book entitled, *Clays in the Critical Zone* (http://criticalzone.org/calhoun/publications/pub/schroeder-2018-clays-in-the-critical-zone/).

b) Land-Use History. Environmental anthropologists continue to assemble the history of changes in the land at the Calhoun CZO A most significant manuscript that associates colonial settlement patterns with first peoples patterns of landuse across the Sumter National Forest was published in 2018 in *PLOS One* with the title of "Legacy effects of prehistoric native American niche construction on Euro-American settlement." Historical land records and maps, deed chains, geo-rectified historic aerial photography, historical photographs, and human and agricultural census records continue to be archived for future investigations. GIS data sets continue to be built that include shapefiles, point layers, and topology.

c) Land-Use History's Effects on CZ Structure and Process. Nine sites have been intensively instrumented to quantify structure and function of CZs affected by contrasting land use histories: three sites are in uncultivated reference hardwoods that exhibit minimal farming impacts on the belowground systems, three in currently cultivated fields, and three in old-field pine forests that have experienced 60 to 90 years of forest regrowth following farm abandonment. In the plots, we are log data on soil moisture, temperature, and CO_2, and O_2 with sensors at 0.5- and 1.5-m. At all 15 of these plots, every three weeks we measure moisture by neutron probe and four gases (CO_2, O_2, CH_4, and N_2O) at 0.5, 1.5, 3, and 5-m. We have supplemented these collections with a full suite of gas samples that PI Cherkinsky and Richter analyzed for stable and radioactive isotopes of CO_2 and O_2. Cherkinsky published the first of a suite of papers in 2018 in *Radiocarbon*.

Historical land-use effects on geomorphology are also being modeled by PhD-graduate Sara Bonetti and PI Porporato who in 2018 submitted a manuscript to the *Royal Society* (Bonetti et al., submitted). Bonetti has given a number of talks on this work starting at the 2017 Arlington All-Hands meeting as well as at AGU, and has moved to a post-doc at ETH-Zurich.

d) Long-term Experimental Watersheds. Measurements of rainfall and streamflow continue on the reinstrumented watersheds that historically operated from the 1940s to the 1960s. Groundwater wells with water sensors continue to operate throughout the

Holcombe's Branch catchment. The reinstrumentation of the Calhoun watersheds will allow us to quantify changes in hydrologic responses of eroded and gullied catchments as they have been reforested over nearly eight decades. The historic catchment data are posted on our website. PhD student John Mallard will submit a manuscript in early 2019 to a hydrologic journal.

2. Erosion-Induced Carbon Dynamics

a) Observations. Samples of legacy sediments along the channel banks of Holcombe's Branch were supplemented with an outstanding series of samples along Holcombe's principle tributary, what we call the Old Ray Tributary. The Old Ray channel is newly incised in its lower reach, exposing buried soil profiles over many 10s of meters. We have estimated the organic C contents in these legacy and pre-legacy sediments, both in the 1 to 2-m deep historic sediments and in the Holocene sediments below. A Duke PhD student, Anna Wade, leads the research toward peer-review papers on Calhoun legacy sediments. Wade's studies will form the basis of two manuscripts, one of which will be submitted in 2019.

b) Modeling. Previous papers by Dialynas et al. 2016, 2017, were complemented with a paper submitted in 2018 by PI Billings, which simulates processes of burial that affect carbon in alluvial bottomlands. Billings' model, which estimates how C budgets are influenced by depositional environments, has both teaching and research value and a manuscript has been accepted for publication (Billings et al. 2019).

3. Persistence of Alternative States

Environmental historians and anthropologists and modelers have met during the year, to better understand changing land and human dynamics, frame several papers, and prepare and submit two major research proposals to NSF's Coupled Human Systems program. The investigators have visited each other's campuses for multiple days of collaboration. While PI Porporato has moved from Duke to Princeton in the fall of 2017, his laboratory has remained committed to the opportunities presented by the Calhoun CZO with recent papers and proposals. Although postdoc Coughlan of UGA has used two recent Calhoun CZO papers (Coughlan et al., 2016, Coughlan and Nelson 2018) to land a research position at Oregon State, Coughlan too remains committed to ongoing work at the Calhoun CZO.

4. Education and Outreach Program

Led by PI Kathy O'Neill of Roanoke College, educational and outreach products continue to advance both the Calhoun CZO and CZ science as a whole. Interactive iBooks use GIS-based maps, images, and videos, based on the Calhoun CZO. CZ and Earth science materials continue to be disseminated at professional meetings for educators. The new undergraduate CZ science class continues to be taught and has become a core part of the environmental curriculum at Roanoke College. Many CCZO field tours were given in 2018, most notably the Southeastern Friends of the Pleistocene

Tour attended by nearly 100! The Calhoun CZO is used by the REU program in soil science at North Carolina State University, for which in 2018 we gave a 1.5-day field tour. We find people to be captivated by the Calhoun landscape and its history, by Critical Zone science.

5. Cross-CZO Projects

In addition to continued collaboration with WyCEHG scientists (Holbrook et al. 2019), Calhoun PIs and students contribute to many Cross-CZO workshop activities. PhD students have dissertation chapters based on cross-CZO research. We shared our hydrology data with the cross-CZO hydrology project of Adam Wlostowski, for whom we gave an indepth tour of the Calhoun. Adam gave a seminar and chalk-talk at Duke. Our E&O leader PI O'Neill participates with the National Office and national E&O team. Our data manager Cook participates with the CZO team of data managers. Kansas PhD student, Emma Hauser, is conducting incubation tests at four different CZO and CZEN observatories, including the Calhoun CZO, in work partially funded by the CZ National Office SAVI program. Richter in 2018 gave talks and posters, write papers, and teach classes focused on both Calhoun CZO and on the scientific enterprise of the Earth's critical zone and Richter produce a 60-min film entitled, "The Education of Bruno Latour: From Critical Zone to the Anthropocene".

Specific Objectives:

Specific objectives, as the major activities described above, are organized by our five specific project goals.

1. Hydro-biogeochemical Decoupling and Regeneration of the CZ following Land Degradation.

a) Deep Geophysics and Geochemistry. To use advanced geophysics and geochemistry techniques and instrumentation to evaluate the structure and processes of the deep, highly weathered Calhoun CZ.

b) Land-Use History. To geographically coordinate historic and contemporary social, land-use, and land-cover data, including aerial photography and remote sensing data, deed chains, census data, and individual farm records, all to describe, evaluate, and model changes in the Calhoun CZ through time, emphasizing how historic land uses shape the contemporary and future of the land, including its management and human livelihoods.

c) Land-Use History's Effects on CZ Structure and Process. To sample, instrument, and model CZ profiles that have experienced contrasting land-use impacts, all to better understand historical legacies, depth dependencies of processes, and regeneration rates of hydro-biogeochemical systems that couple the surface and the deep subsurface Calhoun CZ.

d) Long-term Experimental Watersheds. To re- and up-instrument the Calhoun historic experimental watersheds and continue precipitation and streamflow records of watersheds as they evolve from eroded gullied watersheds in the 1940s through 1960s to fully reforested contemporary catchments that exist today. Intensive instrumentation will allow us to model the intra- and inter-watershed hydrologic changes in hydrologic response over decadal time scales.

e) Calhoun Long-Term Soil-Ecosystem Experiment (LTSE). To resample soils and trees in 2017, in the LTSE's 60th year following conversion of cotton fields to pine forests. Our specific objectives focus on changes of organic carbon at depth and changes in soil macroporosity and aggregation over the decades. To use an eddy flux tower to monitor CO_2, heat, and water fluxes in the midst of our LTSE plots.

2. Erosion-Induced Carbon Dynamics. To model the carbon budget of the Calhoun CZO's Holcombe's Branch watershed from 1800 to the present, and estimate erosional losses from uplands, and burial, storage, and reaccruals on alluvial floodplains that are now inundated with legacy sediments.

3. Persistence of Alternative States. To better understand and model how CZs respond to severe land disturbance that has threatened their resilience and regeneration.

4. Education and Outreach. To develop web-based interactive, educational modules for undergraduates and advanced high school students that illustrate key Critical Zone science concepts, based, in part, on data from the Calhoun CZO; to communicate with local, regional, and national publics about Earth and critical zone science, using a variety of media and formats; and to facilitate research and educational opportunities for undergraduate students at 4-year and 2-year colleges.

5. Cross-CZO Research and Projects. To encourage, develop, and prioritize transformative cross-CZO opportunities for research, sample and data sharing, and other CZ projects. Specifically, to contribute to cross-site modeling, hydrologic analyses, biogeochemistry, forest ecology, flux measurements, pedogenesis, environmental history, systems science, organic carbon cycling, and E&O.

Significant Results:

Results are organized by our project's five goals.

1. Hydro-biogeochemical Decoupling and Regeneration of the CZ following Land Degradation.

a) Deep geophysics and geochemistry of the Calhoun CZ. Our geophysical and geochemical datasets and model results are highly complementary, self-reinforcing, and together enrich understanding of critical zone weathering. A high visibility, data-rich paper was submitted in 2018 to *Scientific Reports* (Holbrook et al., 2019). Additional manuscripts following directly from St. Clair et al. (2015), are being written that detail

the mineralogical transformations in the regolith production system from weathering bedrock to the soil surface. One of these latter was submitted in 2018 to the *Soil Science Society of America Journal*, and unveils a new geologic and geomorphologic history of the Southern Piedmont, in other words that the widely accepted idea of the Piedmont's in-situ regolith masks a much more interesting and transport-derived landscape with major volumes of colluvium now dated by OSL to between 50,000 and 110,000 ybp. This latter submission will be followed by others that describe colluvium burial of organic-enriched wetlands, even with peat, trunks of trees, and pollen.

b) Land-Use History. History of land-use change continues to be actively studied by social scientists who have data that us all appreciate that many 19th c. farmers extensively terraced and intimately interacted with the erosion they accelerated as they farmed. This perspective is supported by 1933 aerial photography, contemporary LiDAR imagery, and historical records. A new paper, Coughlan and Nelson, 2018 *PLoS ONE*, tests the hypothesis that prehistoric Native American land use influenced the Euro-American settlement process in the Piedmont landscape.

c) Land-Use History's Effects on CZ Structure and Process. Stable and radio-isotopes of CO_2 and O_2 contrasted among land uses but also with depth (Cherkinsky et al., 2018, *Radiocarbon*). Radioisotopes of CO_2 indicated that even at 8.5 m depth most of CO_2 was respired by recent years within the contemporary forested ecosystems, indicating that vegetation and the deep CZ are tightly interconnected and actively function on a real-time basis. Biogeochemists have found that microscale processes dominate C-Fe redox cycling (Chen et al., 2018, *Journal of Soils and Sediments*). CCZO microbiologists have documented that microbial community composition is greatly affected by land-use history, *even down to 5-m depth* (Billings et al., 2018, *Elementa*).

d) Historic Experimental Watersheds. Time-series data of over 4-years are collected in the historic Calhoun watersheds and data inform explorations of watershed hydrology both within high-gradient, eroded watersheds and within low-gradient legacy sediments that mediate flow from uplands and low-order streams to higher-order streams because floodplains are inundated with 0.5 to >2-m of historic sediment. The data exhibit dynamic seasonally dependent storm responses and high variability in spatial response due to landscape position, soil depth, season, and antecedent precipitation. Legacy sediments thus often sever connections between low-order and higher-order streams. A hydrological paper will be submitted in early 2019 and a cross-CZO hydrology paper will be submitted as well, complete with Calhoun data.

e) Calhoun Long-Term Soil-Ecosystem Experiment (LTSE). A CO_2, heat, and water flux tower continues to collect data in the Calhoun LTSE (Research site R1P2). The tower is in the midst of the 60-year old field study whose soils were resampled for the 11th time in 2017, when the study of reforestation effects on cultivated soils was 60 years in age. Tower results enrich the long-term data of soil change described in many CCZO papers and a book.

2. Erosion-Induced Carbon Dynamics.

a) Observations. Initial estimates of organic carbon stored in legacy sediments of the Holcombe's Branch were made starting in 2016. A senior honors thesis was written with the data. Spectacular buried profiles were discovered and excavated for research and education. Duke PhD student, Anna Wade, led this research in recent years, has given several presentations, and will soon submit a manuscript on the carbon accumulations of Holcombe's Branch legacy sediments.

b) Modeling. Our previously published results from our spatially-explicit tRIBS model simulations (Dialynas et al. 2016, 2017) will be compared with observed C contents in a manuscript being prepared for submission in 2019 by Duke PhD student Anna Wade.

3. Persistence of Alternative States. We extended a previous formulation of the dynamical system of ecohydrological and human dynamics in agroecosystems at the Calhoun with attention to the history of land use, its land degradations and subsequent reforestation. The group led by PI Porporato at Duke and Princeton has made models spatially explicit to describe the development of agricultural activities starting from more fertile and accessible bottomlands, and then subsequently expanding upland towards hillslopes and ridges. Porporato's group is currently calibrating a model using data obtained by archeological and anthropological research by the UGA group (led by PI Nelson and Postdoc Coughlan). We expect to find mathematically the conditions (possibly indicated by thresholds in the soil biogeochemical variables) leading to the agricultural collapse and abandonment of individual fields to be a function of external pressures induced by the cotton market. We then plan to model spatially the phase of degradation and regeneration with particular attention to the nonlinear interactions between social and ecohydrological processes.

