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Accomplishments

* What are the major goals of the project?

A. Overall goal of Calhoun CZO

In 2001, the USA's National Research Council described the interdisciplinary science of Earth's "critical zone" to be one of the most compelling research areas for the Earth sciences in the 21st century. The excitement embodied in this claim springs 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.

At the Calhoun CZO, our overall 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 as having three phases in its evolution: a) the evolution of the *ancient*, deep, and highly weathered natural system, which on the most geomorphically stable surfaces of the Calhoun CZO have residence times of several million years; b) the changes affected by the *historic* human-natural 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; and c) the *contemporary* human-natural system, marked by reforestation of severely eroded soils, gullied runoff channels, and floodplains that are inundated with meters-deep legacy sediments.

Calhoun research is thus motivated by the growing need to understand and manage Earth's 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). Ultimately, we seek integration of the sciences and broader scholarships within the Calhoun CZO and also across all CZOs.

B. Five specific goals of Calhoun CZO

In our third annual report, we respond to our Virtual Site Visit Review of late 2015 and early 2016, including a suggestion to reorganize our hypotheses and goals. The Calhoun CZO now aims to fulfill five specific goals: three of which are directed at research and test scientific hypotheses, a fourth to promote CZ education and outreach, and a fifth to stimulate cross-CZO science and education. Each of these is briefly described here and addressed in more detail throughout the report.

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, 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 four-and two year 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 encourage and prioritize a variety of cross-CZO relationships and participate in new and on-going projects that involve our PIs and students or data- and sample-sharing.*

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

Major Activities:

Five activities associated with the five CCZO project goals

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

a) Geophysics & Geochemistry. Working with WyCEHG we quantify the structure of the Calhoun CZ and have a *Science* paper on regolith structure and bedrock fracturing, with data from the BoulderCZO (St. Clair et al. 2015). Based on WyCEHG's two trips to the Calhoun in 2016 a new manuscript was prepared in 2017 led by Holbrook, a manuscript that explicitly integrates geophysics and geochemistry using data from the 70-m Calhoun borehole. A second paper is being led by PI Richter to examine the Calhoun CZ as a soil production system.

PI Porporato has new models of hydrologic transport control on chemical weathering. PI Schoeder collaborates with Prof. Rebecca Lybrand (Oregon State) and Prof. Nakao (Kyoto) on field weathering experiments. Schroeder completed a Cambridge book entitled, “Clays in the Critical Zone”. Geomorphology models evaluate hydrologic impacts of gully incision in a paper sent to *Water Resources Research.* Other geomorphologists have a new Hortonian-ordering system for interfluves that corresponds well with cz structure and function with a manuscript to be submitted by early 2018. PhD student Brecheisen will submit a paper by early 2018 that analyzes LiDAR DEMs to estimate land surface roughness created by land use.

b) Land-Use History. Environmental anthropologists have assembled a history of changes in the land at the Calhoun and are in the writing stage of research. A manuscript was published by Coughlan et al. (2017) in the new journal *Land* that modeled historical agricultural economics and geomorphology to predict farmland use and abandonment. A 2nd manuscript associates land use history with indigenous American activities across the Sumter National Forest & was submitted in 2017 to *PLOS One*. Historical land records, deed chains, geo-rectified aerial photography, photographs, and census records continue to be archived. GIS data sets continue to be built that include shapefiles, point layers, and topology.

c) Land-Use History's Effects on CZ Structure & Process. Nine sites have been instrumented to quantify structure and function of CZs affected by land use history. We are logging sensor data on soil moisture, temperature, and CO_2, & O_2 down to 1.5 m, and sampling four gases every three weeks at 0.5, 1.5, 3, 5, and 8.5-m. In 2017, we collected gas samples that PI Cherkinsky and Richter analyzed for stable and radioactive isotopes of CO_2 and O_2. Cherkinsky submitted a paper to *Radiocarbon* that co-authored PIs and PhD students.

We excavated many sites to >2-m depth with a backhoe to sample rooting depths, water-stable aggregates, Ksat, porosity with CT scanning, texture with a particle size analyzer, and other properties. At these sites, we augered to 8-m for deep samples of weathering profiles. A number of our labs split these samples and are well into analyzing them for geochemistry, mineralogy, and microbiology. A first manuscript will be submitted by PI Sharon Billings by the end of 2017. Other papers have been enriched by the field work.

Of great geochemical interest at the Calhoun are C-Fe interactions both in the natural and human-altered cz, and research led by PI Thompson with his PhD students is monitoring C-Fe biogeochemistry across the Calhoun landscape and is very exciting.

PI Porporato (formerly of Duke now Princeton) and PhD student Sara Bonetti are working on a paper that models effects of landuse on geomorphology to be submitted to the *Royal Society*. Bonetti gave a talk at the Arlington VA All-Hands meeting describing her work.

d) Long-term Experimental Watersheds. Rainfall & streamflow data sets continue on historic watersheds the CZO re-instrumented in 2014. Groundwater wells with water sensors operate in the catchment and within Holcombe's Branch legacy sediment. Instrumentation continues to be improved. Historic strip charts have been analyzed jointly by a number of the CCZO PIs and students with the help of the USGS and USFS. The historic catchment data are website posted.

e) Calhoun Long-Term Soil-Ecosystem Experiment (LTSE). Over a six week period in 2017, we re-sampled the Calhoun Long-term Soil Experiment for the 11th time during 60 years. Samples are being prepared for analysis and archiving. Of particular interest in the 2017 collection will be to extend studies of the temporal dynamics of soil organic carbon throughout the upper CZ (extending work of Mobley et al. 2015) and a new study of

structural re-aggregation in A and clayey B horizons is underway with collaborator Prof. Allan Bacon and PhD student Julio Pachon.

2. Erosion-Induced Carbon Dynamics

a) Observations. Samples of legacy sediments collected along channels of Holcombe's Branch were supplemented with samples along the main tributary. The trib channel is relatively newly incised and has exposed clearly buried profiles over many 10s of meters in horizontal reach. We estimated the 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. While a senior thesis (Alexandra Paresian, now a PhD student at UVA) provided initial our estimates of C contents in these historic sediments, a Duke PhD student, Anna Wade, is now leading the research toward peer-review papers on Calhoun legacy sediments. Of major importance are dating via ^{210}Pb, with results arriving early in 2018.

b) Modeling. Modeling carbon loss during erosion and gain during reforestation has led to two published papers, one that describes expansion of the dynamic geomorphology model known as tRIBS and a second that evaluates uncertainties in model estimates, both of these led by PI Bras and his lab at Georgia Tech (Dialynas et al. 2016, Dialynas et al. 2017). The tRIBS model is supplanted by a 2-D, soil-profile scale model developed by PI Billings who is slated to present her new model in a paper that directly expands her previous model and these have teaching and research value. An inter-model study was submitted to Catena by PI Kumar in 2017 to evaluate the role of process representation of erosion, transport, and deposition at contrasting temporal scales.

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 for a research proposal, for example 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 only redoubled their commitment to the Calhoun CZO with recent papers and proposals.

4. E&O Program

E&O products include interactive iBooks with Calhoun GIS-based maps, images, & videos. CZ science materials are disseminated at professional development meetings for educators. A new CZ science class is a core of the environmental curriculum at Roanoke College, with course materials shared with undergraduate educators. CCZO field tours were given in 2017 and tours are scheduled for year five. Visitors are captivated by Calhoun's landscape and history and by CZ science. Interest has been high among REUs who learn about the CalhounCZO.

5. Cross-CZO

Calhoun PIs & students actively participate in cross-CZO workshops and meetings, and contribute to post-workshop publications. Our students have dissertation chapters based on cross CZO research. Our E&O leader PI O'Neill actively works with the NO and the national E&O team on outreach. PI Kumar was invited to talk to the 2017 Cross-CZO modeling group. Data manager Cook participates with cross-CZO data manager meeting. Kansas PhD student, Emma Hauser, conducts incubation tests at four CZO and CZEN observatories, partially funded by NO's SAVI program. Richter was invited to Europe twice in 2017 to give cz science talks.

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 instrumentation and techniques in geophysics and geochemistry 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 dependence 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 upinstrument 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. Intensive instrumentation allow us to model the intra- and inter-watershed hydrologic changes 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 will be to 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 directly estimate and model the carbon budget of the Calhoun CZO's Holcombe's Branch watershed from 1800 to the present, especially accounting for erosional losses and reaccruals on 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 with the same structure as project specific goals, activities, and objectives.

