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NATIONAL EARTH SCIENCE TEACHERS ASSOCIATION

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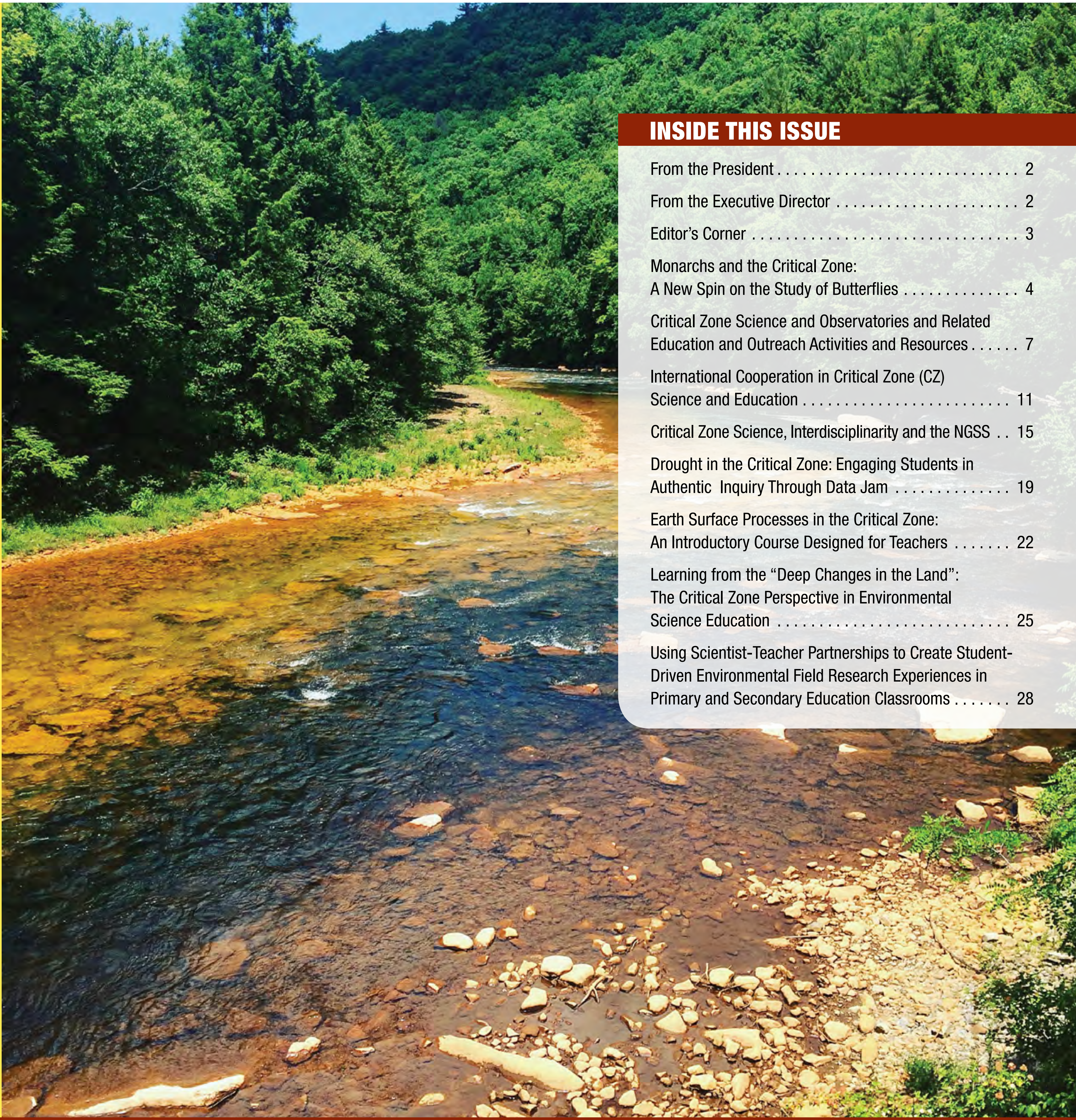

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NESTA Contacts

NESTA Address:
PO Box 271654
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From the President

Dear Teachers of Earth and Space Science,

One of the best parts of being an Earth Science teacher is that I belong to a dynamic and creative community that is continuously looking for the interconnections that make our planet unique. Our teaching can take on that creativity when we take the time to learn about new discoveries, cross-curricular collaborations, and original research. In this issue of *The Earth Scientist*, I hope you have the opportunity to learn how Earth Scientists are collaborating with Soil Scientists, Biologists and Climate Scientists around the globe to develop a better understanding of the "Critical Zone".