4. Education and Outreach. Led by PI Kathy O'Neill, we have developed educational modules derived from spatial datasets for use with Google Earth, cloud-based formats available at no cost to educators. Undergraduate students were involved in this effort. The Calhoun CZO continues to be affiliated with NSF's REU in Soil Science run by North Carolina State and four full-day or 1.5-day field trips have now been given to ~40 REU undergrads. A new undergraduate course called Critical Zone Science and Management continues to be taught at Roanoke College. The class has a lab and has been developed so that it can be taught at different levels of complexity to be used across a range of institutions and student populations. At University of Kansas, PI Sharon Billings co-teaches a class with lab entitled "Biogeochemistry in the Critical Zone." In 2018, the Calhoun CZO hosted the Southeastern Friends of the Pleistocene, a Friday evening to Sunday afternoon field trip that was attended by nearly 100!

5. Cross-CZO Research and Projects. More than half of the CCZO PIs are involved with cross-CZO research projects. Results across sites include field-based mineral weathering experiments led by our Japanese colleagues, soil microbial and biogeochemistry studies, and hydrologic modeling with PIHM. Redox-related experiments have been conducted in several CZOs and are part of a 2018 Calhoun-Luquillo PhD dissertation. We collaborate with the cross-CZO hydrology project and support cross-site E&O projects including co-authoring a paper in *The Earth Scientist* that describes opportunities for

integrating CZ science into environmental science courses at undergraduate and high school levels. Geophysics and geochemistry data from our 70-m weathering profile has drawn such interest that scientists from other CZOs and WyCEHG have written a geophysics-geochemistry paper (Holbrook et al. 2019).

Key outcomes or Other achievements:

Four other exciting outcomes from across the CCZO include.

1. Collaborations with Wofford College Prof. Terry Ferguson and Prof. Missy Eppes of UNC-Charlotte have led to major discoveries of deep paleo-colluvium some of which buries ^{14}C-dead organic matter in landscapes in and around the Calhoun CZO. We have collected and analyzed samples and are cooperating with Dr. Debra Willard of the USGS who is analyzing pollen to enrich the research. We have one of four OSL dates reported of a colluvium that dates to 110,000 ybp. In 2018, we wrote and submitted a paper to the *Soil Science Society of American Journal*, a paper that unveils the beginnings of a new geologic and geomorphologic history of the Southern Piedmont. The widely accepted idea that the Piedmont's regolith is residual derived from weathering rock directly below. In a subsequent manuscript that we hope will be submitted in 2019, the Piedmont is presented as a much more interesting and transport-derived landscape complete with major volumes of colluvium.

2. The establishment and continuation of a "mini-CZO", starting with funding from German and non-Calhoun CZO support. One of our PhD students, Zach Brecheisen, travelled to the University of Koblenz-Landau (Prof. Hermann Jungkunst) in 2015 and installed moisture and biogeochemical sensors and logging equipment, training master's students and scientific technicians. Data loggers continue to monitor dynamics of the critical zone to many meters depth, under beech forest, vineyard, and maize. Jungkunst and Richter are analyzing the datasets.

3. Our USFS scientist colleague on the Calhoun CZO team, Dr. Mac Callaham, has advised a UGA graduate student who graduated in 2018 and successfully wrote a thesis on the effects of historic and contemporary land-uses on soil ecology at the Calhoun CZO. Mac serves as the Director of the Calhoun Experimental Forest beginning in 2016.

4. A sixth Duke PhD student, Anna Wade, has now been supported by the NSF-IGERT program entitled WISeNet, while working on the Calhoun CZO. The IGERT focuses on environmental sensors, their use and data analysis. Anna is monitoring co-located sensors that produce continuous data on redox potential, oxygen concentrations, soil moisture, temperature, and water level in the legacy sediments of Holcombe's Branch.

* What opportunities for training and professional development has the project provided?

1. High school student education. At Duke and University of Georgia, high school students have been included in research. At Duke, a high school honors student from the North Carolina

School of Science and Mathematics was mentored by a Calhoun CZO PhD student for nearly one year. The student orally presented her work in a formal symposium, and wrote a senior thesis on her studies. The experience deeply influenced the student's interests and future trajectory. In PI Mukesh Kumar's lab, high school student Henna Shah from Green Hope High School in NC interned to work on the role of precipitation extremes on sediment yield. At PI Nelson's lab at the University of Georgia, Zach Meyers, a local high school student, joined the team as an intern for the 2016-2017 school year. Zach worked mainly with data organization and analysis. Also at UGA, in PI Thompson's lab, high-school senior Roberto Carlos Villanueva participated in the Young scholars program and benefited from interactions with graduate students, postdocs and Co-PI Thompson, all while performing iron analysis and learning to chemically extract iron-OM complexes from soils. At Roanoke College, K-12 educators participated in a number of science pedagogy meetings at which our E&O PI O'Neill gave a presentation about critical zone and environmental science.

2. Undergraduate education. From the beginning of the CCZO, we have focused on undergraduate education for much or most of our E&O. At Roanoke College, Duke, the University of Georgia, and the University of Kansas, many undergraduates are involved in various ways with CZ science and the Calhoun CZO. At Roanoke College, PI O'Neill for all five years of the project has provided opportunities for professional development to undergrads, supporting multiple research projects that directly contribute to E&O efforts at the CCZO. One Roanoke student was awarded a research fellowship by the College with the potential for support for over four years. Laboratory and classroom activities have been developed by PI O'Neill and tested as part of her new co-taught critical zone science class at Roanoke. One Roanoke undergraduate was enthusiastic enough to volunteer to work on two hot very arduous Calhoun summer field trips "in order to get field experience." PI O'Neill has supported over a dozen independent and research projects over the life of our project and involved several of these students in presentations and manuscript writing. At Roanoke, the development of critical zone educational materials has contributed to the education of many students, in some years over 100 undergraduate students per year take O'Neill's critical zone class. At Duke, a new interdisciplinary course entitled "Environment in Literature, Law, and Science" is being given for the second time to about 50 undergraduates, and the Earth's critical zone is a core concept of the science in the class. About 40 undergraduates in North Carolina State University's REU in Soil Science have been given day- or 1.5-day long field trips to the CCZO. The UGA team of PIs also continues to be active with undergraduates, with a number of them completing research projects that include oral presentations at professional meetings (GSA) and written senior theses. UGA's first ERASMUS+ agreement includes travel to visit Turkish and U.S. faculty and students. UGS geoscience faculty will also promote CZ science in a new program at the UGA Cortona, Italy campus. A number of these undergrads have applied and enrolled in graduate environmental and Earth science programs. Finally, at the University of Kansas, undergraduates have been trained to use lab equipment to analyze soil-sample incubations.

3. Graduate education. At Duke, Georgia Tech, Mississippi State, the University of Georgia, and the University of Kansas, graduate students have been involved in the lifeblood of our CZ science and Calhoun CZO. At Duke, seven PhD students are working on CZ biogeochemistry, hydrology, and systems modeling. Six have earned support from an NSF IGERT program in wireless and sensor technologies. PhD student Zach Brecheisen won a Forest History Society

Fellowship to support his research work. PhD student Anna Wade took two training trips, one to UGA to learn XRD techniques and the other to Saskatoon for synchrotron analyses. Wade won two internal competitions at Duke to support her isotope dating research and time with XRD instrumentation. At Georgia Tech, graduate students work in Rafael Bras' and Jingfeng Wang's laboratories with highly talented post-docs and visiting research scientists at the flux tower, in model development and simulation, and data production, processing, and analysis. At Mississippi State, a graduate student has collected and analyzed environmental history data. At the University of Georgia, graduate students are trained to collect and analyze field EMI, electrical resistivity, stream chemistry, and soil phosphorus data. One, Caitlin Hodges, graduated with a MS from UGA and is now working on a PhD at Penn State where she started in the fall of 2017. Caitlin particularly enjoys teaching. Another PhD student at UGA in PI Don Nelson's lab, Michael Lonneman, collected, digitized, and analyzed a variety of landscape and historical data. Michael was the recipient of a grant to attend a NSF-funded workshop on spatial agent-based modeling at the National Socio-Environmental Synthesis Center (SESYNC). At the University of Kansas, graduate students are trained in the use of soil and enzyme incubation techniques to assess soil microbial activities. All of these graduate students are presenting their results and integrated CZ science in a wide variety of forums, from AGU and SSSA to local science and 4-H clubs. It can be emphasized that Calhoun PIs interact with all graduate students across institutions. Graduate-student and faculty teams from across our institutions are publishing papers together in flagship science journals such as Water Resources Research, JGR, and EGU's Biogeoscience and receiving awards for interdisciplinary training, thanks to CCZO's interinstitutional cooperation.

4. Postdoctoral scientists and young professors. At Duke, Georgia Tech, the University of Georgia, and the University of Kansas, postdoctoral scientists are involved in important ways with our CZ science and the Calhoun CZO. Dr. Jay Austin, well trained as a clay mineralogist, has worked at the University of Georgia and Duke, and is expanding his experience and expertise by sampling and analyzing soils and groundwater. Also at Duke, Anthony Parolari has been involved in all aspects of the CZO research. He has helped mentor graduate students, helped reconstruct the experimental Calhoun watersheds, and conducted a variety of modeling projects with long-term Calhoun data. Dr. Parolari has moved into a tenure-track assistant professor position at Marquette University. The CZO-UGA Geology group garnered a UGA Franklin College visiting professor fellowship for Dr. Koray Yilmaz from Middle East Technical University in Turkey. He spent a summer in residence at UGA (fully subsidized by UGA) to develop a research program on CZ science in the Iznik Lake basin in central Turkey. Also at UGA, Postdoc Mike Coughlan worked has been responsible for developing spatial datasets and models, and for writing and publishing two peer-review papers. At the University of Kansas, postdoc Dr. Christoph Lehmeier is involved in soil incubations and analyzing microbial abundance and community composition. Christoph has worked at the Calhoun on a number of occasions where he has readily learned a variety of field skills. He helped plan what is called the Calhoun Big Dig 2016-17, which is comparing deep soil-weathering profiles of CZs that have experienced contrasting land use histories. He is mentored mainly by PI Billings but also PI Richter.

* How have the results been disseminated to communities of interest?

Calhoun CZO research is being published in the leading international science journals, including *Science*, *Water Resources Research*, *Global Biogeochemical Cycles*, and *New Phytologist* as examples. We are presenting talks at a large number of colleges and universities, to different audiences and programs within universities, and at many scientific conferences (see Products for details). In addition, PIs of the Calhoun CZO explicitly reach out to the Earth sciences, and environmental, engineering, ecological, and humanities communities to explain the details and the need for an integrated critical zone science. Some 18 examples follow.

K-12 and undergraduate educators: Multiple presentations have been given at a variety of pedagogy meetings; many of these presentations have had undergraduate co-authors.

Students in Undergraduate and Graduate Schools: New classes in critical zone science are being taught at two of our institutions, Roanoke College and the University of Kansas. Our PI Billings and O'Neill have developed these classes as part of their involvement in the Observatory program.

Environmental educators and citizen scientists: CZ science was discussed in a statewide webinar for the Virginia Master Naturalist program (used for continuing education credit for citizen scientists). The talk was posted on state Master Naturalist website. Conference presentations have been given to the Virginia Association of Environmental, and individual presentations have been made to citizen scientists and conservationists in the Appalachian Trail Club, Master Naturalists, and the Forest History Scociety.

Graduate and undergraduate student communities: Many presentations, formal and semiformal, have been made to students across many disciplines, all led by Calhoun CZO graduate and undergraduate students.

Hydrologists: PI Porporato and his students and postdocs continue to disseminate results from their CZ research in a variety of hydrology forums. His student Mark Bartlett graduated in 2018 and presented his work at AGU and EGU and at a CUAHSI symposium. As a CUAHSI Board of Director, PI McGlynn is a bridge from CZ science to the CUASI program. PI Mukesh Kumar and his students continue to give critical zone based hydrology talks in a number of venues.

Ecosystem Ecologists & Biogeochemists: PI Richter was invited to Nantes, France to give a keynote to the annual joint meeting of France's CZO and LTER/ILTER programs. His talk was called, "Darwin and Lyell, Ecosystems and Earth's Critical Zones." PI Richter published a piece in EGU's *Biogeosciences*, written out of the collaboration nearly 30 scientists from CZO, LTER, and NEON communities who met at the LTER All Scientists Meeting in late August 2015. PI Thompson continues to lead novel biogeochemical papers into press that acknowledge support from the CCZO project: on the influence of oxygen on the formation of iron precipitates and their subsequent reactivities toward reductive dissolution; on the influence of the frequency of redox fluctuations on iron-carbon dynamics; on a method of standard addition to identify specific

iron phases using Mössbauer approaches with complex soils and sediments; and on iron oxide reactions following a two-year redox fluctuation experiment.

Earth scientists: We gave talks and posters on CZ science and the Calhoun CZO at the meetings of AGU and EGU. A number of CCZO PIs are involved with preparing and submitting a proposal for a Chapman Conference, "Hillscope: Architecture of Porosity in the Critical Zone."