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

a) Deep geophysics and geochemistry of the Calhoun CZ. A remarkable set of multidisciplinary data sets of Calhoun weathering profiles have been assembled and for the most part these are highly complementary. That is, the geophysical structure of the 65-m weathering profiles support many of the geochemical changes we observe. A high visibility paper has been submitted based on these results (Holbrook et al., submitted). A follow-up manuscript, the third in the series starting with St. Clair et al. 2015), is being written that details the mineralogy of the soil production system from weathering bedrock to the soil surface.

b) Land-Use History. History and impacts of land-use change are being studied by social scientists and environmental historians who have gathered data that help all of us appreciate that many cotton farmers were not miners, simply exploiting the land, but that they extensively terraced and intimately interacted with the erosion they accelerated as they farmed. This probably extended back well into the 19th c. and is an interpretation supported by 1933 aerial photography and contemporary LiDAR imagery. Results detailed in Coughlan et al. 2017 suggest that historic farmer responses to changing markets were associated with topographic characteristics of fields and farms.

c) Land-Use History's Effects on CZ Structure and Process. Monitoring of gas concentrations, temperature, and moisture of nine replicate sites affected by a range of land-use histories indicate how land use history strongly affects CZ processes of weathering, hydrology, and land-atmosphere and land-bedrock fluxes of water and gases. Quarterly sampling of soil macroinvertebrates suggests major difference in communities and in bioturbation among the land uses. Stable and radio-isotopes of CO_2 and O_2 are greatly different among land uses and with depth. Radioisotopes of CO_2 indicated that even at 8.5 m most CO_2 is respired in recent years, indicating that vegetation and the deep CZ are connected and functioning on a real-time basis. Biogeochemists have found that microscale processes dominate C-Fe redox cycling. CCZO microbiologists have documented that microbial community composition is greatly affected by land-use history, *even down to 5-m depth*.

d) Historic Experimental Watersheds. Time-series data of well over 3-years are collected from surface streams and from the subsurface in Calhoun watersheds and these inform data-rich explorations of watershed hydrology both within the high-gradient, seriously-eroded watersheds and within the low-gradient zones of legacy sediments that often mediate flow from uplands into high-order streams. The watersheds exhibit highly dynamic seasonal storm response as well as high variability in 3D with spatial response controlled by landscape position and soil depth. Legacy sediment deposits control the transition between surface flow to subsurface flow and partially sever surface connections between low-order watersheds and higher-order streams.

e) Calhoun Long-Term Soil-Ecosystem Experiment (LTSE). A CO_2, heat, and water flux tower has been erected in the Calhoun LTSE and is now collecting data. The tower is in the midst of the 60-year old field study whose soils will be resampled for the 11th time in 2017, when the study of reforestation effects on cultivated soils will be 60 years in age. Tower results will greatly enrich observational data of soil change, results of which to date are summarized in our book and in dozens of peer-review papers.

2. Erosion-Induced Carbon Dynamics.

a) Observations. Initial estimates of organic carbon stored in legacy sediments of the Holcombe's Branch were made by mid-2016. A senior honors thesis was developed using these data, which indicate large buried organic carbon under 50 to 200 cm of legacy sediments. Spectacular buried profiles were discovered and excavated for education and demonstration.

b) Modeling. Results of watershed-scale modeling were published from a spatially and depth-explicit model of soil organic carbon (SOC) dynamics developed for the tRIBS model (Triangulated Irregular Network-based Real-time Integrated Basin Simulator) and applied to Calhoun CZO's Holcombe's Branch. Results indicated that SOC erosion and its replacement exhibit significant topographic variation at small scales of <10s of meters. Net atmospheric C exchange from the Calhoun's Holcombe's Branch watershed is estimated to range from a source of 14.5 g $m^{-2}y^{-1}$ to a sink of 18.2 g $m^{-2}y^{-1}$. The small-

scale complexity of SOC erosion and burial driven by topography exerts a strong control on the landscape's capacity to serve as a C source or a sink.

3. Persistence of Alternative States. The group led by PI Porporato has built a spatially explicit model to describe the development of agricultural activities starting from more fertile and accessible bottomlands, and subsequently expanding upland towards hillslopes and ridges. Porporato's group is currently calibrating the model using data obtained by archeological and anthropological research by the UGA group (led by PI Nelson). We expect to define mathematically the conditions (possibly indicated by thresholds in the soil biogeochemical variables) leading to the agricultural collapse and abandonment as a function of external pressures induced by cotton markets. We 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. Results include development of educational modules derived from spatial datasets using ESRI Story Maps and .kml files for Google Earth, cloud-based formats available at no cost to educators. Undergraduates were involved in this effort, and we believe these can serve as a template for other CZOs. Our E&O leader, Dr. Kathy O'Neill participates actively with the NO and the National E&O team & has helped move several E&O projects ahead. The Calhoun CZO is affiliated with NSF's REU in Soil Science run by North Carolina State and three full-day field trips have now been given to a total of 30 REU undergrads discussing CZ science, soils, and the Calhoun. Educational materials about critical zone science were disseminated at pedagogical workshops for K-12 and undergraduate educators at meetings in SC, NC, and VA. A new undergraduate course called Critical Zone Science & Management was taught twice at Roanoke College in 2017. The class has a lab and is developed to be taught at different levels of complexity across a range of student populations. At Kansas, PI Billings is co-teaching her new graduate-undergraduate class with lab, "Biogeochemistry in the Critical Zone."

5. Cross-CZO Research and Projects. More than half of CCZO PIs are involved with cross-CZO research. Results accumulate across sites from field-based weathering experiments led by our Japanese & Oregon State colleagues, soil microbial and biogeochemistry studies, and hydrologic modeling with PIHM. Redox-related experiments are conducted in several CZOs & will be part of two PhD dissertations. We collaborate with the cross-CZO post-doc who investigates hydrologic partitioning. We support cross-site E&O projects & published a paper in *The Earth Scientist* that describes opportunities for integrating CZ science into environmental science courses at undergraduate and high school levels. PI Thompson co-authored a paper (Li et al 2017, "Expanding the role of reactive transport models in critical zone processes") in *Earth Science Reviews* that was an outgrowth of cross-CZO research. Our geophysics and geochemistry data from our 70-m weathering profile has drawn scientists from other observatories to three papers.

Key outcomes or Other achievements:

Ten other exciting activities and outcomes across the CCZO include.

1. Collaboration with Wofford College Prof. Terry Ferguson has led to major "discoveries" of buried organic matter and deep paleo-colluvium in landscapes near the Calhoun CZO. We have helped Terry collect samples and locate USGS labs that can analyze pollen and hopefully estimate a residence time of burial. The buried organic matter is radio-carbon dead and we have developed old and young hypotheses that range from 0.1 to 1 My post-burial.

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.

3. Our USFS scientist colleague on the Calhoun CZO team, Dr. Mac Callaham, is now advising a new PhD student who is now working at the CCZO on the soil ecology of regenerating forests growing in severely disturbed landscapes. Mac was named the Director of the Calhoun Experimental Forest in 2016.

4. Five Duke PhD students working at the Calhoun CZO have now been supported by the NSF-IGERT program entitled WISeNet.

5. Calhoun CZO Executive Committee. At the suggestion of the Virtual Site Review in 2015, five PIs representing most of the subcontracts and institutions have met electronically nearly every month since February of 2016. No doubt this committee has helped with communications, governance, and in raising new business. PI Sharon Billings of Kansas is the lead of the Executive Committee.

6. Calhoun CZO Research Areas. We have developed eight research areas across the Calhoun CZO, areas in which most of our on-the-ground activities are based. These sites whatever their research history prior to the Calhoun CZO are now developed as long-term research areas. In addition, we have a network of ten hillslopes and small 10-ha scale catchments across the Sumter National Forest, each of which have paired adjacent sites that are impacted by historic agricultural land uses.

7. Calhoun CZO-USFS Relations. Except for some private lands, most of the CCZO is located on the Sumter National Forest. PI Richter and USFS managers interact often and a copy of the highly detailed USFS Research Permit was attached to the 2016 Annual Report. Though the NEPA regulations have required much time to fulfill, the USFS managers are earnestly interested in helping our project succeed and they are very impressed with our students.

8. Fourth Annual Calhoun CZO Summer Science Meetings. In May 2017, investigators met at the campus of the University of South Carolina at Union and at the Rose Hill State

Historic Site to present results, discuss ongoing and new initiatives, and make decisions about the project and new opportunities. This summer we organized researchers to give talks aimed at the five project goals and in demonstrating how they were sharing and collaborating with colleagues, with extensive open-ended discussions occurring on hypotheses, E and O, and cross-CZO research.

9. Calhoun CZO Website. Our website describes our observatory's growing research, infrastructure, data, models, publications, people, and E and O programs. Our data manager, Will Cook, is coordinating year-four updating of the website's descriptions, had greatly expanded data sets on line and is actively working with the CZO program team of data managers.

10. Data Policy and Management. Our data-sharing policy has been strengthened *within our Observatory*. The Executive Committee accelerated from 12 to 6 months as the maximum time that new data can be held without sharing amongst investigators. Our data manager greatly expanded data sets on the Calhoun CZO web site and is actively working with data manager colleagues from all CZOs.

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

All across the Calhoun CZO, PIs are committed to linking research wherever possible with training both in the lab and the field.

Examples of 2016 opportunities for training and professional development include:

1. High school student education. At Duke, UGA, and Roanoke, high school students are included in research. At Duke, a student from North Carolina School of Science and Mathematics was mentored by a CZO PhD student over nearly one year. In PI Kumar's lab, a high school student from Green Hope High interned over much of a year. At PI Nelson's lab at UGA, Zach Meyers, a local high school student, joined the team as an intern for the 2016-2017 school year. Also at UGA, in PI Thompson's lab, a high-school senior Roberto Carlos Villanueva participated in the young scholars program and benefited from interactions with graduate students, postdocs and Co-PI Thompson, while performing iron analysis and learning to chemically extract iron-OM solids. At Roanoke College, K-12 educators participated in four science pedagogy meetings at which our E&O PI gave a presentation about CZ and environmental science.