The Critical Zone is described by the National Research Council as the "heterogeneous, near surface environment in which complex interactions involving rock, soil, water, air, and living organisms regulate the natural habitat and determine the availability of life-sustaining resources" (2001). It is where life happens. This connection to the biological sciences is important to help make Earth Science more relevant to our students who are often unaware of the interconnections between the world we live in and the natural processes that make life possible.

I am very proud and excited to have the opportunity to be a part of this community, to learn from these creative collaborations, and to share this science through the National Earth Science Teachers Association. I hope you are inspired to take your students out to explore the Critical Zone where you live.

Enthusiastically,
Cheryl Manning
NESTA President

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This special issue was funded by the National Science Foundation Science Across Virtual Institutes (SAVI) Program (EAR 1445246) and the work of the CZO National Office (EAR 1360760).

From the Executive Director

As this issue goes to print, the holidays are approaching. We hope your fall semester went smoothly and was filled with many opportunities to incorporate new teaching approaches and stellar materials. In this issue of *The Earth Scientist* you will find many exciting resources related to Earth's Critical Zone including an Open Access online course that you can use for your own professional development and with materials that you can re-use in your own teaching.

If you are planning on attending the American Geophysical Union's annual Fall Meeting in San Francisco, we hope you'll consider joining us Monday and Tuesday, December 12 and 13 at the Geophysical Information for Teachers (GIFT) Workshop. Registration for the meeting is free for K-12 educators and informal science educators!

Sincerely,
Dr. Carla McAuliffe
Executive Director, NESTA

Editor's Corner

Welcome to this special issue of *The Earth Scientist* sponsored by the Critical Zone Observatory Network!

The Critical Zone (CZ) is the porous, near surface layer that covers all the land on Earth. It extends from the tops of the vegetation to the bottom of the groundwater. The interplay of air, water, rock, soil, and living organisms in the Critical Zone is life-giving, and all of us, and indeed, all terrestrial life depends upon the services the CZ provides. This issue is focused on helping you and your students explore where rock meets life. In doing so, we'll also help you teach the three-dimensional science of The Next Generation Science Standards (NGSS), as CZ science is very well suited to teaching in ways that resonate with NGSS.

In 2007, the National Science Foundation created the Critical Zone Observatory (CZO) program, to study this essential, life-giving skin of the Earth. The program began with three observatories, and in the ensuing years, the number of observatories has grown to nine. Later, a CZO National Office was established. Research and infrastructure at these nine observatories and the National Office is supported by the NSF Geoscience Directorate, Earth Science Division.

The articles in this issue of *The Earth Scientist* reflect the symphonic nature of both Critical Zone science and the science of the NGSS. A range of types of scientists – including geologists, ecologists, hydrologists, soil scientists, climatologists, computer scientists and more – are working together to interpret the Critical Zone, how it is changing, and how humans and other organisms depend upon it. Scientists also build their own instruments and use a range of existing technologies from simple to very sophisticated, bringing engineering to bear on the science they do. The interdisciplinary nature of CZ science and the incredible suite of investigations underway support the Next Generation Science Standards' approach to building deep understanding of concepts, ideas, and practices.

Let the articles in this special issue of *The Earth Scientist* be the beginning of you and your students' study of the Critical Zone, and consider how you can extend these innovations to better understand where rock meets life.

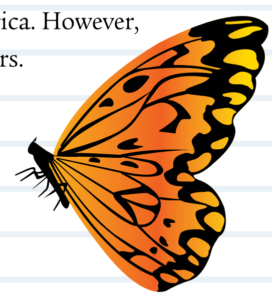
The Critical Zone Observatory Network
Guest Writer of this Editor's Corner
Don Duggan-Haas

Monarchs and the Critical Zone:
A New Spin on the Study of Butterflies

Kyla Cook, The Field Museum, Chicago; Maggie Augustinsky, Northwestern University; Abby Dye, Peggy Notebaert Nature Museum; Jenny Flowers, The Field Museum, Chicago; and Steven McGee, Northwestern University

Critical Zone science provides a framework for converting a common elementary school activity into an NGSS investigation. Monarch butterflies are a very popular topic in early elementary classrooms, particularly in relation to life science concepts such as life cycles and food webs. Yet, the study of monarchs can also be used as a launching point to engage students in inquiry and exploration of Earth science topics and the study of the Critical Zone. These themes can be examined by studying how habitat availability and land usage impact monarchs' annual migration, and by constructing a habitat restoration plan informed by ecoregion data. This involves the study of two important Critical Zone components – climate and soils.