Clay mineralogists: PI Schroeder continues with his active outreach to clay mineralogists. He was a principle host of the Clay Minerals Society meeting held in Atlanta, in which he helped sponsor a session of talks entitled, "Clays in the Critical Zone". A field trip to the Calhoun CZO was conducted. In 2018, Schroeder published a Cambridge University Press book entitled, "Clays in the Critical Zone."

Stratigraphers: PI Richter continues to work as an appointed member of the International Commission on Stratigraphy's Anthropocene Working Group, and in 2018 authored a chapter in the Cambridge University Press book on the Anthropocene to be published in early 2019.

Biogeo-isotopic scientists: PI Cherkinsky led efforts to discuss CZ science at annual meetings such as the Accelerator Mass Spec Conference and Radiocarbon Conference.

Environmental history: PIs Giesen, Nelson, and postdoc Coughlan all advance the interdisciplinary critical zone science as they examine the human-affected legacies of critical zone history across many of the CZOs. They have discussed the possibility of initiating a discussion on environmental history as a Cross-CZO working group. Nearly all Calzones see this as a natural bridge for the Critical Zone research program in years ahead.

Environmental humanities: PI Richter has twice co-taught a popular new Duke class entitled, "Environment in Literature, Law, and Science", an interdisciplinary class taught at a high intellectual level to 40 to 50 Duke undergrads. PI Richter has engaged environmental humanities scholars with critical zone science on several occasions, and is collaborating with Duke's Franklin Humanities Institute dcinematographer Eric Barstow on a 60-min documentary derived from a 2-day trip to the Calhoun CZO by a dozen humanities scholars including philosopher Bruno Latour. The documentary is griping and is about to be released in early 2019. We call the film, "The Education of Bruno Latour: From Critical Zone to the Anthropocene."

Geology and environmental science educators (undergraduates and advanced high school): PI O'Neill and her students continue to disseminate materials via presentations at national and regional scientific and pedagogical meetings, Professional Development Institutes for educators, classroom and laboratory teaching, site visits, public outreach events, and on the CZO website. O'Neill is most focused on building bridges with geology and environmental science professors at small liberal arts institutions.

International geologists: PI Schroeder was invited to give a talk about the Iznik Lake CZO at the 7th International Geochemistry Symposium held in Antalya, Turkey. PI Richter invited UNAM Prof. Christina Siebe to Duke and to AGU, where she talked about being the Lead-PI of the very impressive Mezquital Valley CZO near Mexico City.

International scientists: PI Schroeder, Cherkinsky, Billings, and Richter have been particularly active in giving talks and participating in international discussions to advance CZ science.

Postdoc and graduate student communities: Many formal and informal presentations were given to student groups and organizations by Calhoun CZO students across many disciplines. An example is the Thursday Chalk Talk at Duke's River Center, at which a number of presentations have been given by critical zone scientists.

Rural South Carolina communities: PIs Nelson and Richter initiated a partnership with the Union County Historical Society. Richter is a member of the Historical Society and has used the UCHS's library and collections.

Duke University Alumni: In 2018, *Duke Magazine* published a cover-story on the Calhoun CZO by a highly talented author, Scott Huler. The well written and well illustrated story featured critical zone science as a new 21st century science and we are impressed with the magazine's distribution to nearly 200,000 alumni.

* What do you plan to do during the next reporting period to accomplish the goals?

A. The next year's plans are organized below using the five specific goals of the CCZO project.

1. Hydro-biogeochemical Decoupling and Regeneration of CZs following Land Degradation

a) Deep Geophysics and Geochemistry. We will continue to collaborate writing papers aimed at this project goal. A number of papers are well along and will be submitted in the coming year. A paper led by Steve Holbrook is well into the review process at *Scientific Reports* and we expect that this geophysical-geochemical examination of the 65-m deep core will be published in 2019. PI Richter is writing about the major mineralogical transformations exhibited in the 65-m deep core, concentrating on the feldspars and clay minerals in the full soil-weathering profile. PhD graduate Brecheisen is leading the writing of a paper on soil gas dynamics in nine soil-weathering profiles of 5-m depth, a paper approved by his graduate committee as part of his dissertation. We continue to examine the paleo-colluvium in Pauline, SC, having submitted a first paper in 2018 to (Richter et al. *Soil Science Society of America Journal*). We will continue to collaborate with WyCEHG and elaborate on our surprising and significant conclusions reached in the St. Clair et al. (2015) paper, by proposing to drill nests of proximate but deep boreholes down though fractured bedrock. We are writing a US-DOE proposal to research interconnections of above and belowground processes and fluxes, a proposal that will likely have a clearcutting experiment in which we directly manipulate the interactions of vegetation and deep critical zone weathering reactions.

b) Land-Use History. Environmental anthropologists and historians are continuing to assemble and help interpret the history of changes in the land at the Calhoun CZO. Historical records, aerial and on-ground photography, and census data are used in geographically explicit models to evaluate human forcings that accelerated and subsequently decelerated soil erosion on uplands *and* sedimentation of valley bottoms. Now that these databases are developed, we can conduct

spatial analyses to better understand drivers and feedbacks of land use changes. In partnership with colleagues PI Porporato, we will begin to develop dynamic models of the system based on these empirical data collected over the last years.

c) Land-Use History's Effects on CZ Structure and Process. Nine sites will continue to be used to quantify the structure and function of CZs affected by contrasting land use histories: three in uncultivated reference hardwoods that have minimal farming impacts, three in currently and long-cultivated cultivated fields (more than a century of continuous cultivation), and three sites in old-field pine forests that have grown for 60 to 90 years following farm abandonment. We continue to log continuous soil moisture, temperature, CO_2, and O_2 data at 0.5- and 1.5-m, and measure moisture by neutron probe and four gases (CO_2, O_2, N_2O, CH_4) down to 5-m. At two sites, we continue to monitor these gases down to 8.5m. We will complete estimates of Ksat down to 4-m in soils and upper saprolites of the nine sites. With regard to C-Fe redox biogeochemistry, data will continue to be analyzed and several manuscripts will be submitted in the coming year. With regard to C turnover within the full CZ, organic acids will be estimated, and experiments conducted to evaluate the degree to which organic acids and phosphatases generate plant-available P throughout soil weathering profiles of the CCZO.

d) Long-term Experimental Watersheds. Measurements of rainfall and streamflow continue on the CCZO-reinstrumented watersheds in addition to water level in an array of groundwater wells. Soil water sensors are instrumented throughout Watershed 4 and within Holcombe's Branch legacy sediments. Analysis of historic strip charts have been completed with the help of the US Geological Survey and USFS Coweeta Hydrologic Lab.

e) Calhoun Long-Term Soil-Ecosystem Experiment (LTSE). Soils in the 16 LTSE plots that were resampled and archived in 2017 in year 60 after project initiation. Analyses have begun with a focus on temporal dynamics of organic carbon throughout the upper CZ and structural re-aggregation in the clayey B horizon. A study of lead biogeochemistry will be completed in 2019, and aims at quantifying the accumulation and redistribution of atmospheric lead from combustion of leaded gasoline at this site remote from point sources.

2. Erosion-Induced Carbon Dynamics

Observations. Our manuscript on soil carbon in legacy sediments continues to be assembled, a paper based on the sediment inundation of soil organic carbon (SOC) in Holcombe's Branch. Organic-carbon fractionation studies will be completed to better evaluate the changes in soil organic matter as it lies buried in legacy sediments. We are generally impressed with the coarse textures of legacy sediments of low order floodplain-terraces and the relatively low carbon burial.

A set of five sites along Holcombe's Branch have been instrumented to monitor water level dynamics in legacy sediments along with redox potential, O_2 concentrations, soil moisture, temperature, dissolved organic carbon, to characterize how legacy sediments despite being in receiving areas are generally oxygenated and unable to store much organic carbon.

3. Persistence of Alternative States

PIs Nelson and Porporato, environmental anthropologists and system modelers will continue to interact to better model and simulate the history of changing land and human dynamics. This team will write and submit a research proposal to NSF's Coupled Human Systems program. The investigators are excited about their continued interactions and their potential to extend their work from the Calhoun to other geographic areas.

4. Education and Outreach Program

We will continue to classroom test educational materials for the Roanoke College undergraduate course in CZ science, and to publish educational materials that integrate interactive maps, text, imagery, and video. We will write and submit a manuscript that argues for the use of the critical zone model in field-based environmental education, a significant pedagogy that is clearly on the wane. In addition we will publish and improve outreach materials using cloud-based and distributed formats, and collaborate on cross-CZO E&O teams coordinated through the National Office, and continue recruitment of undergraduate students, especially from underrepresented groups, to assist with Calhoun research.

5. Cross-CZO Projects

PIs and students are continuing to participate in cross-CZO projects, specifically the soil microbiology (with paper accepted in 2018), biogeochemistry (with paper published in 2018), hydrology (with paper well underway in 2018), and E&O projects. Our data manager continues to participate in the Cross-CZO effort to promote and improve program-wide data management.

B. Plans that support the project at large

1. Biweekly conference calls. Most members of the CCZO are able to participate in biweekly research phone calls, which are described earlier.

2. Calhoun CZO-USFS Relations. We continue to work closely with the managers of the Sumter National Forest, managers who have recently changed though our research permitting continues to operate well.

3. Sixth Annual Calhoun Summer Science Meeting. Richter is organizing this year's Summer Science Meeting. We will coordinate some research activities and field trips along with the meeting.

4. Calhoun CZO Website. Our website will continue to be the focus for our observatory’s growing research, infrastructure, data, models, publications, people, and E&O programs.

5. Data Policy and Management. We will work to implement our accelerated data-sharing policy *within our Observatory*. Our data manager and PI Richter will continue to work to improve design of our data management platform to both analyze and report CZO data.

Supporting Files

	Filename	Description	Uploaded By	Uploaded On
(Download)	2018 CCZO Supplementary subm.pdf	Supplementary Information for Calhoun CZO Year 5: 1 Dec. 2017 â?? 30 Nov. 2018 from Terms and Conditions for CZOs (NSF 12-575)	Daniel Richter	03/08/2019

Back to the top

Products

Books

- Coleman, D.C., M.A. Callaham, Jr., and D.A. Crossley, Jr. (2017). *Fundamentals of Soil Ecology 3.* Academic Press. London. Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; ISBN: 9780128052518
- Schroeder, Paul A. (2018). *Clays in the Critical Zone* Cambridge University Press. Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1017/9781316480083

Book Chapters

- Billings SA, Sullivan PL. (2018). Working across scales to project soil biogeochemical responses to climate. *Multi-scale Biogeochemical Processes in Soil Ecosystems: Critical Reactions and Resilience to Climate Changes (Wiley-IUPAC Series on Biophysico-chemical Processes in Environmental Systems)* 5. Yu Yang, Marco Keiluweit, Nicola Senesi, Baoshan Xing. . Status = UNDER_REVIEW; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes
- Lajtha, K., V. Bailey, K. McFarlane, K. Paustian, D. Bachelet, R . Abramoff, D. Angers, S. A. Billings, D. Cerkowniak, Y. G. Dialynas, A. Finzi, N. French, S. Frey, N. Gurwick, J. Harden, J. M. F. Johnson, K. Johnson, J. Lehmann, S. Liu, B. McConkey, U. Mishra, S. Ollinger, D. Paré, F. Paz Pellat, D. deB. Richter, S. M. Schaeffer, J. Schimel, C. Shaw, J. Tang, K. Todd-Brown, C. Trettin, M. Waldrop, T. Whitman, and K. Wickland (2018). Chapter 12: Soils. *Second State of the Carbon Cycle Report (SOCCR2): A Sustained Assessment Report* Cavallaro, N., G. Shrestha, R . Birdsey, M. Mayes, R . Najjar, S. Reed, P. Romero-Lankao, and Z. Zhu. U.S. Global Change Research Program. Washington, DC, USA. . Status = PUBLISHED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes
- Richter, D.deB., S.A. Billings, C. Waters (2018). A pedology and pedostratigraphy for the Anthropocene. *The Anthropocene as a Geological Time Unit (In Chapter 2, Stratigraphic Signatures of the Anthropocene)* Jan Zalasiewicz, Colin Waters, Mark Williams, Colin Summerhayes. Cambridge University Press. . Status = UNDER_REVIEW; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