2. Undergraduate education. At Roanoke, Duke, UGA, and Kansas, many undergraduates are involved with CZ science and the Calhoun CZO. At Roanoke, PI O'Neill continues to provide training and opportunities for professional development to undergrads in 2017 supporting three research projects that directly contribute to E&O efforts at the Calhoun. A fourth Roanoke student was awarded a research fellowship by the college with the potential for support over four years. Laboratory and classroom activities have been developed and tested as part of the new 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 a total of 11 independent and research projects over our project's life and involved several of these students in presentations and manuscript writing. At Roanoke, the development of critical zone educational materials have contributed to the training and educational development of more than 140 undergraduate students in the past 12 months, with an additional 96 students registered for fall courses. 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 concept of the science in the class. Also at Duke, twelve undergraduates in North Carolina State University's REU in Soil Science were given a day-long field tour in CZ science. The UGA team of PIs continues to be particularly active with undergraduates, three of whom completed research projects that included 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. Undergraduate geoscience majors will exchange classes in this latter program. UGA undergraduate Tony Moraes finished his undergraduate degree and will start graduate school at the University of Wyoming. UGA undergraduates David Richards finished his undergraduate degree and will start graduate school at the University of Georgia. Peter Steiner finished his undergraduate degree at Depauw University and will start graduate school at the University of Georgia. Sophia Sanders is starting her undergraduate research at UGA in CZO science and has established a position in the UGA Electron Microscopy lab. At the University of Kansas, three undergraduates were trained to use lab equipment to analyze soil sample incubations.

3. Graduate education. At Duke, Georgia Tech, Mississippi State, UGA, and Kansas, graduate students are deeply involved with CZ science and the Calhoun CZO. t Duke, seven PhD students are working on CZ biogeochemistry, hydrology, and systems modeling. Five have earned support from an NSF IGERT program in wireless technologies. PhD student 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 for time on an XRD. Wade will give her first professional presentations at SSSA and AGU. 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 worked to collect and analyze environmental history data. At the University of Georgia, several 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 accepted a PhD offer at PSU where she started in the fall of 2017. Caitlin enjoys teaching and got to teach soil texture analysis to 4-H students at a workshop in summer 2017. 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). He is using ABMs as part of his dissertation work for the CZO. 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 at a wide variety of

forums, from AGU and EGU to local science and 4-H clubs. Calhoun PIs try to interact with all of these graduate students across institutions.

4. Postdoctoral scientists and young professors. At Duke, the University of Georgia, and the University of Kansas, postdoctoral scientists are involved in important ways with our CZ science and the Calhoun CZO. At Duke, Dr. Jay Austin has moved from the University of Georgia to Duke in the last year and has moved into a position that will decidedly broaden his range of expertise. Well trained as a clay mineralogist, Jay is now monitoring groundwater, sampling and analyzing soil and water chemistry, and expanding his purview of CZ science. 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 recently moved to an 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 the 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, Dr. Mike Coughlan worked as a post-doc and has been responsible for developing spatial datasets and models, and writing 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 has helped plan what is called the Calhoun Big Dig 2016-17, which is comparing deep soil 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 many universities and different programs within universities, and at many scientific conferences (see Products for details). In addition, PIs of the Calhoun CZO frequently reach out to Earth science, environmental, engineering, and ecological communities to explain the details and the need for an integrated critical zone science. Some examples follow.

K-12 and undergraduate educators: Five presentations and workshops either given or accepted for forthcoming pedagogy meetings; three of these presentations had undergraduate co-authors. One additional abstract under review for national pedagogy conference.

Students in Undergraduate and Graduate Schools: New classes in critical zone science are being taught in 2017 at two of our institutions, Roanoke College and the University of Kansas. At

Environmental educators and citizen scientists: CZ science was advanced in several ways, in a statewide webinar on 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 will be given to the Virginia Association of Environmental Educators (accepted; forthcoming). Other outreach talks were given to citizen scientists and conservationists (Appalachian Trail Club and Master Naturalist chapters).

Graduate and undergraduate student communities: Many presentations, many 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 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 and his hydrology student John Mallard won an "outstanding student presentation award" at the 2016 EGU general assembly. PI Mukesh Kumar and his students continue to give critical zone based hydrology talks in a number of venues.

Ecosystem Ecologists & Biogeochemists: 1) PI Richter was invited to Nantes, France to give a keynote to the annual meeting of Frances CZO and LTER/ILTER program. His talk was called, "Darwin, Lyell, Ecosystems, and Earth's Critical Zone." 2) Richter is revising a piece originally written in collaboration between CZO, LTER, and NEON communities, which was declined by *BioScience*. This was a outgrowth of an invitation to Richter to the All Scientists Meeting of LTER in late August 2015. PI Thompson has 5 papers currently in review that acknowledge support from this project: the first (Wilmoth et al, submitted) reports on the influence of oxygen concentrations on the formation of iron precipitates and their subsequent reactivity toward reductive dissolution; the second (Barcellos et al, submitted) describes the influence of shortening the frequency of redox fluctuations on iron dynamics and carbon content; the third and fourth papers are collaborative works that support the objectives of this proposal and were made possible by sharing Mössbauer instrument time with this project. The fourth (Jing et al, submitted) describes a method of standard addition to identify specific iron phases in complex soils and sediments. The fifth (Winkler et al, submitted) describes iron behavior following a two-year redox fluctuation experiment in soils of southeast Asia.

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 a proposal for a Chapman Conference, "Hillscope: Architecture of Porosity in the Critical Zone."

Clay mineralogists: PI Schroeder continues with his very 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 organized. Schroeder will be the co-author of a Cambridge book called, "Clays in the Critical Zone."

Stratigraphers: PI Richter continues to work with the International Commission on Stratigraphy's Anthropocene Working Group, and authored a chapter in a soon-to-be-published Cambridge book on the Anthropocene.

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

Environmental history: PIs Giesen, Nelson, and postdoc Coughlan all advance the interdisciplinary critical zone science as they see the latent importance 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.

Environmental humanities: PI Richter co-taught a new Duke class entitled, "Environment in Literature, Law, and Science", an interdisciplinary class taught at high intellectual level to 50 Duke undergrads. In the fall of 2016, PI Richter is working full time on the Calhoun CZO but has an office in the Franklin Humanities Institute (FHI), engaging environmental humanities scholars with critical zone science. Richter is collaborating with FHI's videographer Eric Barstow on a 20- to 30-min video surrounding the discussions between about a dozen humanities scholars and philosopher Bruno Latour, who visited the Calhoun CZO and Duke in September 2015. The video is called, "The Critical Zone Education of Bruno Latour."

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 in May 2016. PI Richter invited UNAM Prof. Christina Siebe to Duke and to the 2015 AGU meeting, as she is Lead-PI of the very impressive Mezquital Valley CZO near Mexico City.

International scientists: Both PIs Schroeder and Richter have been active in giving talks and participating in international discussions to advance CZ science. PI Schroeder gave another talk in Turkey in 2016, following his 10 invited lectures at universities and conferences while on sabbatical in Turkey during 2015.

Postdoc and graduate student communities: Many formal and informal presentations were given to student groups and organizations by Calhoun CZO students across many disciplines.

Rural South Carolina communities: PIs Nelson and Richter initiated a partnership with the Union County Historical Society.

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

A. Year five plans are organized using the five specific goals of the CCZO project.

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

a) Geophysics & Geochemistry. We will continue to collaborate writing papers aimed at this project goal. At least three papers are well along and will be submitted in the coming year, one by PI Billings, another by PI Richter, and a third by PhD student Brecheisen. PI Kumar will begin to investigate the changes in water budget in all CCZO watersheds, and by implementing PIHM3D model in the CCZO watersheds to evaluate the role of land cover regeneration on catchment response. This latter effort will be framed as an investigation of how deforestation, abandonment, erosion and reforestation of agricultural land affects the hydrologic response of the watershed. We will track changes in watershed responses by performing data mining on the streamflow hydrographs collected from 1948 to 1962 and our contemporary data of 2014 to present. We will continue to collaborate with WyCEHG in our beginning tests of the surprising conclusions reached in the St. Clair et al. (2015) paper, by drilling two boreholes. The new boreholes are funded by a grant received from outside of the CCZO. CCZO PIs are preparing several additional proposals to NSF one that is currently entitled, "Cross observatory network quantification of mineral assemblages using X-ray diffraction and elemental measures". We are writing proposals for expanded drilling and for a clearcutting experiment to test vegetation-deep critical zone weathering reactions. UGA mineralogy PIs will implement their new ERASMUS+ international program in CZ science.

b) Land-Use History. Environmental anthropologists and historians are continuing to assemble 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 interpret human forcings that accelerated and decelerated soil erosion on uplands and hillslopes and sedimentation of valley bottoms. Now that several databases are developed, we will begin to conduct spatial analyses to understand the drivers and feedbacks of land uses changes. Further, we will develop a land use intensity index for each property, where possible, to better understand the impacts of behavior on the landscape by correlating land use intensity with current geochemical and physical processes. In partnership with colleagues from Duke and Princeton (mainly PI Porporato), we will begin to develop models of the system based on the empirical data.

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 cultivated fields, and three sites in old-field pine forests that are 60 to 90 years from farm abandonment. We will continue to log soil moisture, temperature, CO_2, and O_2 at 0.5- and 1.5-m, and measure moisture by neutron probe and four gases down to 5-m, and in two sites to 8.5m. Late in 2017 or early 2018, we will estimate Ksat throughout soils and upper saprolite of the nine sites, and initiate the broadcast to the internet via modem of some of our logged data. 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 vs 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 reinstrumented watersheds in addition to the array of groundwater wells with water sensors throughout Watershed 4 and within Holcombe's Branch legacy sediments. Analysis of historic strip charts will be completed with the help of instruments at the US Geological Survey and Coweeta Hydrologic Lab.

e) Calhoun Long-Term Soil-Ecosystem Experiment (LTSE). The 16 LTSE plots will be resampled in 2017, and samples archived 60 years from the initiation of the field study. Analyses will focus on temporal dynamics of organic carbon throughout the upper CZ and structural re-aggregation in the clayey B horizon.