Monarch butterflies are important pollinators in North America. However, due to habitat loss their numbers have dwindled in recent years. Monarchs complete a migration from southern Canada to northern Mexico annually to escape cold winters. During this journey, they need access to habitats rich in nectar producing plants for food and rich in milkweed on which to lay their eggs. Milkweed is the only plant that the monarch larvae eat.



The following example unit storyline, aligned to the Next Generation Science Standards (NGSS) Performance Expectation 4-ESS2-2* (NGSS Lead States) illustrates how students could engage in a progression of investigations to study elements of the Critical Zone.

Investigation 1 – Where Do Monarch Butterflies Go In Winter?

Students build awareness and understanding of monarch migration patterns. Students explore maps (Figure 1) of monarch butterfly flight paths to conclude that monarchs migrate south for the winter and return north for the summer.

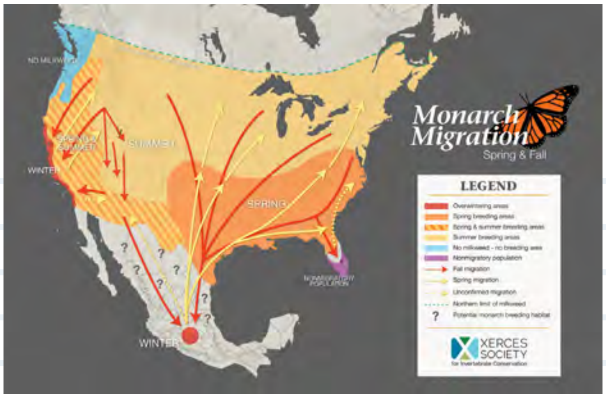


Figure 1. North American Monarch Migration Path

Credit: www.xerces.org/monarchs

Investigation 2 – What do monarch butterflies need to survive their migration?

Students conduct web research and read text to determine that monarch butterflies need a habitat with nectar producing plants for food and milkweed on which to lay their eggs during the migration journey.

Investigation 3 – Could monarch butterflies use our neighborhood/ schoolyard habitat as a stopping place during their migration?

Students examine satellite images of their school and surrounding neighborhood to determine how land is currently used. Students color the images to code between developed land (buildings, sidewalks, roads) and green space (gardens, planters, fields etc.). After identifying one or more green spaces, students visit and analyze them using a Monarch Breeding Habitat Assessment Tool (Monarch Joint Venture) to look for the presence of nectar producing flowers and milkweed to determine the extent to which these spaces meet monarch butterfly needs.

Investigation 4 – How can we improve our local monarch butterfly habitat?

Students outline a plan for planting milkweed to improve monarch habitat in their schoolyard or neighborhood. However, students must first learn about ecoregions - geographic zones defined by soil type and climate - and identify the zone in which their school is located using an Ecoregions Map (Figure 2). Then, students can cross-reference which types of native milkweed would be suitable to plant in their specific ecoregion.

Figure 2. Ecoregions of the United States

Credit: USDA http://srs.fs.usda.gov/uplandhardwood/research-topics/duplicates/ecoregions-mcnab.html

The interdisciplinary nature of critical zone science provides promise for reorienting stand-alone activities into NGSS investigations. The popularity of monarch butterflies provides an accessible example of using Critical Zone science to integrate Earth and life science topics in a meaningful way for students.