Inventions

Journals or Juried Conference Papers

- Austin, J.C., A. Perry, D.D. Richter, and P.A. Schroeder (2018). Modifications of 2:1 clay minerals in a kaolinite dominated Ultisol under changing land-use regimes. *Clays and Clay Minerals*. 66 (1), 61. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1346/CCMN.2017.064085
- Barcellos, Diego, K. Taylor Cyle, and Aaron Thompson (2018). Faster redox fluctuations can lead to higher iron reduction rates in humid forest soils. *Biogeochemistry*. 137 (3), 367. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10533-018-0427-0
- Bartlett, M.S., and A. Porporato (2018). A class of exact solutions of the Boussinesq equation for horizontal and sloping aquifers. *Water Resources Research*. 54 (2), 767. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2017WR022056
- Bartlett, M.S., and A. Porporato (2018). State dependent jump processes: Ito–Stratonovich interpretations, potential, and transient solutions. *arXiv*. 1807.01848. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No
- Bastola, S., Y. G. Dialynas, R. L. Bras, L. V. Noto, and E. Istanbulluoglu (2018). The role of vegetation on gully erosion stabilization at a severely degraded landscape: A case study from Calhoun Experimental Critical Zone Observatory. *Geomorphology*. 308 25. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.geomorph.2017.12.032
- Billings SA, Richter D deB, Ziegler SE, Prestegaard K, Wade A. (2018). Distinct contributions of erosional and depositional profiles to land-atmosphere exchange of CO2 in two contrasting forests. *Frontiers in Earth Science*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Billings, S.A., D. Hirmas, P.L. Sullivan, C.A. Lehmeier, S. Bagchi, K. Min, Z. Brecheisen, E. Hauser, R. Stair, R. Flournoy, D. deB. Richter (2018). Loss of deep roots limits biogenic agents of soil development that are only partially restored by decades of forest regeneration. *Elementa Science of the Anthropocene*. 6 (1), 34. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1525/elementa.287
- Bonetti, S., A.D. Bragg, and A. Porporato (2018). On the theory of drainage area for regular and non-regular points. *Proceedings of the Royal Society A*. 474 (2211), 20170693. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1098/rspa.2017.0693
- Bonetti, S., Richter, D. D., and Porporato, A. (2018). The effect of accelerated soil erosion on hillslope morphology. *Earth Surface Processes and Landforms*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Brantley, S.L., McDowell, W.H., Dietrich, W.E., White, T.S., Kumar, P., Anderson, S., Chorover, J., Lohse, K.A., Bales, R.C., Richter, D., Grant, G., and Gaillardet, J. (2017). Designing a network of critical zone observatories to explore the living skin of the terrestrial Earth. *Earth Surface Dynamics*. 5 841. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/esurf-2017-36

- Brecheisen, Z.S., D. deB. Richter (2018). Micro-Topographic Roughness Analysis (MTRA) highlights minimally eroded terrain in a landscape severely impacted by historic agriculture. *Remote Sensing of Environment*. . Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Buendía, Corina, Axel Kleidon, Stefano Manzoni, Björn Reu, and Amilcare Porporato (2018). Evaluating the effect of nutrient redistribution by animals on the phosphorus cycle of lowland Amazonia. *Biogeosciences*. 15 279. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/bg-15-279-2018
- Calabrese, S., Porporato, A., and Parolari, A.J. (2017). Hydrologic transport of dissolved inorganic carbon and its control on chemical weathering. *Journal of Geophysical Research: Earth Surface*. 122 (10), 2016. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2017JF004346
- Calabrese, Salvatore, Daniel D. Richter, and Amilcare Porporato (2018). The formation of clay-enriched horizons by lessivage. *Geophysical Research Letters*. 45 (15), 7588. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1029/2018GL078778
- Chen, Chunmei, and Aaron Thompson (2018). Ferrous iron oxidation under varying pO2 levels: The effect of Fe(III)/Al(III) oxide minerals and organic matter. *Environmental Science & Technology*. 52 (2), 597. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1021/acs.est.7b05102
- Chen, Chunmei, Christof Meile, Jared Wilmoth, Diego Barcellos, and Aaron Thompson (2018). Influence of pO2 on iron redox cycling and anaerobic organic carbon mineralization in a humid tropical forest soil. *Environmental Science & Technology*. 52 (14), 7709. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1021/acs.est.8b01368
- Chen, Chunmei, Diego Barcellos, Daniel D. Richter, Paul A. Schroeder, Aaron Thompson (2019). Redoximorphic Bt horizons of the Calhoun CZO soils exhibit depth-dependent iron-oxide crystallinity. *Journal of Soils and Sediments*. 19 (2), 785. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s11368-018-2068-2
- Cherkinsky A, Prasad G. V. Ravi, Hai Pan, Richter D deB (2018). AMS and IRMS studies of soil organic matter fractions in Ultisol profiles, Calhoun CZO, South Carolina USA. *Nuclear Instruments and Methods in Physics Research, Part B*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Cherkinsky A., Brecheisen Z , Richter D. (2018). Carbon and oxygen isotope composition in soil carbon dioxide within deep Ultisols at the Calhoun CZO, South Carolina, USA. *Radiocarbon*. 60 (5), 1357. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1017/RDC.2018.99
- Coughlan, M.R., D.R. Nelson (2018). A Fuzzy Logic analysis of prehistoric settlement dynamics and niche construction on the South Carolina Piedmont, North America. *Journal for Archaeological Science*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Coughlan, M.R., D.R. Nelson (2018). Influences of Native American land use on the Colonial Euro-American settlement of the South Carolina Piedmont. *PLoS*

ONE. 13 (3), e0195036. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1371/journal.pone.0195036

- Gao, M., M.K. Taylor, and M.A. Callaham, Jr. (2017). Trophic dynamics in a simple experimental ecosystem: Interactions among centipedes, Collembola and introduced earthworms. *Soil Biology and Biochemistry*. 115 66. Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1016/j.soilbio.2017.08.001
- Hajji, I., D. F. Nadeau, B. Music, F. Anctil, and J. Wang (2018). Application of the maximum entropy production model of evapotranspiration over partially vegetated water-limited land surfaces. *Journal of Hydrometeorology*. 19 989. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1175/JHM-D-17-0133.1
- Hartzell, Samantha, Mark Bartlett, Jun Yin, Amilcare Porporato (2018). Similarities in the evolution of plants and cars. *PLoS ONE*. 13 (6), e0198044. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1371/journal.pone.0198044
- Hartzell, Samantha, Mark S. Bartlett, and Amilcare Porporato (2018). Unified representation of the C3, C4, and CAM photosynthetic pathways with the Photo3 model. *Ecological Modelling*. 384 173. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.ecolmodel.2018.06.012
- Hodges, C., E. King, J. Pett-Ridge, A. Thompson (2018). Potential for iron reduction increases with rainfall in montane basaltic soils of Hawaii. *Soil Science Society of America Journal*. 82 176. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/sssaj2017.06.0193
- Holbrook, W. Steven, Allan Bacon, Susan L. Brantley, Bradley J. Carr, Brady A. Flinchum, Virginia Marcon , Daniel deB. Richter, and Clifford S. Riebe (2018). Links between physical and chemical weathering inferred from a 65-m-deep borehole through Earth's critical zone. *Scientific Reports*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Liu, Y., M. Kumar, G. Katul, and A. Porporato (2018). Reduced Resilience as an Early Warning Signal of Reduced Mortality. *Science*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Lybrand, Rebecca A., Jason C. Austin, Jennifer Fedenko, Rachel E. Gallery, Erin Rooney, Paul Schroeder, Dragos G. Zaharescu, and Odeta Qafoku (2018). The nano-landscape of weathering: A microscopy-spectroscopy approach to assess biota-rock interactions. *Scientific Reports*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Mobley, M.L., K.A. Nelson, D.D. Richter, R.D. Yanai (2018). Detecting forest soil response to reforestation and ecological succession at the Calhoun Critical Zone Observatory, USA. *Soil Science Society of America Journal*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Nelson, D.R., M.R. Coughlan (2018). Anthropogenic drivers and the reconstruction of historical forest cover change in the South Carolina Piedmont. *Ecosphere*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

- O'Neill K.P., J.F. Rice, and D. deB. Richter (2017). Cultivating a sense of place in the southern Piedmont using Esri Story Maps. *In the Trenches*. 7 (October), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No
- Pelak, Norman, Roberto Revelli, and Amilcare Porporato (2017). A dynamical systems framework for crop models: Toward optimal fertilization and irrigation strategies under climatic variability. *Ecological Modelling*. 365 80. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.ecolmodel.2017.10.003
- Revelli, Roberto, and Amilcare Porporato (2018). Ecohydrological model for the quantification of ecosystem services provided by urban street trees. *Urban Ecosystems*. 21 (3), 489. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s11252-018-0741-2
- Richardson, Justin B., Arnulfo A. Aguirre, Heather L. Buss, A. Toby O'Geen, Xin Gu, Daniella M. Rempe, and Daniel deB. Richter (2018). Mercury sourcing and sequestration in weathering profiles at six Critical Zone Observatories. *Global Biogeochemical Cycles*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1029/2018GB005974
- Richter, D.D., M.C. Eppes, J.C. Austin, A.R. Bacon, S.A. Billings, Z. Brecheisen, T.A. Ferguson, D. Markewitz, J. Pachon, P.A. Schroeder, A.M. Wade (2018). Soil production, regolith evolution, and the soil geomorphology legacy of G.K. Gilbert. *Soil Science Society of America Journal*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Richter, D.D., S.A. Billings, P.M. Groffman, E.F. Kelly, K.A. Lohse, W.H. McDowell, T.S. White, S. Anderson, D.D. Baldocchi, S. Banwart, S. Brantley, J.J. Braun, Z.S. Brecheisen, C.W. Cook, H.E. Hartnett, S.E. Hobbie, J. Gaillardet, E. Jobbagy, H.F. Jungkunst, C.E. Kazanski, J. Krishnaswamy, D. Markewitz, K. O'Neill, C.S. Riebe, P. Schroeder, C. Siebe, W.L. Silver, A. Thompson, A. Verhoef, G. Zhang (2018). Ideas and perspectives: Strengthening the biogeosciences in environmental research networks. *Biogeosciences*. 15 4815. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/bg-15-4815-2018
- Ryland, R. D. Radcliffe, D. Markewitz, and A. Thompson (2017). A HYDRUS 2D evaluation of altered depths to the argillic horizon due to erosion: What impacts on hillslope interflow?. *Proceedings of the 2017 Georgia Water Resources Conference*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No
- Sun, J., Mailloux, B.J., Chillrud, S.N., van Geen, A., Thompson A., & Bostick, B.C. (2018). Simultaneously quantifying ferrihydrite and goethite in natural sediments using the method of standard additions with X-ray absorption spectroscopy. *Chemical Geology*. 476 248. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.chemgeo.2017.11.021
- Wade, A., D.D. Richter, V.Medjbe, L.J.T. White, and J.R. Poulsen (2018). Determinants and estimates of stocks of deep soil carbon in Gabon, Central Africa. *Geoderma*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Wang, Dongdong, Yanlan Liu, and Mukesh Kumar (2018). Using nested discretization for a detailed yet computationally efficient simulation of local hydrology in a distributed

hydrologic model. *Scientific Reports*. 8 5785. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/s41598-018-24122-7

- Yin, Jun, and Amilcare Porporato (2017). Diurnal cloud cycle biases in climate models. *Nature Communications*. 8 2269. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/s41467-017-02369-4
- Yin, Jun, and Amilcare Porporato (2018). Radiative effects of daily cloud cycle: general methodology and application to cloud fraction. *arXiv*. 1803.01742. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No
- Yin, Jun, and Amilcare Porporato (2018). Reinforcement of climate hiatus by decadal modulation of daily cloud cycle. *arXiv*. 1803.01752. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No

Licenses

Other Conference Presentations / Papers

- Wade, Anna, and Daniel deB. Richter (2017). *A Layered Past: the Transformation and Development of Legacy Sediments as Alluvial Soils*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Dialynas, Yannis G, Efi Foufoula-Georgiou, William E Dietrich, Rafael L Bras (2017). *A dynamic hydrology-critical zone framework for rainfall-triggered landslide hazard prediction*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Brecheisen Z., Richter D., Cook C., and Heine P. (2018). *A tale of two CZ's: Comparing shallow and deep old-field forest regeneration at the Calhoun CZO*. Goldschmidt Conference. Boston, MA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Hauser, E., Billings, S.A. (2018). *An omnivore's dilemma? The plasticity of rooting system nutritional strategies toward organic- vs. mineral-bound nutrient forms*. Calhoun CZO 2018 Summer Science Meeting. Glendale, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Foroughi, M., Sutter, L., and Markewitz, D. (2018). *Bioavailability of soil Phosphorus distribution in long term soil ecosystem*. Calhoun CZO 2018 Summer Science Meeting. Glendale, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- O'Neill KP, D deB Richter (2018). *CZ science as a future for education in geology, Earth science, and environment*. Southeastern Friends of the Pleistocene. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Braun, J.-J., M.-C. Paiz, M. J. McGrath, N. Rabenkogo, A. P. Mbonda, L. White, J. Gaillardet, J. Bouchez, J. S. Moquet, V. Regard, S. Carretier, J. P. Bricquet, G. Mahé, and D.deB. Richter Jr. (2017). *CZO perspective in Central Africa: The Lopé watershed, Lopé National Park, Ogooué River basin, Gabon*. International Long Term Ecological Research Network & LTER-France (Zones Ateliers Network & Critical Zone Observatories) joint conference. Nantes, France. Status = PUBLISHED; Acknowledgement of Federal Support = No