2. Erosion-Induced Carbon Dynamics

a) Observations. Our first manuscript on legacy sediments will be produced in 2017, a paper focused on the sediment inundation of soil organic carbon (SOC) in Holcombe's Branch. Studies will be conducted in the laboratory of the changes in microbiology and biogeochemistry of soil organic matter as it is buried in legacy sediments.

b) Modeling. The update of the distributive model tRIBS-ECO will be initiated updating the initial simulations with much more data that have been gathered as the research teams have studied the Calhoun. We actually anticipate that in year five this paper will be written and submitted but a deliberate approach to the model which can in years 4 and 5 include many more PIs and students will be well worth the effort.

3. Persistence of Alternative States

Environmental historians and anthropologists will be producing at least two papers during the year, and also working with modelers to better quantify the history of changing land and human dynamics. This team intends to submit a research proposal to NSF's Coupled Human Systems program. The investigators will continue to visit each other's campuses for multiple day of collaborations.

4. E&O

If needed, resubmit a proposal to the NSF-REU program. Classroom test educational materials for the new undergraduate course in CZ science. Publish educational materials that integrate interactive maps, text, imagery, and video. Document pedagogical materials and assessments in a manuscript to be submitted to a pedagogical journal. Publish outreach materials using cloud-based and distributed formats. Collaborate on cross-CZO E&O teams coordinated through the National Office. Publish teaching cases based on the CCZO through the National Socio-Environmental Synthesis Center with submission to *Journal of Case Studies in the Environment*.

Continue and expand recruitment of undergraduate students, especially from underrepresented groups, to assist with Calhoun research.

5. Cross-CZO Projects

PIs and students will continue to actively participate in several cross-CZO projects, specifically the soil biogeochemistry, hydrology, and E&O projects. Our data manager will continue to participate in the Cross-CZO effort to promote program-wide data management. Intensive measurement of O_2, redox potential, Fe(II), DOC, and pH will be conducted at the Calhoun over six weeks to match a study successfully completed at the Luquillo CZO, to demonstrate the widespread importance of redox fluctuations in upland CZs.

B. Plans that support the project at large

1. Calhoun CZO Executive Committee. The Executive Committee will continue to meet once a month, with the sole objective of getting the most scientific and societal impact from our CZO.

2. Calhoun CZO-USFS Relations. We will continue to work closely with the managers of the Sumter National Forest.

3. Fifth Annual Calhoun Summer Science Meeting. The Executive Committee will be in charge of organizing this coming year's Summer Science Meeting. We are considering coordinating research activities 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)	2017 Ann Rep CCZO - ONeill Lab (KO).pdf	Example AnnReport E&O PI O'Neill	Daniel Richter	10/21/2017
(Download)	2017 Ann Rep CCZO - Brecheisen.pdf	Example AnnReport PhD student Brecheisen	Daniel Richter	10/21/2017
(Download)	Bonetti_PRSA_DrainageArea_last.pdf	PhD student Sara Bonetti's manuscript for submission to Royal	Daniel Richter	10/21/2017

Filename	Description	Uploaded By	Uploaded On
(Download) 2017 CCZO Supplementary.pdf	Society Transactions Calhoun 2017 Supplementary Annual Report	Daniel Richter	10/21/2017

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Products

Books

Book Chapters

- Richter, D.deB., S.A. Billings, C. Waters (2017). A pedology and pedostratigraphy for the Anthropocene. *Statigraphic Signatures of the Anthropocene* Waters, C. and J. Zalasiewicz. Cambridge University Press. . Status = AWAITING_PUBLICATION; Acknowledgement of Federal Support = No ; Peer Reviewed = Yes

Inventions

Journals or Juried Conference Papers

- Austin, J.C., A. Perry, D.D. Richter, and P.A. Schroeder (2017). Modifications of 2:1 clay minerals in a kaolinite dominated Ultisol under changing land-use regimes. *Clays and Clay Minerals*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Bacon, A. R., F. von Blanckenburg, M. Oelze, L. E. Nave, K. A. Heckman, T. J. Veverica, and D. deB. Richter (2017). Subsoil's coupled carbon-iron cycle controls contemporary carbon stabilization. *Nature Geoscience*. . Status = SUBMITTED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes
- Billings, S., K. Min, F. Ballantyne IV, Y. Chen, M. Sellers (2016). Aging exo-enzymes can create temporally shifting, temperature-dependent resource landscapes for microbes. *Biogeochemistry*. 131 (1-2), 163. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s10533-016-0273-x
- Bonetti, S., A. D. Bragg, and A Porporato (2017). On the definition and the equation for the drainage area at regular and non-regular points in watersheds. *Proceedings of the Royal Society A*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Bonetti, S., and Porporato, A. (2017). On the dynamic smoothing of mountains. *Geophysical Research Letters*. 44 (11), 5531. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2017GL073095

- 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*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/esurf-2017-36
- Brecheisen, Z.S., D. deB. Richter (2017). Microtopographic roughness analysis highlights uneroded terrain in an ancient landscape wrinkled by agriculture. *Earth Surface Processes and Landforms*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Brecheisen, Z.S., P. N. Halpin, S. Moon, D. deB. Richter (2017). Ordered interfluves couple critical zone landscape structure and function. *Nature Geosciences*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Chen, X., M. Kumar, D. Richter, and Y. Mau (2017). Impact of gully incision on hillslope hydrology. *Water Resources Research*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Coughlan, M., D.R Nelson, M. Lonneman (2017). Continuity and change in the southern Piedmont: A social-ecological perspective on people and their land (1790-1940). *Human Ecology*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Coughlan, M., D.R. Nelson (2017). Human niche construction and legacy effects of prehistoric Native American land use on Euro-American settlement in the South Carolina Piedmont. *PLOS ONE*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Coughlan, Michael R., Donald R. Nelson, Michael Lonneman, Ashley E. Block (2017). Historical land use dynamics in the highly degraded landscape of the Calhoun Critical Zone Observatory. *Land*. 6 (2), 32. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.3390/land6020032
- Coyle, D.R., U.J. Nagendra, M.K. Taylor, J.H. Campbell, C.E. Cunard, A.H. Joslin, A. Mundepi, C.A. Phillips, and M.A. Callaham, Jr. (2017). Soil fauna responses to natural disturbances, invasive species, and global climate change: Current state of the science and a call to action. *Soil Biology and Biochemistry*. 110 116. Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1016/j.soilbio.2017.03.008
- Dialynas, Y. G., R. L. Bras, and D. deB. Richter (2017). Hydro-geomorphic perturbations on the soil-atmosphere CO2 exchange: How (un)certain are our balances?. *Water Resources Research*. 53 (2), 1664. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016WR019411
- Holbrook, W. Steven, Allan Bacon, Susan L. Brantley, Bradley J. Carr, Brady A. Flinchum, Virginia Marcon , Daniel deB. Richter, and Clifford S. Riebe (2017). 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
- Huang, S.-Y., Y. Deng, and J. Wang (2017). Revisiting the global surface energy budgets with maximum-entropy-production model of surface heat fluxes. *Climate*

Dynamics. 49 (5-6), 1531. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1007/s00382-016-3395-x

- Leone, JD, WS Holbrook, J Pelletier, C Rasmussen, DD Richter, D Markewitz, B Carr, and N Abromson (2017). A ground penetrating radar attribute analysis method for mapping soil thickness. *Vadose Zone Journal*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Li Li, Kate Maher, Alexis Navarre-Sitchler, Jenny Druhan, Christof Meile, Corey Lawrence, Joel Moore, Julia Perdrial, Pamela Sullivan, Aaron Thompson, Lixin Jin, Edward W. Bolton, Susan L. Brantley, William E. Dietrich, K. Ulrich Mayer, Carl I. Steefel, Albert Valocchi, John Zachara, Benjamin Kocar, Jennifer Mcintosh, Benjamin M. Tutolo, Mukesh Kumar, Eric Sonnenthal, Chen Bao, Joe Beisman (2017). Expanding the role of reactive transport models in critical zone processes. *Earth-Science Reviews*. 165 280. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.earscirev.2016.09.001
- Liu, Yanlan, Anthony J. Parolari, Mukesh Kumar, Cheng-Wei Huang, Gabriel G. Katul, and Amilcare Porporato (2017). Increasing atmospheric humidity and CO2 concentration alleviate forest mortality risk. *PNAS*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1073/pnas.1704811114
- Min, Kyungjin, Christoph A. Lehmeier, Ford Ballantyne IV, and Sharon A. Billings (2016). Carbon availability modifies temperature responses of heterotrophic microbial respiration, carbon uptake affinity, and stable carbon isotope discrimination. *Frontiers in Microbiology*. 7 2083. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.3389/fmicb.2016.02083
- Noto, L. V., S. Bastola, Y. G. Dialynas, E. Arnone, and R. L. Bras (2017). Integration of fuzzy logic and image analysis for the detection of gullies in the Calhoun Critical Zone Observatory using airborne LiDAR data. *ISPRS Journal of Photogrammetry and Remote Sensing*. 126 209. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.isprsjprs.2017.02.013
- O'Neill K.P., J. Rice, and D. deB. Richter (2017). Cultivating a sense of place in the southern Piedmont using Esri Story Maps. *In the Trenches*. . Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No
- O'Neill, K.P., and D.deB. Richter (2016). Learning from the "deep changes in the land": The Critical Zone perspective in environmental science education. *The Earth Scientist*. 32 (3), 25. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No
- Parolari, A.J., M.L. Mobley, A.R. Bacon, G.G. Katul, D.deB. Richter, and A. Porporato (2017). Boom and bust carbon-nitrogen dynamics during reforestation. *Ecological Modelling*. 360 108. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.ecolmodel.2017.06.023
- Richardson, J.B., Aguirre, A.A., Buss, H.L., O'Geen, A.T., and Richter, D.deB. (2017). Sequestration of Hg in deep soil horizons across Critical Zone Observatories. *Global Biogeochemical Cycles*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