The Earth Scientist

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Maggie Augustinsky, Kyla Cook, Dr. Don Duggan-Haas, Abby Dye, Jenny Flowers, Michelle Gilmore, Dr. Steven McGee, Matthew Meadows, Dr. Manoj Menon, Dr. Katherine O'Neill, Dr. Daniel D. Richter, Noelia Baez Rodriguez, Erin Stacy, Lynn Sullivan, Dr. Tim White

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About the Author

Kyla Cook is the School Learning Experiences Coordinator at The Field Museum in Chicago and a collaborator on the Early Elementary Science Partnership (E2SP). A collaboration between The Field Museum, The Chicago Academy of Sciences and its Peggy Notebaert Nature Museum, Northwestern University, and the Big Shoulders Fund, E2SP transforms how pre-K-3rd grade teachers engage their students in science. As lead author, Kyla leveraged her experience developing E2SP units aligned to the Next Generation Science Standards with support from her E2SP colleagues: **Maggie Augustinsky**, Northwestern University; **Abby Dye**, Peggy Notebaert Nature Museum; **Jenny Flowers**, The Field Museum; and **Steven McGee**, Northwestern University.

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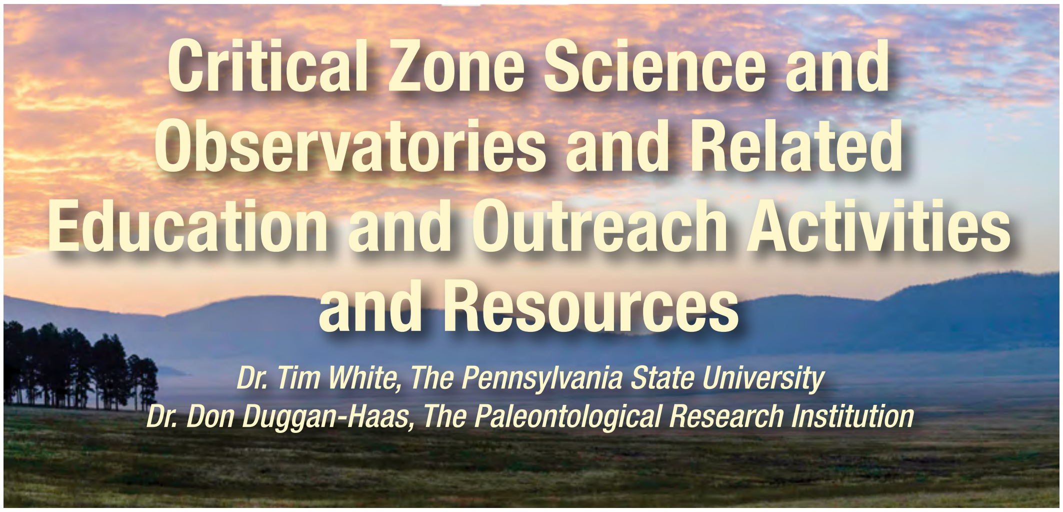

Critical Zone Science and Observatories and Related Education and Outreach Activities and Resources

Dr. Tim White, The Pennsylvania State University
Dr. Don Duggan-Haas, The Paleontological Research Institution

Abstract

The Critical Zone (CZ) encompasses the thin outer veneer of Earth's surface extending from the top of the vegetation canopy down to subsurface depths of fresh groundwater. CZ Observatories (CZOs) are natural watershed laboratories that study Earth surface processes involving fresh water. The CZO approach is to develop a network of study sites, data, research infrastructure and people. Ultimately our goal is to introduce the term "Critical Zone" into society's lexicon. This paper describes the philosophy, history and development of education and outreach activities by the CZOs, and includes brief descriptions of various resources available for teachers for use in their classrooms. The remainder of this special issue provides more detailed descriptions of some of these activities and resources.

Critical Zone Science and Observatories

The Critical Zone (CZ) encompasses the thin outer veneer of Earth's surface extending from the top of the vegetation canopy down to subsurface depths of fresh groundwater (National Research Council, 2001). See Figure 1. A broad array of scientific disciplines and expertise is needed to understand the complex interactions between biological, chemical and physical processes in the CZ that transform rock and biomass into soil and support much of the terrestrial biosphere including humanity. The CZ has evolved in response to myriad environmental perturbations throughout Earth history, but changes have more recently accelerated due to human activities. (Banwart et al., 2013; White et al., 2015).

CZOs are natural watershed laboratories that study Earth surface processes involving fresh water (www.criticalzone.org). Interdisciplinary research at CZOs includes monitoring streams, climate/weather, atmospheric chemistry, biogeochemistry, and groundwater. CZOs are instrumented for hydrological and chemical measurements and are sampled for soil, vegetation and bedrock. In the U.S., a CZO network includes 9 observatories (Figure 2) and a national office. CZOs represent a unique opportunity to transform our understanding of coupled Earth surface processes to guide societal adaptations toward a more sustainable future (White et al., 2015).