- Richter D deB., J Wang, R Bras, D Markewitz, D Nelson, J Austin, P Schroeder, SA Billings, KP O'Neill, J Giesen, WS Holbrook, B Carr (2017). *Calhoun CZO as an ancient geobiologic and land-use altered time machine*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Jordan, Bear (2018). *Changes in clay mineral assemblages of legacy sediments in the Calhoun Critical Zone Observatory, SC: Evidence for anthropogenic landscape change*. Center for Undergraduate Research Opportunities Symposium. University of Georgia, Athens, GA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Lybrand, Rebecca, Jason Austin, Paul A. Schroeder, Dragos Zaharescu, Rachel Gallery (2017). *Cross-scale perspectives on mineral weathering in the Critical Zone (Invited Presentation)*. Geological Society of America Annual Meeting. Seattle, WA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D.D. (2018). *Darwin, Lyell and Earth's Critical Zones -- An Introduction to the Calhoun CZO*. Southeastern Friends of the Pleistocene Meeting. Glendale, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D., M. Mobley, S. Billings, D. Markewitz, A. Wade (2018). *Decadal restructuring of soil carbon and nitrogen in a regenerating forest on long cultivated land in the southern piedmont of the USA*. North American Forest Soils Conference – International Symposium on Forest Soils. Quebec City, Quebec, Canada. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Mobley, Megan, Kevin Nelson, Daniel Richter, Ruth Yanai (2018). *Detecting change over time with depth in forest soils: an example from the Calhoun Critical Zone Observatory, USA*. North American Forest Soils Conference – International Symposium on Forest Soils. Quebec City, Quebec, Canada. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Liu, Yanlan, Mukesh Kumar, Gabriel George Katul, Amilcare M Porporato (2017). *Detection of early warning signals of forest mortality in California*. American Geophysical Union 2017 Fall Meeting. New Orleans, Louisiana. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Rice J., and K.P. O'Neill (2017). *Developing a "sense of place": Exploring the Earth's critical zone using ESRI Story Maps*. Virginia STEM Conference: Inspiring teachers. Lexington VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Cherkinsky, Alexander, Ravi Prasad, Daniel Richter, Hai Pan (2018). *Distribution of 14C and 137 Cs in the profile of Ultisol, Calhoun CZO*. International Radiocarbon Conference. Trondheim, Norway. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Ryland, Rachel, Daniel Markewitz, David E. Radcliffe, Aaron Thompson, and Lori Sutter (2017). *Erosion alters depth to the argillic horizon: What impacts on hillslope interflow?*. Soil Science Society of America 2017 Annual Meeting. Tampa, FL. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Cherkinsky, Alexander, Zachary Brecheisen, Daniel deB. Richter, Hong Sheng (2017). *Estimation of soil respiration rates and soil gas isotopic composition for the different land use of Ultisols from Calhoun CZO*. American Geophysical Union 2017

Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Richter, D.D. (2017). *Every rural resident knows that the geosciences matter!*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- O'Neill, K.P., D. DeB. Richter (2017). *Exploring landscape processes in South Carolina's southern piedmont using data from the Calhoun Critical Zone Observatory*. South Carolina Science Council, Nov. 10, 2017. . Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Pachon, Julio Cesar, Allan Roy Bacon, Daniel deB. Richter (2017). *Fine earth aggregates and aggregating particles at the Calhoun Critical Zone Observatory*. Soil Science Society of America International Annual Meeting. Tampa, FL. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Bonetti, S.; Porporato, A. M. (2017). *Forward and backward evolution of the Calhoun CZO: the effect of natural and anthropogenic disturbances*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D. deB. (2017). *Gilbert's soil production and the soil clay factory*. Soil Science Society of America International Annual Meeting. Tampa, FL. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, Daniel deB., Jason Austin, Robert S Anderson, Allan R Bacon, Susan L Brantley, Zachary Brecheisen, Paul A Schroeder, Anna Wade, W. Steven Holbrook, Virginia Marcon, Aaron Thompson (2017). *Gilbert's soil production paradigm applied to a critical zone's fractionation of particle sizes*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Coughlan, M., D.R. Nelson, and M. Lonneman (2018). *Gone with the witness tree: A reconstruction of historical forest cover change in the South Carolina Piedmont ca. 1790-1940 using metes and bounds survey witness trees*. American Association of Geographers Annual Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Dialynas, Yannis G., Rafael L. Bras, Daniel deB. Richter (2017). *Hydrologic drivers of soil organic carbon erosion and burial: Insights from a spatially-explicit model of a degraded landscape at the Calhoun Critical Zone Observatory*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Hauser, Emma, and Sharon A Billings (2017). *Illuminating pathways of forest nutrient provision: relative release from soil mineral and organic pools*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Bonetti, Sara; Ferguson, Terry; Richter, Daniel; Porporato, Amilcare (2018). *Impact of climate-vegetation interactions on natural and disturbed landscape evolution: insights from the Calhoun Critical Zone Observatory*. European Geosciences Union General Assembly 2018. Vienna, Austria. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Pelak, N. F., III; Revelli, R.; Porporato, A. M. (2017). *Impact of seasonal variability in water, plant and soil nutrient dynamics in agroecosystems*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Carr, B.J., Y. Zhang, S. Ren, B. Flinchum, A. Parsekian, W.S. Holbrook, C. Riebe, B. Moravec, J. Chorover, J. Pelletier, and D. Richter (2017). *Insights into the base of the critical zone from geophysical logging and groundwater flow testing at U.S. Critical Zone Observatories (CZOs) and critical zone study sites (CZs)*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Kumar, Mukesh, Tan Zi, John D Albertson (2017). *Intercomparing model configurations with varied erosion, deposition and transport representations for simulating sediment yield*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Meile, Christof D, Chunmei Chen, Diego Barcellos, Jared Wilmoth, Aaron Thompson (2017). *Iron cycling under oscillatory redox conditions: from observations to processes (Invited)*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Schroeder, Paul A. Jason C. Austin, and Daniel deB. Richter (2018). *Landshed position and management and their relation to mineral and chemical weathering as assessed by hierarchal cluster analysis of regolith elemental data*. Clay Minerals Society Annual Meeting. University of Illinois at Urbana-Champaign. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Brecheisen, Zachary Scott, Daniel deB. Richter, Mac Callaham, Roberto Carrera-Martinez, Paul Heine (2017). *Landuse legacies of old-field succession and soil structure at the Calhoun Critical Zone Observatory in SC, USA*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- O'Neill KP (2018). *Last child in the soil pit: The role of field based education in critical zone science*. Calhoun CZO 2018 Summer Science Meeting. Spartanburg SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Wade, A., and D. deB. Richter (2017). *Legacy sediments as novel soil profiles*. Soil Science Society of America International Annual Meeting. Tampa, FL. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Porporato, Amilcare M (2017). *Macroscopic behavior and fluctuation-dissipation response of stochastic ecohydrological systems (Invited)*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richardson, J.B. and D. deB. Richter (2017). *Mercury in soils of the Calhoun Critical Zone Observatory: Importance of redox features in sequestration*. Soil Science Society of America International Annual Meeting. Tampa, FL. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Austin, Jason, Amelia Perry, Daniel deB. Richter, and Paul A. Schroeder (2018). *Modifications of 2:1 Clay Minerals In a Kaolinite Dominated Ultisol Under Changing Land-Use Regimes at the Calhoun Critical Zone Observatory, South*

Carolina, USA. Clay Minerals Society Annual Meeting. University of Illinois at Urbana-Champaign. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Chen, Xing, Mukesh Kumar, Stefano Basso, Marco Marani (2017). *On the effectiveness of recession analysis methods for capturing the characteristic storage-discharge relation: An intercomparison study*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Carrera-Martínez, R., M.K. Taylor, and M.A. Callaham, Jr. (2018). *Opening a can of worms: Uncovering the diversity of native semiaquatic earthworms from the Southern Appalachian Piedmont of the US*. Ecological Society of America Annual Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Markewitz, Daniel, Lori Sutter, Daniel deB. Richter (2017). *Patterns in soil electrical resistivity across land uses in the Calhoun Critical Zone Observatory landscape*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Cannida, Tyler (2018). *Petrography of gneisses from the Mary Lou Quarry in Clinton, SC: Implications for quantifying mineral compositions in the critical zone*. Center for Undergraduate Research Opportunities Symposium. University of Georgia, Athens, GA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Bartlett, M. S., Jr.; Porporato, A. M. (2017). *Rainfall-runoff response informed by exact solutions of Boussinesq equation on hillslopes*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richards, David F., IV (2017). *Rare earth distributions in the critical zone: Possible roles of pine versus hardwood vegetative covers*. 36th Annual Technical Conference of the National Association of Black Geoscientists. Atlanta, GA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Liu, Y., M. Kumar, G.G. Katul, and A. Porporato (2018). *Reduced resilience as a potential early warning signal of forest mortality*. Ecological Society of America Annual Meeting. New Orleans, Louisiana. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Brecheisen, Zachary, Mac Callaham, Daniel Richter (2017). *Regeneration of critical zone structure: Macroporosity and soil gasses in old-field forest soils of the southeastern US*. Soil Science Society of America International Annual Meeting. Tampa, FL. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Foroughi, M., Sutter, L., and Markewitz, D. (2018). *Soil phosphorus distribution under different land uses in the southeastern US Piedmont*. Warnell School, UGA Graduate Student Symposium. Athens, GA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Foroughi, Maryam, Lori Sutter, and Daniel Markewitz (2017). *Soil phosphorus distributions in the Calhoun CZO landscape*. Soil Science Society of America 2017 Annual Meeting. Tampa, FL. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Billings, Sharon A, Daniel deB. Richter, Daniel Hirmas, Christoph Lehmeier, Samik Bagchi, Zachary Brecheisen, Pamela L Sullivan, Kyungjin Min, Emma Hauser, Rena Stair, Rebecca Flournoy (2017). *Soil weathering agents are limited where deep tree roots*

are removed, even after decades of forest regeneration. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Calabrese, Salvatore, Daniel deB. Richter, Amilcare M Porporato (2017). *Stochastic dynamics of clay translocation and formation of argillic horizons*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Mallard, JM; McGlynn, BL; Richter, deB (2017). *Terrain and subsurface influences on runoff generation in a steep, deep, highly weathered system*. American Geophysical Union Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Billings, S.A. (2018). *The CZ paradigm advances environmental understanding in many ways*. Calhoun CZO 2018 Summer Science Meeting. Glendale, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Romero, A., Hauser, E., and Billings, S.A. (2018). *The effect of soil development and pH on phosphorus availability across forest ecosystems*. University of Kansas REU Research Symposium. Lawrence, KS. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Sanders, Sophia (2018). *The fate of degraded biotites in the deep critical zone: Implications for the K-Uplift hypothesis*. Center for Undergraduate Research Opportunities Symposium. University of Georgia, Athens, GA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Thompson, Aaron, Chunmei Chen, Nadia Noor, Caitlin Anne Hodges, Diego Barcellos, Daniel deB. Richter (2017). *The potential for iron reduction in upland soils in Calhoun Critical Zone Observatory*. American Geophysical Union 2017 Fall Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Callaham, M.A., Jr., R. Carrera-Martínez, S.W. James, B.A. Snyder, and M.K. Taylor (2018). *The shovel – a surprisingly effective, but often overlooked tool for soil biodiversity discovery*. Ecological Society of America Annual Meeting. New Orleans, LA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- O'Neill K.P., T. Poelzing (2017). *Water resources and the Earth's critical zone: Diving below the surface to reach far across the standards*. Virginia Environmental Education Conference. Front Royal, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D. deB. (2017). *What do Darwin and Lyell have to do with 21st century ecosystem and critical zone science? (Keynote)*. International Long Term Ecological Research Network & LTER-France (Zones Ateliers Network & Critical Zone Observatories) joint conference. Nantes, France. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Other Products

Other Publications

Patents

Technologies or Techniques

- Dexter White, an undergraduate research scholar at the University of Kansas, is developing matrix-specific protocols for analyses of leaves and soils using portable XRF technology.
- University of Kansas graduate student Emma Hauser has developed protocol for analyzing soil extracts for organic acid concentrations using IC.

Thesis/Dissertations

- Bonetti, Sara. *Analysis and Modeling of Landscape Topography: Statistical Description and Evolution Under Natural and Disturbed Conditions (PhD Dissertation)*. (2018). Duke University. Acknowledgement of Federal Support = Yes
- Barcellos, Diego. *Biogeochemical cycling of iron and carbon in humid (sub)tropical forest soils under fluctuating redox conditions (PhD dissertation)*. (2018). University of Georgia. Acknowledgement of Federal Support = Yes
- Svoboda, Samuel. *Clay abyss: Underclays of the Şile region critical zone (senior thesis)*. (2017). University of Georgia, Department of Geology. Acknowledgement of Federal Support = Yes
- Moraes, Anthony. *Clay mineral concentration with depth and land use history in the Critical Zone in Calhoun, SC (senior thesis)*. (2017). University of Georgia, Department of Geology. Acknowledgement of Federal Support = Yes
- Ryland, Rachel Carolan. *Depth to the Argillic Horizon on Historically Farmed Soil in the Southeastern USA Piedmont: Spatial Mapping and Hydrologic Influence*. (2017). University of Georgia. Acknowledgement of Federal Support = No
- Carrera-Martínez, Roberto. *Distribution and diversity of semiaquatic Sparganophilidae earthworms in the Southern Appalachian Piedmont, USA (Master's Thesis)*. (2018). University of Georgia. Acknowledgement of Federal Support = Yes
- Hodges, Caitlin. *Drivers and Variability of Iron Reduction in Upland Soils*. (2017). University of Georgia, Department of Crop & Soil Sciences. Acknowledgement of Federal Support = No
- Dialynas, Y. G.. *Influence of Linked Hydrologic and Geomorphic Processes on the Terrestrial Carbon Cycle (doctoral dissertation)*. (2017). Georgia Institute of Technology. Acknowledgement of Federal Support = Yes
- Brecheisen, Zachary S.. *Macro to Micro Legacies of Landuse at the Calhoun Critical Zone Observatory (PhD dissertation)*. (2018). Duke University. Acknowledgement of Federal Support = No
- Richards, David. *Rare Earth Elements (REE) and their association with deeply weathered saprolite in the Calhoun Critical Zone Observatory, Calhoun, SC (senior thesis)*. (2017). University of Georgia, Department of Geology. Acknowledgement of Federal Support = Yes
- Parisien, Alexandra. *Soil carbon contents of legacy sediments in the Calhoun Critical Zone Observatory (undergraduate senior honors thesis)*. (2016). Duke University. Acknowledgement of Federal Support = Yes