- Richter, D.deB., Sharon A. Billings, Peter M. Groffman, Eugene F. Kelly, Kathleen A. Lohse, William H. McDowell, Clifford S. Riebe, Whendee L. Silver, Timothy S. White, Suzanne Anderson, Susan Brantley,, Zachary S. Brecheisen, Oliver A. Chadwick, Hilairy E. Hartnett, Sarah E. Hobbie, Clare E. Kazanski, Daniel Markewitz, Katherine O'Neill, Paul A. Schroeder, Aaron Thompson (2017). What might Darwin and Lyell say about integrating biology and geology across environmental science networks?. *BioScience*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- 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?. *Georgia Water Resources Conference Proceedings*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No
- Zalasiewicz, Jan; Waters, Colin N.; Wolfe, Alexander P.; Barnosky, Anthony D.; Cearreta, Alejandro; Edgeworth, Matt; Ellis, Erle C.; Fairchild, Ian J.; Gradstein, Felix M.; Grinevald, Jacques; Haff, Peter; Head, Martin J.; Ivar do Sul, Juliana A.; Jeandel, Catherine; Leinfelder, Reinhold; McNeill, John R.; Oreskes, Naomi; Poirier, Clément; Revkin, Andrew; Richter, Daniel deB.; Steffen, Will; Summerhayes, Colin; Syvitski, James P.M.; Vidas, Davor; Wagreich, Michael; Wing, Scott; Williams, Mark (2017). Making the case for a formal Anthropocene Epoch: an analysis of ongoing critiques. *Newsletters on Stratigraphy*. 50 (2), 205. Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1127/nos/2017/0385
- Zi, T., M. Kumar, and J. Albertson (2017). Intercomparing model configurations with varied erosion, deposition and transport representations for simulating sediment yield. *Catena*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses

Other Conference Presentations / Papers

- El Sharif, H., S.-Y. Huang, Y. Tang, S. Shahnaz, and J. Wang (2016). *A comparison study of terrestrial evapotranspiration models*. Asia Oceania Geosciences Society 13th Annual Meeting. Beijing, China. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Pachon, Julio, Allan Bacon, Kayci Kowalski, and Joshua Butterick, Dan Richter, Aaron Thompson, Madison K. Akers, Joshua Cucinella, Rosvel Bracho-Garrillo, John M. Davis, Sabine Grunwald, Eric J Jokela, Michael Kane, Marshall A. Laviner, Daniel Markewitz, Timothy Martin, Gary F. Peter, C. Wade Ross, and Jason G. Vogel (2017). *A new way to look at soil aggregation and aggregating particles: What laser diffraction tells us*. Southeastern Biogeochemistry Symposium. Athens, GA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Cherkinsky, A., G.V.R. Prasad, H. Pan, D. Richter (2017). *AMS and IRMS studies of different soil organic matter fractions in Ultisol profiles, Calhoun CZO, South Carolina*

USA. 14th International Conference on Accelerator Mass Spectrometry. Ottawa, Canada. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- O'Neill, K.P., and H. Morrison (2016). *Adventures in the Earth's critical zone: The Calhoun Critical Zone Observatory*. Virginia Association of Science Teachers. Williamsburg VA. 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 = ACCEPTED; Acknowledgement of Federal Support = No
- Richter, D. deB., J. Wang, R. Bras, D. Markewitz, D. Nelson, J. Austin, P. Schroeder, S.A. Billings, K. O'Neill, J. Giesen, W.S. Holbrook, and 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
- Thompson, A. (2016). *Can we predict iron reduction rates across terrestrial ecosystems?*. Telluride Summer Science Series. Telluride, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Cherkinsky, A., Brecheisen Z., Richter D. (2017). *Carbon and oxygen isotope composition in soil carbon dioxide within deep Ultisols at the Calhoun CZO, South Carolina, USA*. 2nd International Radiocarbon in the Environment Conference. Debrecen, Hungary. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Austin, J.C.; Schroeder, P.A.; Perry, A. (2017). *Clay mineral alterations in response to land-use change in the kaolinite dominated residual soil of the Calhoun Critical Zone Observatory*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Anctil, François, Islem Hajji, Audrey Maheu, Charles Malenfant, Biljana Music, Daniel Nadeau, Vincent Fortin, Étienne Gaborit, Jingfeng Wang, and René Therrien (2017). *Construction of a hydrological surface model around Maximum entropy production*. CGU and CSAFM Joint Annual Scientific Meeting. Vancouver, BC, Canada. Status = PUBLISHED; Acknowledgement of Federal Support = No
- Lonneman, M. (2017). *Continuity and change in the southern Piedmont: A social-ecological perspective on people and their land (1790-1940)*. Society for Applied Anthropology annual meeting. Santa Fe, NM. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Bacon, A. (2016). *Critical zone science for research and education on the Atlantic coastal plain*. NSF CZO Network Review Meeting. Arlington, VA. 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 = ACCEPTED; Acknowledgement of Federal Support = Yes

- Billings, S.A., Richter, D.D., Sullivan, P.L., Lehmeier, C.A., Bagchi, S., Min, K., Hauser, E., Stair, R., Flournoy, R. (2017). *Deep and persistent consequences of long-term changes in land cover*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. 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 = ACCEPTED; Acknowledgement of Federal Support = Yes
- O'Neill KP, T. Poelzing (2017). *Digging deep within the Earth's critical zone to reach across the disciplines*. Copenhaver Institute "21st century skills: Inspiring creativity in the classroom". Salem VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Gao, M., M.K. Taylor, and M.A. Callaham, Jr. (2016). *Do non-native earthworms influence trophic dynamics in experimental soil ecosystems?*. International Visitors Program Science Leadership Forum. Washington, DC. Status = PUBLISHED; Acknowledgement of Federal Support = No
- Barcellos, Diego, Dan Markewitz, Caitlin Hodges, Aaron Thompson (2017). *Drivers of redox, iron and carbon in soils from the Calhoun CZO*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Sullivan, P.L., Goddéris, Y., Li, L., Billings, S., Macpherson, G.L., Shi, Y., Schott, J., Brantley, S.L. (2017). *Earthcasting controls of vegetation on solute fluxes and soil development in the critical zone*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Cherkinsky A; Ehlinger R. (2016). *Effect of Agriculture and Reforestation on Turnover Rates SOM in Ultisol Profiles, Calhoun CZO*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D. deB. (2016). *Emerging hypotheses at the Calhoun Critical Zone Observatory*. NSF CZO Network Review Meeting. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Martin C., K.P. O'Neill (2017). *Estimating soil erosion potential at the Calhoun Critical Zone Observatory using a spatially-explicit RUSLE model*. Virginia GIS/LIS Conference. Blacksburg VA. 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 = ACCEPTED; Acknowledgement of Federal Support = Yes
- O'Neill KP (2016). *Exploring landscape processes in South Carolina's southern Piedmont using data from the Calhoun Critical Zone Observatory*. South Carolina Science Council Conference. Columbia SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Barcellos, D, C Hodges, D Markewitz, E. Ardington, and A Thompson (2016). *Field measurements of soil iron and carbon cycling during spring warm-up in an aggrading pine forest at the Calhoun CZO*. Soil Science Society of America Annual Meeting. Phoenix, AZ. 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 = ACCEPTED; Acknowledgement of Federal Support = Yes
- Bonetti, Sara, and Amilcare Porporato (2017). *Forward and backward evolution of the Calhoun CZO landscape*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Lonneman, M. (2017). *From slavery to wage labor: Livelihood change and land use transitions in the U.S. Piedmont, 1850-1880*. Society for Applied Anthropology annual meeting. Sante Fe, NM. 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 = ACCEPTED; Acknowledgement of Federal Support = Yes
- Richter, D. deB. (2017). *Gilbert's soil production paradigm and the critical zone*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D.deB., J. Austin, R. Anderson, A. Bacon, S. Brantley, Z. Brecheisen, A. Cherkinsky, W.S. Holbrook, V. Marcon, J.Pachon, P. Schroeder, A. Thompson, and A. Wade (2017). *Gilbert's soil production paradigm and a critical zone's size-dependent fractionation of particles*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Tang, Yao, Sabina Shahnaz, Yawen Shen, Jinge Huo, Minjae Kim, Shih-Yu Huang, Husayn El Sharif, Cheng Yao, Satish Bastola, Rafael Bras, Jingfeng Wang (2017). *Historical data digitization and micrometeorological measurements at Calhoun Critical Zone Observatory (CCZO)*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Coughlan, Michael R., Donald R. Nelson, Michael Lonneman, and Ashley E. Block (2017). *Historical land use dynamics in the highly degraded landscape of the Calhoun Critical Zone Observatory*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Barcellos, D., and Thompson, A. (2017). *Hot spots and hot moments for redox, iron and carbon cycling in soils across Luquillo and Calhoun CZOs*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Callaham, M.A. Jr., K.R. Butt, J. Görres, D.deB. Richter, and Z. Brecheisen (2017). *How to make soil: Add parent material, soil animals, roots, weather, and set the blender on*

"liquefy". 5th Nereis Park Conference. Southampton, NY. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Calabrese, Salvatore, Tony Parolari, Amilcare Porporato (2017). *Hydrologic controls on chemical weathering in the Critical Zone*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Bastola, Satish, and Cheng Yao (2017). *Hydrological/landscape modeling of CCZO*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Krapu, Christopher, and Mukesh Kumar (2016). *Impact of deforestation and recovery on streamflow recession statistics*. American Geophysical Union 2016 Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Chen, Xing, and Mukesh Kumar (2016). *Impact of gullying on hillslope hydrology at the Calhoun Critical Zone Observatory*. American Geophysical Union 2016 Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Chen, Xing, Mukesh Kumar, Daniel deB. Richter, Yair Mau (2017). *Impact of gullying on hillslope hydrology at the Calhoun Critical Zone Observatory*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Calabrese, Salvatore, Daniel Richter, Amilcare Porporato (2017). *Impact of stochastic bioturbation and transport on the formation of argillic horizons*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Ferguson, Terry A. (2017). *Implications of 1930s Piedmont research by the Soil Conservation Service for the Calhoun CZO*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Liu, Y.; Parolari, A.; Kumar, M.; Porporato, A. M.; Katul, G. G. (2016). *Increasing atmospheric humidity and CO2 concentration alleviate forest hydraulic failure risk.* American Geophysical Union 2016 Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Liu, Yanlan, Anthony Parolari, Mukesh Kumar, Cheng-Wei Huang, Gabriel Katul, Amilcare Porporato (2017). *Increasing atmospheric humidity and CO2 concentration alleviate forest mortality risk*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Villanueva, R.C., Mantripragada, N., and Thompson, A. (2017). *Influence of land-use on the abundance of soil mineral reactivity at the Calhoun CZO*. University of Georgia Young Scholars Conference. Athens, GA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Chen, Chunmei, Nadia Noor, Diego Barcellos, Caitlin Hodges, and Aaron Thompson (2017). *Iron reduction potential in upland soils in CCZO*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Thompson, Aaron; Meile, Christof; Wilmoth, Jared; Barcellos, Diego; Chen, Chunmei; Ginn, Brian; Hodges, Caitlin (2017). *Key features of redox fluctuating soils that influence*

iron cycling. American Chemical Society National Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Lonneman, M. (2017). *Land use and environmental change during the transition from slavery to wage and contract farming in the South Carolina Piedmont*. Dimensions of Political Ecology Conference. Lexington, KY. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Nelson, Donald R., Daniel D. Richter Jr., Michael Coughlan, Michael Lonneman, Zachary Brecheisen (2017). *Land use legacies in the Calhoun CZO: The implications of human behavior for Critical Zone processes*. Calhoun CZO 2017 Summer Science Meeting. Union, 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 = ACCEPTED; Acknowledgement of Federal Support = Yes
- Wade, Anna, Dan Richter, Allan James, Alex Cherkinsky, Will Cook (2017). *Legacy sediments in Holcombe's Branch: a complicated dataset*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Ryland, R., Markewitz, D., and Thompson, A. (2016). *Mapping depth to argillic horizons using electromagnetic induction on historically farmed soils within the Piedmont region of the United States*. American Geophysical Union 2016 Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Ryland, R.C. (2017). *Mapping depth to the argillic horizon on historically farmed hillslopes in the Calhoun CZO*. Crop and Soil Science Graduate Student Seminar, University of Georgia. Athens, GA. 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 = ACCEPTED; Acknowledgement of Federal Support = Yes
- Brecheisen, Zachary, Daniel Richter, Will Cook, Paul Heine (2017). *Old-field succession: Land-use legacies and below-ground respiration*. Ecological Society of America Annual Meeting. Portland, OR. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Gutierrez-Jurado, H. A.; Guan, H.; Wang, J.; Wang, H.; Simmons, C. T.; Bras, R. L. (2016). *On the coupled effect of topography, vegetation cover, and soil properties on the partition of water and energy fluxes of seasonally water-stressed ecosystems*. American Geophysical Union 2016 Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = No
- Brecheisen, Zachary, Seulgi Moon, Daniel Richter, Patrick Halpin (2017). *Ordering interfluves: an analytical framework for hierarchical patterns in landscape structure and function*. American Association of Geographers Annual Meeting. Boston, MA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Brecheisen, Zachary S., Seulgi Moon, Patrick Halpin, Daniel deB. Richter (2017). *Ordering interfluves: quantifying critical zone landscape structure and*

function. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Callaham, Mac, Roberto Carrera-Martínez, Zach Brecheisen, Melanie Taylor, Dan Markewitz, and Dan Richter (2017). *Past, present and future earthworm-related research at the Calhoun CZO*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- O'Neill KP (2016). *Place-based exploration of the southern Piedmont: The Calhoun Critical Zone Observatory*. North Carolina Science Teachers' Association. Greensboro NC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Billings, S.A., D. Richter, S.E. Ziegler, K.L. Prestegaard (2016). *Projecting soil feedbacks to atmospheric CO2 following erosion and deposition on centennial timescales in two contrasting forests: A study of critical zone-atmosphere exchange*. American Geophysical Union 2016 Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Schroeder, Paul A., Jason C. Austin, and Daniel deB. Richter (2017). *Quantifying mineral transformations in the Calhoun Critical Zone Observatory (CCZO): What is it and how much is there?*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D., M.L. Mobley, S.A. Billings, and D. Markewitz (2016). *Rapid turnover and minimal accretion of mineral soil carbon during 60-years of pine forest growth on previously cultivated land*. American Geophysical Union 2016 Fall Meeting. San Francisco, CA. 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 = ACCEPTED; Acknowledgement of Federal Support = Yes
- Lonneman, M. (2017). *Reorganizing land and labor: Exploring agricultural land use change in the postbellum South Carolina Piedmont using an agent-based model*. Integrative Research and Ideas Symposium, University of Georgia. Athens, GA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Thompson, A., Druhan, J.L., Keiluweit, M., Wagai, R., Plante, A.F., Lawrence, C.R., Berhe, A.A., Sierra, C.A., Rasmussen, C., Marin-Spiotta, E., Blankinship, J.C., Schimel, J., Heckman, K.A., Crow, S.E., and Wieder, W.R. (2016). *Representation of diffusion controlled carbon stabilization in reactive transport models*. American Geophysical Union 2016 Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Hodges, Caitlin, John Mallard, Dan Markewitz, Aaron Thompson (2017). *Seasonal variation of Fe reduction at the Calhoun CZO*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Foroughi, M., and D. Markewitz (2017). *Soil Phosphorous redistribution in the Calhoun CZO*. Warnell Graduate Student Symposium, University of Georgia. Athens, GA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Foroughi, Maryam, and Daniel Markewitz (2017). *Soil Phosphorus distribution in contrasting land-use history*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Billings, S.A., Sullivan, P.L., Richter, D.D., Lehmeier, C.A., Min, K., Bagchi, S., Flournoy, R., Hauser, E. (2017). *Soil biogeochemistry reveals the importance of deep roots as biotic controls of CZ evolution: a belowground analog to Ruddiman's hypothesis*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Callaham, M.A., Jr. (2016). *Soil invertebrates in ecosystem restoration: Indicators, exotic species, and engineers on the slow train to recovery*. Soil Science Society of America Annual Meeting. Phoenix, AZ. Status = PUBLISHED; Acknowledgement of Federal Support = No
- Coward, E.K., Thompson, A., Markewitz, D., Richter, D. deB., and Plante, A.F. (2016). *Soil organic matter stabilization by Fe-C interactions in temperate and tropical soils: A cross-CZO comparison*. Soil Science Society of America Annual Meeting. Phoenix, AZ. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Coward, E.K., Thompson, A., and Plante, A.F. (2017). *Soil organic matter stabilization by Fe-C interactions in temperate and tropical soils: A cross-CZO comparison*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Richter, D. (2017). *Soil production, Earth's critical zone, and the Anthropocene (Keynote talk for Theme 2: Climate Change)*. Wageningen Soil Conference 2017, 'Soil Science in a Changing World'. Wageningen, The Netherlands. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Mallard, John, Brian McGlynn, and Daniel Richter (2017). *Subsurface and terrain controls on runoff generation in deep soil landscapes*. European Geosciences Union General Assembly 2017. Vienna, Austria. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Mallard, J.M., B.L. McGlynn, D. Richter Jr. (2016). *Subsurface and terrain controls on runoff generation in deep soil landscapes*. American Geophysical Union 2016 Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Mallard, John, Brian McGlynn, and Daniel Richter (2017). *Subsurface, terrain, and anthropogenic influences on shallow groundwater dynamics in deep soil landscapes*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Hodges, C., Mallard, J., Markewitz, D., Thompson, A., and McGlynn, B. (2016). *Temporal variation of water and carbon influence the distribution of upland iron reduction in soils*. Soil Science Society of America Annual Meeting. Phoenix, AZ. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Chen, C., and Thompson, A. (2017). *The impact of O2 concentrations and organic matter on Fe(II) oxidation and the resulting Fe(III) solids in the presence of Fe/Al oxide sorbents*. Critical Zone Science: Current Advances and Future Opportunities. Arlington, VA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