- Chen, Xing. *Understanding the Role of Model Structure and Watershed Properties on Streamflow Response (PhD dissertation)*. (2017). Duke University. Acknowledgement of Federal Support = Yes

Websites

Supporting Files

	Filename	Description	Uploaded By	Uploaded On
(Download)	Billings_Elementa_2018.pdf	Billings et al., 2018, Loss of deep roots limits biogenic agents of soil development that are only partially restored by decades of forest regeneration, Elementa Science of the Anthropocene 6(1): 34	Daniel Richter	03/08/2019
(Download)	Richter_Biogeosciences_2018-compressed.pdf	Richter et al., 2018, Ideas and perspectives: Strengthening the biogeosciences in environmental research networks, Biogeosciences 15: 4815-4832	Daniel Richter	03/08/2019
(Download)	Calabrese_et_al-2018-Geophysical_Research_Letters.pdf	Calabrese et al., 2018, The formation of clay-enriched horizons by lessivage, Geophysical Research Letters 45(15): 7588-7595	Daniel Richter	03/08/2019
(Download)	Schroeder_Clays_2018.pdf	New book: Paul A. Schroeder, 2018, Clays in the Critical Zone, Cambridge University Press	Daniel Richter	03/08/2019

Back to the top

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Richter, Daniel	PD/PI	9
Kumar, Mukesh	Co PD/PI	9
McGlynn, Brian	Co PD/PI	1
Palmroth, Sari	Co PD/PI	0
Porporato, Amilcare	Co PD/PI	3
Billings, Sharon	Co-Investigator	5
Bras, Rafael	Co-Investigator	1
Callaham, Mac	Co-Investigator	1
Cherkinsky, Alexander	Co-Investigator	1
Markewitz, Daniel	Co-Investigator	2
Nelson, Donald	Co-Investigator	1
O'Neill, Katherine	Co-Investigator	4
Schroeder, Paul	Co-Investigator	2
Thompson, Aaron	Co-Investigator	2
Wang, Jingfeng	Co-Investigator	1
Bacon, Allan	Faculty	1
Austin, Jason	Postdoctoral (scholar, fellow or other postdoctoral position)	7
Bartlett, Mark	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Chen, Chunmei	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Coughlan, Michael	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Chapman, Gregg	Technician	1
Cook, Charles	Technician	12
Heine, Paul	Technician	12
Taylor, Melanie	Technician	1
Bastola, Satish	Staff Scientist (doctoral level)	3
Sutter, Lori	Staff Scientist (doctoral level)	4
Barcellos, Diego	Graduate Student (research assistant)	9
Bonetti, Sara	Graduate Student (research assistant)	12
Brecheisen, Zachary	Graduate Student (research assistant)	6
Calabrese, Salvatore	Graduate Student (research assistant)	4
Carrera-Martinez, Roberto	Graduate Student (research assistant)	12

Name	Most Senior Project Role	Nearest Person Month Worked
Foroughi, Maryam	Graduate Student (research assistant)	12
Ghasemian, Soudeh	Graduate Student (research assistant)	4
Hauser, Emma	Graduate Student (research assistant)	4
Huo, Jinge	Graduate Student (research assistant)	1
Liu, Yanlan	Graduate Student (research assistant)	12
Lonneman, Michael	Graduate Student (research assistant)	9
Mallard, John	Graduate Student (research assistant)	9
Martin, Melissa	Graduate Student (research assistant)	1
Noor, Nadia	Graduate Student (research assistant)	3
Pachon, Julio	Graduate Student (research assistant)	1
Ryland, Rachel	Graduate Student (research assistant)	2
Souza, Ligia	Graduate Student (research assistant)	1
Tang, Yao	Graduate Student (research assistant)	12
Wade, Anna	Graduate Student (research assistant)	12
Wang, Zhine	Graduate Student (research assistant)	12
Ardington, Emma	Undergraduate Student	1
Arroyo, Eva	Undergraduate Student	1
Casson, David	Undergraduate Student	1
Jordan, Bear	Undergraduate Student	1
Moraes, Anthony	Undergraduate Student	1
Osota, Elizabeth	Undergraduate Student	2
Richards, David	Undergraduate Student	1
Ryang, Junmo	Undergraduate Student	2
Sanders, Sophia	Undergraduate Student	1
Sanford, Tierra	Undergraduate Student	1
Stair, Rena	Undergraduate Student	2
Steiner, Peter	Undergraduate Student	1
Sutton, Eric	Undergraduate Student	2
Svoboda, Samuel	Undergraduate Student	1
Thedford, Joshua	Undergraduate Student	3
Villalobos, Samantha	Undergraduate Student	1
White, Dexter	Undergraduate Student	2
Meyers, Zach	High School Student	1
Romero Ponce, Armeliz	Research Experience for Undergraduates (REU) Participant	2

Full details of individuals who have worked on the project:

Daniel D Richter
Email: drichter@duke.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 9

Contribution to the Project: Lead-PI and responsible for all aspects of the Observatory

Funding Support: Duke University

International Collaboration: No
International Travel: No

Mukesh Kumar
Email: mukesh.kumar@ua.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 9

Contribution to the Project: Advised Yanlan Liu. Gave invited talks at several national and international venues. Wrote project report/ papers.

Funding Support: This project plus NSF CAREER

International Collaboration: No
International Travel: No

Brian L McGlynn
Email: brian.mcglynn@duke.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: McGlynn has provided guidance and collaboration on watershed hydrology field research including installation of stream gauging stations, nested well networks, precipitation gauges, and soil water content monitoring stations. Additionally he has supported management and analysis of collected and historic data along with serving as a contact to facilitate implementation of CUAHSI's data model for the CCZO hydrologic data. He continues to integrate findings at the CCZO satellite location in Duke Forest with the larger CCZO project.

Funding Support: Duke University salary and lab startup funds

International Collaboration: No
International Travel: No

Sari Palmroth
Email: sari.palmroth@duke.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 0

Contribution to the Project: Discussions to assist graduate student Zach Brecheisen in his research.

Funding Support: This award.

International Collaboration: No
International Travel: No

Amilcare Porporato
Email: aporpora@princeton.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 3

Contribution to the Project: Deputy director, Led modeling efforts for weathering and soil erosion at the CCZO. Advised Two PhD students and one postdoc involved in the project (Sara Bonetti, Salvatore Calabrese and Mark Bartlett).

Funding Support: This award.

International Collaboration: No
International Travel: No

Sharon A Billings
Email: sharon.billings@ku.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 5

Contribution to the Project: Billings developed the Ruddiman-CZ hypothesis and analyses or assists in analysis and interpretation of all data sets, including development of R scripts, and writing of results into manuscripts and presentations. She initiated, built, refined and implemented the 2-D erosion/deposition model and wrote the resulting manuscript with assistance of co-authors. She wrote the Elementa paper with assistance of co-authors. She trains all relevant KU personnel on the project, and conducted multiple consultations with graduate students at Duke (Wade, Brecheisen). Billings also organized and implemented plans for CCZO Executive Committee meetings, oversaw all efforts to obtain concentrations of inorganic nutrients and organic C in soil extracts, and guided the design of one PhD student's cross-CZO studies. Billings is responsible for all aspects of the project sub-contracted to the University of Kansas.

Funding Support: University of Kansas

International Collaboration: Yes, switzerland
International Travel: No

Rafael Bras
Email: rlbras@gatech.edu

Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Dr. Bras serves as the co-PI of GT team supervising all team members and coordinating collaborations of research and education activities. Given his extensive expertise and experience, Dr. Bras worked on the eco-hydrological recovery theme through design of field experiment, model development and simulation.

Funding Support: This award only.

International Collaboration: No
International Travel: No

Mac Aaron Callaham
Email: mcallaham@fs.fed.us
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Identification of invertebrates collected from CCZO sites; co-advisement of graduate student working on CCZO projects.

Funding Support: USDA Forest Service, Center for Forest Disturbance Science

International Collaboration: No
International Travel: No

Alexander Cherkinsky
Email: acherkin@uga.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: The sample collection and analyses for 14C and d13C composition of soil organic matter to estimate the turn over rates on the sites with different land use history.

Funding Support: Center for Applied Isotope Studies, University of Georgia

International Collaboration: No
International Travel: Yes, norway - 0 years, 0 months, 7 days

Daniel Markewitz
Email: dmarke@uga.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Field work, professional mentoring.

Funding Support: This award only.

International Collaboration: No
International Travel: No

Donald R Nelson
Email: dnelson@uga.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Responsible for activities in the human-CZO theme and contributes to interdisciplinary modeling activities. Contributed to data collection, overseeing graduate work, and professional mentoring

Funding Support: NSF

International Collaboration: No
International Travel: No

Katherine P O'Neill
Email: oneill@roanoke.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 4

Contribution to the Project: Education and outreach. CCZO Executive Committee member.

Funding Support: Roanoke College Environmental Studies program

International Collaboration: No
International Travel: No

Paul A Schroeder
Email: schroe@uga.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Field work, professional mentoring, planning of international symposium.

Funding Support: ERASMUS+

International Collaboration: No
International Travel: Yes, turkey - 0 years, 1 months, 0 days

Aaron Thompson
Email: aaront@uga.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Overseeeing graduate student and postdoctoral research. Field soil collection and analysis.

Funding Support: University of Georgia

International Collaboration: No
International Travel: No

Jingfeng Wang
Email: jingfeng.wang@ce.gatech.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Dr. Wang serves as the lead co-PI of GT team responsible for daily operation of research and education activities. Dr. Wang focused on the eco-hydrological recovery theme for the test of the Eco-hydrological Recovery Hypothesis (H1) through design of field experiment, model development/simulation, and data processing and archiving.

Funding Support: This award only.

International Collaboration: No
International Travel: No

Allan R Bacon
Email: allan.bacon@ufl.edu
Most Senior Project Role: Faculty
Nearest Person Month Worked: 1

Contribution to the Project: Assisted with particle size analysis and manuscript preparation/submission related to several papers.

Funding Support: University of Florida

International Collaboration: No
International Travel: No

Jason C Austin
Email: jayc.austin@gmail.com
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 7

Contribution to the Project: Field work, X-ray diffraction, stable isotope sample collection and analysis, undergrad student mentoring.

Funding Support: This award only.

International Collaboration: No
International Travel: No

Mark Bartlett
Email: mark.bartlett@duke.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 1

Contribution to the Project: Developed semi-distributed hydrological models of rainfall runoff response with probabilistic components.

Funding Support: This award.

International Collaboration: No
International Travel: No

Chunmei Chen
Email: cmchen@uga.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 6

Contribution to the Project: Field and laboratory research on iron and carbon in soils

Funding Support: Other NSF

International Collaboration: No
International Travel: No

Michael Coughlan
Email: coughlan@uga.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 6

Contribution to the Project: Fieldwork and database development

Funding Support: NSF

International Collaboration: No
International Travel: No

Gregg Chapman
Email: gchapman@fs.fed.us
Most Senior Project Role: Technician
Nearest Person Month Worked: 1

Contribution to the Project: Gregg assists with soil gas measurements, earthworm surveys, and soil sampling.

Funding Support: USDA Forest Service

International Collaboration: No
International Travel: No

Charles W Cook
Email: cwcook@duke.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Field lab manager in charge of field construction, operations, sample collection, and data management for diverse field experiments at the Calhoun CZO.

Funding Support: This project only.

International Collaboration: No
International Travel: No

Paul Heine
Email: pheine@duke.edu
Most Senior Project Role: Technician
Nearest Person Month Worked: 12

Contribution to the Project: Field, laboratory, data, and website contributions.

Funding Support: This award only.

International Collaboration: No
International Travel: No

Melanie K Taylor
Email: melaniekaytaylor@gmail.com
Most Senior Project Role: Technician
Nearest Person Month Worked: 1

Contribution to the Project: Melanie works with Mac Callaham studying soil macroinvertebrates at the Calhoun CZO.

Funding Support: USDA Forest Service

International Collaboration: No
International Travel: No

Satish Bastola
Email: satish.bastola@ce.gatech.edu
Most Senior Project Role: Staff Scientist (doctoral level)
Nearest Person Month Worked: 3

Contribution to the Project: Model development and simulation of the effects of soil erosion and deposition on the carbon cycle.

Funding Support: This award only.

International Collaboration: No
International Travel: No

Lori A Sutter
Email: lsutter@uga.edu
Most Senior Project Role: Staff Scientist (doctoral level)
Nearest Person Month Worked: 4

Contribution to the Project: Laboratory management, field work, professional mentoring.

Funding Support: This award only.

International Collaboration: No
International Travel: No

Diego Barcellos
Email: barcello@uga.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 9

Contribution to the Project: Field and laboratory research on iron and carbon in soils.

Funding Support: other NSF

International Collaboration: No
International Travel: No

Sara Bonetti
Email: sara.bonetti@duke.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Development of models of soil erosion and landscape evolution, analytical theory of contributing area and stability analysis of landscape stability under natural and anthropogenic disturbances.

Funding Support: teaching assistantship

International Collaboration: No
International Travel: No

Zachary S Brecheisen
Email: zachary.brecheisen@duke.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Geospatial analysis, soil and tree coring, plot mapping, soil gas monitoring.

Funding Support: Duke University

International Collaboration: No
International Travel: No

Salvatore Calabrese
Email: salvatore.calabrese@princeton.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Developed models of hydrology and bedrock weathering and iron redox dynamics for the Calhoun CCZO.

Funding Support: This grant, graduate school fellowship, and IGERT grant.

International Collaboration: No
International Travel: No

Roberto Raul Carrera-Martinez
Email: rcarrmart@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Field and laboratory research on soil invertebrates.

Funding Support: NSF

International Collaboration: No
International Travel: No

Maryam Foroughi
Email: mforoughi@uga.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Field and laboratory research, water chemistry.

Funding Support: This award and a SAVI travel grant award.

International Collaboration: No
International Travel: No

Soudeh Ghasemian
Email: soudeh.ghasemian@gmail.com

Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Ghasemian joined the Billings lab in August 2017 and is working on the Calhoun project to understand how past erosion and topography can influence forest productivity.

Funding Support: University of Kansas teaching assistantship.

International Collaboration: No
International Travel: No

Emma Hauser
Email: emhauser@ku.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Hauser joined the Billings lab in August 2016. She is being trained on laboratory equipment to become adept at multiple biogeochemical assays, including inorganic N and phosphate soil extractions and quantification, exo-enzyme assays, and microbial biomass assays.

Funding Support: University of Kansas teaching assistantship

International Collaboration: No
International Travel: No

Jinge Huo
Email: huojinge@gatech.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Historical data digitization and processing and analysis (stream-flow and rainfall) (H1).

Funding Support: None

International Collaboration: No
International Travel: No

Yanlan Liu
Email: yanlan.liu@duke.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Evaluating early warning signals of forest mortality.

Funding Support: This project only.

International Collaboration: No
International Travel: No

Michael Lonneman
Email: mclonn01@uga.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 9

Contribution to the Project: Data collection, organization, analysis.

Funding Support: NSF

International Collaboration: No
International Travel: No

John McDevitt Mallard
Email: john.mallard@duke.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 9

Contribution to the Project: Ongoing installation of sensor network; field hydrologic measurements; hydrologic data acquisition and analysis; assembling and writing manuscripts.

Funding Support: This award and Duke University teaching stipend

International Collaboration: No
International Travel: No

Melissa Martin
Email: Melissa.martin25@uga.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Field and laboratory research training

Funding Support: University of Georgia

International Collaboration: No
International Travel: No

Nadia Noor
Email: nadia.noor25@uga.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 3

Contribution to the Project: Laboratory research contributing measurements of iron reducing populations in soils.

Funding Support: UGA and other NSF

International Collaboration: No
International Travel: No

Julio Cesar Pachon
Email: jpachon@ufl.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Julio is using laser diffraction methods to quantify the particle size distribution of soil and subsoil samples from the Calhoun CZO.

Funding Support: University of Florida

International Collaboration: No
International Travel: No

Rachel Carolan Ryland
Email: rryland@uga.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 2

Contribution to the Project: Field and laboratory research on determining the depth of the clay horizon.

Funding Support: University of Georgia

International Collaboration: No
International Travel: No

Ligia Souza
Email: ligiaftsouza@gmail.com
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Souza joined the Billings lab in August 2017 and though not funded on the project assisted in analysis of soil gas isotopes.

Funding Support: University of Kansas teaching assistantship

International Collaboration: No
International Travel: No

Yao Tang
Email: tangyao1208@gatech.edu

Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Constructing the two flux towers. Retrieving and processing historical hydrometeorological data and modeling gas fluxes (stream-flow and rainfall)(H1).

Funding Support: This award only.

International Collaboration: No
International Travel: No

Anna Wade
Email: anna.wade@duke.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Wade has continued ongoing research in Holcombe's Branch by installing soil moisture sensors, oxygen and carbon dioxide gas sensors, and redox sensors. Wade is also measuring the long-term soil experiment plots for historic deposition of lead (Pb), and has been trained on the ICP-MS at Duke for analysis of samples.

Funding Support: NSF IGERT – WISeNet traineeship DGE-1068871

International Collaboration: No
International Travel: No

Zhine Wang
Email: ZhineWang@uga.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Field and laboratory research on determining P availability from clay vs saprolite

Funding Support: University of Georgia

International Collaboration: No
International Travel: No

Emma Ardington
Email: eca47061@uga.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Worked on techniques to quantify carbon stability in soils.

Funding Support: University of Georgia

International Collaboration: No
International Travel: No

Eva Arroyo
Email: eva.arroyo@duke.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Worked on legacy sediments at Holcombe's Branch.

Funding Support: Duke University

International Collaboration: No
International Travel: No

David Casson
Email: decasson@mail.roanoke.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Nutrient inputs from leaf litter at the Calhoun CZO

Funding Support: Roanoke College

International Collaboration: No
International Travel: No

Bear Jordan
Email: bearjordan@gmail.com
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Undergraduate research assistant

Funding Support: None

International Collaboration: No
International Travel: No

Anthony Moraes
Email: wolfbane@uga.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Working with Dr. Paul Schroeder to better describe the clay mineralogy and weathering processes at the CCZO.

Funding Support: None

International Collaboration: No
International Travel: No

Elizabeth Osota
Email: elizabeth.osota25@uga.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Worked on image processing and fitting of the iron rod data.

Funding Support: University of Georgia

International Collaboration: No
International Travel: No

David Richards
Email: david.richards25@uga.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Worked with Dr. Paul Schroeder on analyzing soil samples; rare earth elements.

Funding Support: None

International Collaboration: No
International Travel: No

Junmo Ryang
Email: junmo.ryang@duke.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Assisted with analysis of Holcombe's Branch legacy sediments. Wrote Python program to merge two datasets.

Funding Support: None

International Collaboration: No
International Travel: No

Sophia Sanders
Email: scs51899@uga.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Undergraduate research assistant

Funding Support: None

International Collaboration: No
International Travel: No

Tierra Sanford
Email: tierra.sanford25@uga.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Field and laboratory research experiences

Funding Support: University of Georgia

International Collaboration: No
International Travel: No

Rena Stair
Email: stairr32@gmail.com
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Stair generated much of the root abundance data and analyzes soil extracts for phosphate concentrations.

Funding Support: This award

International Collaboration: No
International Travel: No

Peter Steiner
Email: petersteiner_2017@depauw.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Working with Paul Schroeder on analyzing soil samples.

Funding Support: None

International Collaboration: No
International Travel: No

Eric Sutton
Email: emsutton@mail.roanoke.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: Nutrient inputs from leaf litter at the Calhoun CZO

Funding Support: Roanoke College Environmental Studies program

International Collaboration: No
International Travel: No

Samuel Svoboda
Email: samueljsvoboda@gmail.com
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Working with Paul Schroeder to analyze soil samples.

Funding Support: None

International Collaboration: No
International Travel: No

Joshua Thedford
Email: jbt25373@uga.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: Worked on techniques to quantify carbon stability in soils.

Funding Support: University of Georgia

International Collaboration: No
International Travel: No

Samantha Villalobos
Email: samantha.villalobos@duke.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Assisted with analysis of Holcombe's Branch legacy sediments.

Funding Support: None

International Collaboration: No
International Travel: No

Dexter White
Email: dewhite@ku.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 2

Contribution to the Project: White works with the portable XRF and helps Hauser with litter incubations.

Funding Support: This award and University of Kansas undergraduate scholarship

International Collaboration: No
International Travel: No

Zach Meyers
Email: zacharymeyers@clarke.k12.ga.us
Most Senior Project Role: High School Student
Nearest Person Month Worked: 1

Contribution to the Project: Data collection

Funding Support: Clarke County School District

International Collaboration: No
International Travel: No

Armeliz Romero Ponce
Email: armeliz.romero@upr.edu
Most Senior Project Role: Research Experience for Undergraduates (REU) Participant
Nearest Person Month Worked: 2

Contribution to the Project: She analyzed leachates for phosphate concentrations.

Funding Support: NSF REU award to KU

International Collaboration: No
International Travel: No
Year of schooling completed: Junior
Home Institution: University of Puerto Rico Mayagüez
Government fiscal year(s) was this REU participant supported: 2018

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
Anthropocene Working Group	Other Nonprofits	Various
Coweeta Hydrologic Lab	Other Organizations (foreign or domestic)	Otto, NC
Franklin Humanities Institute	Academic Institution	Duke University
NSF-REU in Soil Science (North Carolina State Univ)	Academic Institution	Calhoun CZO & Duke Forest
Rose Hill Plantation State Historic Site and SC State Parks	State or Local Government	Union and Columbia, SC
South Carolina State Parks	State or Local Government	Columbia, SC

Name	Type of Partner Organization	Location
Sumter National Forest, Enoree District	Other Organizations (foreign or domestic)	Union and Whitmire, SC
USFS Southern Research Station	Other Organizations (foreign or domestic)	Athens, GA
WyCEHG: Wyoming Cent Environmental Hydrology & Geophysics	Academic Institution	University of Wyoming

Full details of organizations that have been involved as partners:

Anthropocene Working Group

Organization Type: Other Nonprofits
Organization Location: Various

Partner's Contribution to the Project:
Other: Platform for advancing critical zone science

More Detail on Partner and Contribution: The relations of the proposed Anthropocene and critical zone science are many and to date relatively little explored.

Coweeta Hydrologic Lab

Organization Type: Other Organizations (foreign or domestic)
Organization Location: Otto, NC

Partner's Contribution to the Project:
In-Kind Support
Facilities
Collaborative Research

More Detail on Partner and Contribution: Training given to PhD student for a summer's work (2015) digitizing historic strip chart data. Coweeta hydrologists provided some oversight as well of the progress to the work.

Franklin Humanities Institute

Organization Type: Academic Institution
Organization Location: Duke University

Partner's Contribution to the Project:
Financial support
In-Kind Support

Facilities
Collaborative Research

More Detail on Partner and Contribution: FHI co-sponsored a 2-day visit to the Calhoun by Bruno Latour, widely renowned philosopher of science. FHI entirely sponsored lunch for about 100 scholars at a high-visibility public event we called "The Critical Zone Education of Bruno Latour." A professional videographer was assigned to the two day visit to the Calhoun and is in the final stages of video creation. FHI has also provided an office for PI Richter on his Fall 2016 sabbatical.

NSF-REU in Soil Science (North Carolina State Univ)

Organization Type: Academic Institution
Organization Location: Calhoun CZO & Duke Forest

Partner's Contribution to the Project:
Personnel Exchanges

More Detail on Partner and Contribution: The Calhoun CZO is an affiliate of the NCSU REU Program in Soil Science, whose director is Prof. Josh Heitman. For the second of three years, we have given a whole day field trip in Critical Zone science to about a dozen high potential students. In both years, by days end they have been very intrigued and excited by the experience.

Rose Hill Plantation State Historic Site and SC State Parks

Organization Type: State or Local Government
Organization Location: Union and Columbia, SC

Partner's Contribution to the Project:
In-Kind Support
Facilities

More Detail on Partner and Contribution: The South Carolina State Park Service issued the CCZO a research permit on the grounds of the Rose Hill Plantation State Historic Site and have interests in our work with the old hardwood forest to the north of the Gist home and in exploring the seriously gullied old fields of the Gist plantation. In 2016, our CZO has agreed to help the SC State Parks with a reinterpretation of Rose Hill, a long-term project that will be led by the University of South Carolina.

South Carolina State Parks

Organization Type: State or Local Government
Organization Location: Columbia, SC

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: Our project's LiDAR-derived data and our interpretation of geomorphological features and human-land impacts are being shared with local Park employees and with the State Park system itself, all to enrich the understanding of the remarkable history of South Carolina.

Sumter National Forest, Enoree District

Organization Type: Other Organizations (foreign or domestic)
Organization Location: Union and Whitmire, SC

Partner's Contribution to the Project:
In-Kind Support
Facilities

More Detail on Partner and Contribution: The USDA Forest Service is responsible for managing research activities on the Calhoun Experimental Forest and in 2014 began the permitting of research activities that were contained in 30-page Research Plan. In 2015 we gave a half-day tour to two prominent USFS managers.

USFS Southern Research Station

Organization Type: Other Organizations (foreign or domestic)
Organization Location: Athens, GA

Partner's Contribution to the Project:
In-Kind Support

More Detail on Partner and Contribution: Dr. Mac Callaham participates in our observatory as a soil biologist

WyCEHG: Wyoming Cent Environmental Hydrology & Geophysics

Organization Type: Academic Institution
Organization Location: University of Wyoming

Partner's Contribution to the Project:
In-Kind Support

More Detail on Partner and Contribution: Collaboration on geophysical measurements and modeling with 2nd and 3rd visits to Calhoun in 2016. Writing a 2016 research proposal for a Calhoun drilling research.

What other collaborators or contacts have been involved?

Nothing to report

Back to the top

Impacts

What is the impact on the development of the principal discipline(s) of the project?