- Thompson, A. (2016). *The role of redox variability in structuring iron cycling in soils*. Georgia Tech Environmental Science and Technology Sympoium Series. Atlanta, GA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Bastola, S., Y.G. Dialynas, R.L. Bras, L.V. Noto, and E. Istanbulluoglu (2016). *The role of vegetation on gully stabilization at a severely degraded landscape: a case study from Calhoun experimental critical zone observatory*. American Geophysical Union 2016 Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Giesen, James C. (2017). *The view from Rose Hill: Landscape and memory in the Piedmont*. Southern Forum on Agricultural, Rural, and Environmental History. Rice University. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Bonetti, S., and Porporato, A. (2017). *Topographic controls on vegetation patterns*. SIAM Conference on Applications of Dynamical Systems. Snowbird, UT. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Cook, C.W. (2017). *Update on tree age distribution at the Calhoun CZO*. Calhoun CZO 2017 Summer Science Meeting. Union, SC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes
- Hodges, C., Mallard, J., Markewitz, D., and Thompson, A. (2017). *Water and carbon influence the distribution of iron reduction at the Calhoun CZO*. University of Georgia Plant and Soil Symposium. Athens, GA. 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 = ACCEPTED; 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 = ACCEPTED; Acknowledgement of Federal Support = Yes

Other Products

Other Publications

Patents

Technologies or Techniques

- A method for comparing organic acid vs. phosphatase release of phosphate is being developed by Billings and Hauser.
- A method for quantifying root abundances from soil pit face photos has been developed by Billings.
- PhD candidate Zachary Brecheisen (Duke University) has developed and built four lightweight field-portable gas samplers/analyzers for in situ field measurements of O2 and CO2 as well as benchtop applications for laboratory incubation experiments. Features

include Vaisala CO2 and Apogee O2 sensors, an air pump to circulate gases and to take gas samples for laboratory analysis, a water trap to protect the instrument from inadvertent circulation of liquid water, and a voltmeter to read the voltage from the CO2 meter.

Thesis/Dissertations

- 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, Tony. *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
- Ramey, A.. *Development of an interactive Virtual Field Experience for teaching Critical Zone concepts (undergraduate senior honors thesis in Environmental Studies)*. (2015). Roanoke College. 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
- 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

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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

Name	Most Senior Project Role	Nearest Person Month Worked
McGlynn, Brian	Co PD/PI	1
Palmroth, Sari	Co PD/PI	0
Porporato, Amilcare	Co PD/PI	2
Billings, Sharon	Co-Investigator	5
Bras, Rafael	Co-Investigator	1
Callaham, Mac	Co-Investigator	1
Cherkinsky, Alexander	Co-Investigator	1
Giesen, James	Co-Investigator	2
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)	12
Chen, Chunmei	Postdoctoral (scholar, fellow or other postdoctoral position)	6
Coughlan, Michael	Postdoctoral (scholar, fellow or other postdoctoral position)	11
Lehmeier, Christoph	Postdoctoral (scholar, fellow or other postdoctoral position)	12
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)	2
Yao, Cheng	Staff Scientist (doctoral level)	3
Barcellos, Diego	Graduate Student (research assistant)	9
Bonetti, Sara	Graduate Student (research assistant)	3
Brecheisen, Zachary	Graduate Student (research assistant)	12
Calabrese, Salvatore	Graduate Student (research assistant)	9
Carrera-Martinez, Roberto	Graduate Student (research assistant)	12
Chen, Xing	Graduate Student (research assistant)	12

Name	Most Senior Project Role	Nearest Person Month Worked
Dialynas, Yannis	Graduate Student (research assistant)	3
Foroughi, Maryam	Graduate Student (research assistant)	12
Ghasemian, Soudeh	Graduate Student (research assistant)	1
Hauser, Emma	Graduate Student (research assistant)	4
Hodges, Caitlin	Graduate Student (research assistant)	9
Huang, Shih-Yu	Graduate Student (research assistant)	1
Huo, Jinge	Graduate Student (research assistant)	1
Kim, Minjae	Graduate Student (research assistant)	1
Krapu, Christopher	Graduate Student (research assistant)	4
Liu, Yanlan	Graduate Student (research assistant)	12
Lonneman, Michael	Graduate Student (research assistant)	9
Mallard, John	Graduate Student (research assistant)	10
Noor, Nadia	Graduate Student (research assistant)	3
Pachon, Julio	Graduate Student (research assistant)	1
Ryland, Rachel	Graduate Student (research assistant)	12
Shahnaz, Sabina	Graduate Student (research assistant)	1
Souza, Ligia	Graduate Student (research assistant)	1
Tang, Yao	Graduate Student (research assistant)	12
Wade, Anna	Graduate Student (research assistant)	12
Arroyo, Eva	Undergraduate Student	1
Casson, David	Undergraduate Student	1
Jordan, Bear	Undergraduate Student	1
Martin, Conor	Undergraduate Student	1
Moraes, Anthony	Undergraduate Student	1
Osota, Elizabeth	Undergraduate Student	2
Rankin, Hannah	Undergraduate Student	1
Rice, Jane	Undergraduate Student	3
Richards, David	Undergraduate Student	1
Ryang, Junmo	Undergraduate Student	1
Sanders, Sophia	Undergraduate Student	1
Sanford, Tierra	Undergraduate Student	1
Stair, Rena	Undergraduate Student	2
Steiner, Peter	Undergraduate Student	1
Sutton, Eric	Undergraduate Student	1
Svoboda, Samuel	Undergraduate Student	1
Thibideaux, Matthew	Undergraduate Student	3

Name	Most Senior Project Role	Nearest Person Month Worked
Villalobos, Samantha	Undergraduate Student	1
Meyers, Zach	High School Student	1
Tang, Tiffany	High School Student	1
Villanueva, Roberto	High School Student	2

Full details of individuals who have worked on the project:

Daniel deB 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 Calhoun CZO

International Collaboration: No
International Travel: Yes, france - 0 years, 0 months, 6 days; netherlands - 0 years, 0 months, 6 days

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

Contribution to the Project: Advised Xing Chen, Yanlan Liu & Chris Krapu. Gave x-CZO modeling talk. Wrote project report/ papers.

Funding Support: 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: None this year.

Funding Support: None.

International Collaboration: No
International Travel: No

Amilcare Porporato
Email: amilcare.porporato@duke.edu
Most Senior Project Role: Co PD/PI
Nearest Person Month Worked: 2

Contribution to the Project: Leader of the CCZO modeling team, and modeling of clay horizon formation and evolution of topographic statistics of the CCZO under natural and anthropogenic disturbances.

Funding Support: Duke University

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 helped contribute ideas about the categories of land use history investigated for the project and assists in the design of soil organic matter investigations. She designed soil incubations, initiated and built the 2-D erosion/deposition model, trained the research associate, post-doc, graduate students, technician and undergraduate students at U. Kansas, conducted multiple consultations with graduate students at Duke and Georgia Tech, and assisted the KU Research Associate in experimental design for laboratory experiments. Billings also is a contributor to two cross-CZO Working Groups (Biogeochemistry, and Organic Matter), and is a contributing writer to two of these groups' features in a CZO white paper generating after our Arlington meeting. In addition to these tasks, Billings wrote the manuscript

for Elementa, is training three additional graduate students, guided lab experiments for microbial carbon and carbon isotope budgets, interpreted microbial community data, 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: Completed second year of soil invertebrate sampling on land-use legacy plots at Calhoun CZO

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, hungary - 0 years, 0 months, 5 days

James C Giesen
Email: jcg245@msstate.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Continuing research on land use history.

Funding Support: This award only.

International Collaboration: No
International Travel: No

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. CCZO Executive Committee member.

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. CCZO Executive Committee member.

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: Attended CCZO summer science meeting; assisted with manuscript preparation related to past dissertation research on pedogenesis and anthropedogenesis in the Southern Piedmont.

Funding Support: University of Florida

International Collaboration: No
International Travel: No

Jason C Austin
Email: austinj1@uga.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 12

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: Yes, japan
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: 11

Contribution to the Project: Fieldwork and database development

Funding Support: University of Georgia

International Collaboration: No
International Travel: No

Christoph Lehmeier
Email: christoph.lehemeir@gmail.com
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 12

Contribution to the Project: Lehmeier has assisted in field sampling, conducted laboratory incubations and performed incubation sampling for extracts and gas samples, analyzed exo-enzyme activities, designed and performed microbial growth experiments, assisted with soil processing for bulk SOC and d13C-SOC and soil archiving, and served as a co-author for manuscripts emanating from this award. He also has assisted in the training of the graduate students and three undergraduates.

Funding Support: This award

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: 2

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

Funding Support: Dr. Sutter is partly supported by the Warnell School at UGA.

International Collaboration: No
International Travel: No

Cheng Yao
Email: cheng.yao@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 hydrology recovery theme.

Funding Support: None

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: 3

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

Funding Support: Duke University 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: 12

Contribution to the Project: Geospatial analysis, soil and tree coring, plot mapping, and helping construct wireless sensor network.

Funding Support: Duke University

International Collaboration: No
International Travel: No

Salvatore Calabrese
Email: salvatore.calabrese@duke.edu

Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 9

Contribution to the Project: Development of statistical dynamical system describing the clay horizon formation due to eluviation.

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

Funding Support: NSF

International Collaboration: No
International Travel: No

Xing Chen
Email: xing.chen@duke.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 12

Contribution to the Project: Evaluating the role of gully incision on hillslope hydrology. Submitted one paper in WRR and another is about to be submitted in WRR

Funding Support: NSOE TA-ship

International Collaboration: No
International Travel: No

Yannis G Dialynas
Email: ydialynas@gatech.edu
Most Senior Project Role: Graduate Student (research assistant)
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: Luquillo CZO (half)

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 only.