The principal fields of scholarship at the Calhoun CZO are geology and geomorphology; geophysics, geochemistry, pedology, and biogeochemistry; hydrology and ecohydrology; ecology and ecosystem science; environmental history and anthropology; Earth science education; Earth systems science; and straddling all of the above, environmental modeling. Though ambitious, the combination and integration of disciplines represented in the work of the 15 PIs, their students and collaborators, ensure that research planning, techniques, results, and interpretations impact all principle fields of the Calhoun CZO.

The full value of five major data sets will be realized when results of observations and models fully circulate within all disciplines of the Calhoun CZO project. The data sets are: a) the LiDAR-DEM data from the Calhoun CZO flight in July 2014 and the high resolution ground-return data from the flight in Feb 2016, b) the geophysics data sets obtained from WyCEHG instruments deployed in Calhoun's Geophysics Weeks I and II in April 2014 and February 2016; c) the time-series observations of CZ metabolism (gas concentration data that began in 2015 down to 8.5-m depth and that will continue into 2018); d) the spatially explicit models using information from archeology, geo-historical records from maps and aerial photography, geospatial soils data, LiDAR data, dendrochronology, and environmental history; and e) the historic and contemporary experimental catchment precipitation and discharge data. Our work aims to identify and quantify the depths and persistence of legacies of human alterations of landscapes. Using field sites from profiles and plots to small catchments and whole landscapes, lab experiments, and models, we work across temporal and spatial scales of complexity. NSF is investing in critical zone science to integrate the Earth sciences and scholarships, something widely recognized to be transformative but still rarely practiced.

Our E&O efforts mainly strive to use our specific CZ developments to create new approaches to teaching Earth and environmental sciences at the undergraduate level. Calhoun's program in E&O reaches a much wider audience than undergrads and includes advanced high school students, graduate students, K-12 teachers, and the general public. The pedagogy of the Critical Zone is new and has the potential to contribute greatly to the development of new teaching approaches, with regards to interdisciplinary earth sciences, coupled human and natural systems, and the environmental sciences.

What is the impact on other disciplines?

One of the most exciting aspects of critical zone science is its capacity to span disciplines and scholarships and marshal scientists with disciplinary skills and perspectives to interact in new ways. The CZOs are ambitious integrative projects and are in the act of creating a new Earth science as an *inter-discipline*.

This interdisciplinary vision was first articulated in the 2001 NRC report led by Thomas Jordan, Gail Ashley, and others; it is articulated now by the growing number of CZOs that are being established internationally on all continents (Giardino and Houser 2015, Richter et al. 2018). At the Calhoun CZO, not only the Earth scientists who are enthused by the interdisciplinarity of the challenges we face, but even our humanity's scholar, an environmental historian, has expressed his enthusiasm and amazement as well, saying: "Environmental history is a relatively new field of history and for all of its growth and impact, only with my involvement in the CZO have I seen environmental scientists argue that a fully human-historical perspective to environmental science is not just nice but necessary."

In keeping with the interdisciplinary nature of critical zone science, the educational and outreach materials developed as part of this project are explicitly interdisciplinary, with elements that cut across the natural sciences (e.g., soils, hydrology, geology, ecology, modeling), the social sciences (e.g., anthropology, land use, land management and policy) and the humanities (e.g., environmental history). The incorporation of critical zone science as an integrating theme in the interdisciplinary environmental educational program at Roanoke College and University of Kansas and other colleges and universities is new but it has the potential to impact educational practices broadly.

A quote from an annual report from one of our environmental engineers, "the theory of age and residence time of Earth's integrated surface systems is of great interest not only to hydrology and geophysics but to chemical engineering, population dynamics, and statistical and fluid mechanics."

The CCZO PIs are excited by the interactions between the integrative CZ science and traditional academic disciplines.

What is the impact on the development of human resources?

This is at least partly described in the general responses about project personnel.

The Calhoun CZO has 15 PIs based at six universities and colleges as well as the USDA Forest Service. These institutions and PIs involve a very large number of students from many backgrounds, students from high schools to graduate schools to post-docs who are heading in many directions. These are detailed and quantified in other parts of our annual report.

The Calhoun CZO held its fifth all-hands science meeting in 2018 ("Calhoun Summer Science Days"), but we also hold all-hands work sessions at the CCZO including three “Calhoun Geophysics Weeks”, in which a wide variety of students (including underrepresented students) were invited to assemble at the Calhoun to help scientists from WyCEHG who had travelled from Wyoming to work at the Calhoun. We also hosted two “Calhoun BigDigs”, efforts to attract students and scientists to work together on deep hand-coring to install gas reservoirs to 5 and 8.5-m depth and to sample backhoe-excavated soil and saprolite pits across sites with contrasting land-use histories. We are working with Dr. Justin Richardson (University of Massachusetts) on two research projects that involve rare earth elements in the Calhoun CZO's 70-m deep core. In the past, the assembled scientists camp together, which leads to science

discussions late into the evenings. We are constructively demanding on our scientists and scholars, but most experience not only the hard work but also the intense joy of scientific investigation. This comes across in a soon to be released documentary film entitled, "The Education of Bruno Latour: From Critical Zone to Anthropocene."

E&O activities at the Calhoun project targets students and teachers at small 4-year and 2-year collegiate institutions. Representation of the Earth sciences at these institutions is typically low compared to research universities. Providing educational opportunities in the Earth sciences within these communities directly "enhances development of human resources in Earth sciences." Curricular materials are largely consistent with Next Generation Science Standards.

What is the impact on physical resources that form infrastructure?

The Calhoun CZO leverages nearly 70 years of previous research (1947 to present) of land, vegetation, and water at the USFS Calhoun Experimental Forest, a landscape of long scientific interest due to massive impacts of about 150 years of agricultural use from about 1800 to 1950. While the USDA Forest Service initiated the Calhoun research program in 1947, in 1962 the USFS dismantled all scientific infrastructure at the Calhoun Experimental Forest, despite 15 years of highly productive research by soil, ecology, and hydrology scientists (Richter et al. 2014). Fortunately, two USFS researchers kept working at two field experiments from 1962 to 1989, when the USFS invited PI Richter and soon after PI Markewitz to join them at the Calhoun Experimental Forest. The latter two have been able to marshal nearly continuous financial support from the National Science Foundation (Biological and Geosciences Directorates), several USDA research programs, and the Andrew Mellon, Wallace, and Trent Foundations to keep the Calhoun's long-term experiments alive and productive.

With the support of our CZ colleagues, we have very significantly re- and up-instrumented hydrologic and biogeochemical investigations all across the Calhoun Experimental Forest. Not only are we re-instrumenting historic experimental catchments, but we have significantly up-instrumented the Calhoun watersheds with intensive and highly sophisticated hydrologic instrumentation. An inverted flux tower is constructed and collecting data from above and deep belowground data streams aimed to quantify legacies of land-use impacts on critical zone hydrology, geomorphology, biology, and biogeochemistry. While the USFS recognized the special values of the Calhoun Experimental Forest, they were institutionally unable to keep it staffed and funded. Thus, NSF's CZO program has been able to build upon an unusually strong research base and reconstitute a research site that would otherwise have dwindled or even been completely lost except to the historic literature.

What is the impact on institutional resources that form infrastructure?

The Calhoun CZO unites and strengthens our diverse institutions in many ways. The institutions include a small undergraduate college (Roanoke), land-grant universities (University of Georgia and Mississippi State), an EPSCoR university (Kansas), large public research universities (Kansas, UGA, Georgia Tech, and Mississippi State), and a private research university (Duke).

Within each institution, PIs and students are based at a variety of departments (e.g., Geology, Engineering, Environmental Sciences and Policy, Anthropology, Biology, History, and Earth Sciences). We use this diversity to strengthen the project at large. For example, our web-based CZ science meetings among PIs and their students are useful and interesting scientifically, these meetings are also a study of contrasting academic cultures as well.

Perhaps the most remarkable example of CZO impact on institutions is at Roanoke College, a small 4-year liberal arts college and home to the Calhoun's E&O program. At Roanoke, PI O'Neill has with her colleagues redesigned their interdisciplinary Environmental Studies curriculum with Earth's Critical Zone as an organizing theme. All three of the introductory courses in the Environmental Studies curriculum (Environmental Science, Environment and Society, and Environment and Culture) address different perspectives of the Earth's critical zone. In addition to a new upper-level course in Critical Zone Science and Management, Critical Zone concepts are woven into the curriculum. This new curriculum was put in place in 2017, the core course that features the CZ and the environment has been offered twice to many students.

These programmatic changes at Roanoke have been documented in an article for *The Earth Scientist* (in a cross-CZO effort) and will be further disseminated in journal articles and presentations to provide a model or template for other institutions and scholars.

What is the impact on information resources that form infrastructure?

In addition to constantly circulating email, discussions by telephone and Skype, we use CRITICALZONE.ORG as our main website for project management and communication. We have developed a Google-based system of communications, including Calhoun CZO Google Maps, Calendar, Docs, and Sheets to share writing, maps, sampling locations, and to facilitate general communications. Both Calhoun staff (Will Cook, Paul Heine) update and build the Calhoun website on CRITICALZONE.ORG. Many data sets are now uploaded, and we have recently modified our data policy in an attempt to speed this process we see as important to enhancing scientific integration within the project.

What is the impact on technology transfer?

Technology transfer is both research and education based.

The visit of WyCEHG scientists during Calhoun's three Geophysics Weeks (one in 2014, two in 2016) has been greatly stimulating to our geophysics expertise within the CZO. Our PIs with geophysics equipment and experience (Markewitz and Schroeder), have developed collegial relationships with WyCEHG scientists and have worked with a University of Wyoming graduate student who is investigating GPR data from the Calhoun landscape. During the first WyCEHG visit, our colleagues in regional offices of the National Resource Conservation Service (NRCS) visited the Calhoun and were extremely interested in WyCEHG instrumentation and data analysis. These same NRCS personnel are involved in our Big Dig! 2016 and 2017, in which

they formally described soil profiles and helped initiate our extensive Ksat measurement and education.

Educational materials are developed and are widely disseminated in electronic and interactive formats, increasing both the scope and the potential for public use. Use of ESRI Story Maps as a framework for Virtual Field Experiences facilitates access to spatially-explicit datasets.

What is the impact on society beyond science and technology?

Amilcare Porporato, the CCZO's Co-Lead PI, perhaps answers this question best.

"Simple models of social-CZ dynamics have the potential to capture the imagination and interest of the scientific and general public, providing simple and tantalizing explanations for long-term land-management practices. At the Calhoun CZO, we link social-land practices to a remarkable history of soil and land degradation of historical and national importance. Such cross-disciplinary approaches are important to educating citizens about a more respectful use of water and soil and to encourage the next generation to appreciate the usefulness of quantitative tools that address environmental problems."

In addition, we use the Calhoun CZO and our science at the CCZO to interact very actively with the emerging field of environmental humanities. These scholars are in great need of a data-based perspective of the environment and have large and complex networks with the culture at large. The Calhoun CZO based documentary film entitled "The Education of Bruno Latour: From Critical Zone to Anthropocene", will advance critical zone science to many communities without scientific training.

Back to the top

Changes/Problems

Changes in approach and reason for change

Developing the Calhoun CZO on the USDA Forest Service's Sumter National Forest required a major effort on the part of the Lead PI to work with USFS managers and NEPA coordinators and to comply with environmental assessment requirements. Our CZO decided early on that we would operate in full compliance with USFS's requirements. USFS managers allowed us to operate right from the start of our project, and by the fall of 2014 we received a formal Research Permit for most of our proposed research, based on a decision of "nominal environmental impact". In 2015 through 2018, we have continued to work with USFS managers on permit amendments as the CCZO grows and develops.

While the USFS has been generally cooperative and supportive of our research, we have had to redesign the flux tower in our research plan to comply with USDA Forest Service concerns about safety. The flux tower was approved and rapidly erected in 2016 and continues to collect above and belowground data, which we are using to write a DOE Above-Belowground Research proposal in 2018-2019. The Calhoun PIs consider that we have turned the USFS permitting

process to our advantage as we seem to be enjoying built-up trust on the part of many of the USFS managers.

Actual or Anticipated problems or delays and actions or plans to resolve them

Described above.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.

Back to the top

< Back
Research.gov
National Science Foundation

About Services

- Account Management
- Award Cash Management Service (ACM$)
- Notifications & Requests
- Project Reports
- Proposal Status
- Public Access

NSF Award Highlights

- Research Spending & Results

Contact

- Contact Help Desk

News & Discoveries

- News
- Discoveries
- Multimedia Gallery

Funding & Awards

- Recently Announced Funding Opportunities
- Upcoming Funding Opportunity Due Dates
- A-Z Index of Funding Opportunities
- Find Funding
- Award Search
- Proposal & Award Policies & Procedures Guide (PAPPG)

Publications & About NSF

- Publications
- About the National Science Foundation
- Careers
- Staff Directory

Feedback

- Facebook
- Twitter
- LinkedIn
- YouTube

See all NSF social media

- Website Policies
- Budget and Performance
- Inspector General
- Privacy
- FOIA
- No FEAR Act
- USA.gov
- Accessibility
- Plain Language
- Contact

The National Science Foundation, 2415 Eisenhower Avenue, Alexandria, Virginia 22314, USA
Tel: (703) 292-5111, FIRS: (800) 877-8339 | TDD: (800) 281-8749