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: 1

Contribution to the Project: Ghasemian joined the Billings lab in August 2017 and is working on the Calhoun project to understand how past erosion has influenced tree functioning.

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: Teaching assistantship

International Collaboration: No
International Travel: No

Caitlin Hodges
Email: chodges@uga.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 9

Contribution to the Project: Field and laboratory research on redox processes in soils.

Funding Support: This award only.

International Collaboration: No
International Travel: No

Shih-Yu Huang
Email: shuang83@gatech.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Modeling soil temperature and soil moisture dynamics and surface water and energy budget under ecohydrological recovery (H1).

Funding Support: This award only

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

Minjae Kim
Email: mkim810@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

Christopher Krapu
Email: clk27@duke.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 4

Contribution to the Project: Developing techniques to evaluate changes in streamflow regime. Preparing manuscript.

Funding Support: IGERT: Training Program in Wireless Intelligent Sensor Networks (WISeNet) at Duke University, NSF Award Number: 1068871

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 changes in forest mortality risks due to climate change. Published paper in PNAS.

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: 10

Contribution to the Project: Ongoing installation of sensor network; field hydrologic measurements; hydrologic data acquisition, maintenance, and analysis.

Funding Support: This award and IGERT: Training Program in Wireless Intelligent Sensor Networks (WISeNet) at Duke University, NSF Award Number: 1068871

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: 12

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

Sabina Shahnaz
Email: sshahnaz3@gatech.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 1

Contribution to the Project: Retrieving and processing historical hydrometeorological data (stream-flow and rainfall)(H1).

Funding Support: This award only.

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 is working on the Calhoun project to understand how pH influences phosphatase activities.

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: Planning and execution of Calhoun CZO Summer Science Days. Worked in laboratory on dissertation research, including sample preparation and analysis.

Funding Support: NSF IGERT – WISeNet traineeship DGE-1068871

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

Conor Martin
Email: cjmartin@mail.roanoke.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: GIS analysis in support of education and outreach, field work.

Funding Support: Roanoke College Office of Student Research

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

Hannah Rankin
Email: sharonb@ku.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 1

Contribution to the Project: Was trained in root abundance technique, and generated data for this project.

Funding Support: This award.

International Collaboration: No
International Travel: No

Jane Rice
Email: jfrice@mail.roanoke.edu
Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: Story Maps in support of Education and Outreach

Funding Support: NSF

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: 1

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

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 analyzed 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: 1

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

Matthew Thibideaux
Email: mlt10722@uga.edu

Most Senior Project Role: Undergraduate Student
Nearest Person Month Worked: 3

Contribution to the Project: Field and laboratory assistance

Funding Support: None

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

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

Tiffany Tang
Email: tang17t@ncssm.edu
Most Senior Project Role: High School Student
Nearest Person Month Worked: 1

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

Funding Support: North Carolina School of Science and Mathematics

International Collaboration: No
International Travel: No

Roberto Carlos Villanueva
Email: roberto.villanueva@uga.edu

Most Senior Project Role: High School Student
Nearest Person Month Worked: 2

Contribution to the Project: Summer work internship conducting selective extractions of the Calhoun Big Dig soils.

Funding Support: University of Georgia

International Collaboration: No
International Travel: No

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
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

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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:

a) the high resolution LiDAR-DEM data from the Calhoun CZO flight in July 2014 and the super-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 will be realized when results of interdisciplinary models circulate among all the Earth and ecosystem scientists, as well as environmental historians and anthropologists. 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 project's E&O efforts mainly strive to use our specific CZ developments to create new approaches for 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 follows is a sample of how our PIs have seen their work's impact on "the principal disciplines of the project", with quotations taken from our PI's annual reports this year and in the past, all with only slight rewording.

- My learning and fascination with the Earth sciences has accelerated more in these last four years than in any time in my life.
- Our models of coupled weathering and ecohydrologic dynamics and related theoretical analyses offer insight into the coupling of hydrology, biogeochemistry, and ecology. The models may be used to assess nutrient availability to plants and soil degradation.
- Our work helps identify and quantify the depth and persistence of historic human alterations of landscapes and CZs. By having field and laboratory components to the research, we work across temporal scales and scales of complexity. These approaches help reveal patterns of land use history's impact on biogeochemistry and the mechanisms driving them.
- We develop ground-based tools, i.e., EMI, resistivity, and NIRS, through a digital soil mapping framework that helps us parameterize ecohydrological and biogeochemical models with much greater spatial intensity.
- We advance understanding of social, political, and cultural dimensions of human forcings of the CZ, and are particularly interested in understanding the complexity and legacy of these forcings of the CZ.
- The portable gas sampling and analyzer system I designed can be patented and further developed for much broader utility.
- My multilayered geo-pdf maps allow non-GIS researchers and the public to explore and understand the CZ like never before.
- Understanding and quantifying hydrologic interactions with sediment transport and soil organic dynamics is one of the highlights of our research. Process-based models, developed and implemented in this project, are advantageous over empirical approaches

as they represent physical theory and hydrologic processes in data-scarce, spatially heterogeneous terrains.
- Educational materials contribute to new pedological approaches in the Earth and environmental sciences. The pedagogy of the CZ is new and has the potential to transform teaching, especially 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 and potentially fruitful aspects of critical zone science is its capacity to span the disciplines and marshal scientists with disciplinary skills and perspectives to interact in new and important 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 is articulated directly in the 2001 NRC report led by Thomas Jordan, Gail Ashley, and others; it is articulated indirectly by the growing number of CZOs that are being established internationally on all continents (Giardino and Houser 2015). At the Calhoun CZO, it is 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 become convinced that environmental scientists see that a fully human-historical perspective to their environmental sciences is 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 fourth all-hands science meeting in 2017 ("Calhoun Summer Science Days"), but we also hold all-hands calls-to-work at the site such as our 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 have travelled from Wyoming to work at the Calhoun. In 2016-17, we hosted two "Calhoun BigDigs", efforts to attract a variety of 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 (of Cornell University and the CZO National Office) on two research projects that involve rare earth elements in the Calhoun CZO's 70-m deep core. In the past, many or most of 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.

Educational and outreach from our Calhoun project targets mainly students and teachers at small 4-year and 2-year collegiate institutions. Representation of the Earth sciences at these institutions is typically low-level compared to many research universities. Providing educational opportunities in the Earth sciences within these collegiate communities directly "enhances development of human resources in Earth sciences." Curricular materials are largely consistent with Next Generation Science Standards and may be adapted for use in advanced high school courses (AP Environmental Science).

What is the impact on physical resources that form infrastructure?

The Calhoun CZO leverages nearly 75 years of research (1947 to present) of land, vegetation, and water at the USFS Calhoun Experimental Forest, a landscape of long and on-going scientific interest due to the serious 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 they invited PI Richter and soon after PI Markewitz to join them at the Calhoun. The latter two have marshalled 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 CZO. Not only are we re-instrumenting four 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 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 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 (Mississippi State and University of Georgia), 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., History, Geology, Engineering, Environmental Sciences and Policy, Anthropology, Biology, and Earth Sciences). We use this diversity to contribute to the project at large. For example, in the fall of 2013, PI Aaron Thompson organized a set of web-based CZ science seminars among the PIs and their students. While the science was useful and interesting for certain, this activity was a study of contrasting academic cultures as well. In the fall of 2016, our remote e-discussions are on a bi-weekly basis. With data sets maturing, this is an exciting format to involve scientists of all stripes!

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 affected with her colleagues a redesign of the interdisciplinary Environmental Studies curriculum with Earth's Critical Zone as one of the organizing themes. 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 will be woven throughout the curriculum. This new curriculum has been put in place and 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* (cross-CZO effort) and will be further disseminated in upcoming journal articles and presentations to provide a model for other institutions.

What is the impact on information resources that form infrastructure?

In addition to the constantly circulating email, discussions by telephone and Skype, we use two websites for project management and communication, CZEN.ORG and CRITICALZONE.ORG. While the CZEN.ORG site was an initial repository for proposals, data sets, figures,

miscellaneous documents, and communications among Calhoun PIs, we have moved to a Google-based system of communications, including Calhoun CZO Google Maps, Calendar, Docs, and Sheets that share writing, maps, sampling locations, and to facilitate general communications. Calhoun staff (Will Cook, Paul Heine) update and build the Calhoun website on CRITICALZONE.ORG. Many data sets are uploaded, and we have recently modified our data policy to speed this process which 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! Fall 2016, in which they plan to formally describe soil profiles and help us with Ksat measurement and education.

Educational materials will be developed such that they can be widely disseminated in electronic and interactive formats, greatly increasing both the scope and the potential for public use. Use of ESRI Story Maps as a framework for Virtual Field Experiences will facilitate 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."

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Changes/Problems

Changes in approach and reason for change

Developing the Calhoun CZO on the USDA Forest Service's Sumter National Forest has required a considerable effort on the part of the Lead PI and selected PIs and students to interact 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 2017, we continue to work with USFS managers on annual permit amendments as the CCZO continues to grow and develop.

While the USFS has been very cooperative and supportive of our research, one example of the latter point is that we redesigned the flux tower in our research plan to comply with USDA Forest Service concerns about safety. We were able to finally get the flux tower approved in 2016 and our flux tower was rapidly erected and continues to collect data. The Calhoun PIs consider that we have turned the permitting process to our advantage as we seem to be enjoying a large amount of trust on the part 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.