CZ science and CZOs evolved from the recognition that many similar scientific questions were being asked by diverse groups of Earth surface and

Figure 1. The Critical Zone. Illustration modified from Chorover, J., R. Kretzschmar, F. Garcia-Pichel, and D. L. Sparks. 2007. Soil biogeochemical processes in the critical zone. Elements 3, 321-326.

Credit: Artwork by R. Kindlimann

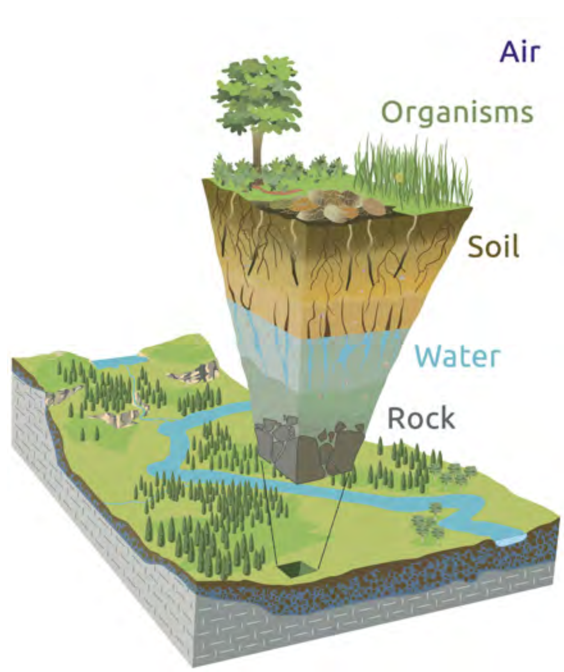

Figure 2. The U.S. CZO network consists of 6 sites developed since 2007 (2 linked as 1 CZO in NM and AZ) shown in white, with an additional 4 sites recently designated in 2014 (yellow).

environmental scientists who did not typically collaborate. A decade of interdisciplinary cooperation and collaboration led to the identification of four driving questions in CZ science:

1. How do processes that nourish ecosystems change over human and geological time scales?
2. How do biogeochemical processes govern long-term sustainability of water and soil resources?
3. What processes control fluxes of carbon, particulates, and reactive gases over different time scales?
4. How do variations in and perturbations to chemical and physical weathering impact the CZ?

These questions have since evolved and been refined and expanded but are fundamental to CZ science.

The CZO approach is to develop a network of study sites, data, research infrastructure and people. The goal of CZOs is to bring diverse interdisciplinary communities together to build cross-science alliances that help to understand broad patterns of behavior that help to answer the complex interdisciplinary questions. This goal is achieved by recognizing that the CZ is a very complex system, that it is global in extent and requires international cooperation (discussed in another paper in this special edition), and that because CZ science is deeply interdisciplinary, it requires the development and training of a new cadre of scientists. Through research and education opportunities associated with each CZO, cross-CZO endeavors, and annual meetings, the CZO community engages young scientists, teachers and the public in Critical Zone science, developing understanding of this new and evolving realm of science.

Higher Education

The development of a new scientific discipline requires focused education of young scientists engaged in the new discipline – thus by necessity, the CZO education and outreach effort has focused on the Earth surface and environmental science community and on those graduate students and postdoctoral researchers who are deeply engaged in CZ science. Outside of the numerous M.S. and Ph.D. degrees awarded to student scientists working in the CZOs, the most successful of these education activities has been the CZO International Scholars program. Through support from the U.S. National Science Foundation (NSF) International Programs-Europe from 2007-12, 54 graduate students within and outside of the CZOs from 16 universities throughout the U.S. visited more than 20 European host institutions and field sites. In the process, the student travelers broadened their scientific knowledge and perspective, availed of unique expertise and instrumentation not available in the U.S., and generated data sets to compare to information gathered from field sites and labs at or associated with the various U.S. CZOs.

A group of six CZO collaborators have developed a new undergraduate course entitled "Introduction to Critical Zone science" with support from the NSF InTeGrate program (Interdisciplinary Teaching about Earth for a Sustainable Future) (White et al, in review). The semester-long course is comprised of stand-alone, ~two-week long modules. The course is fully developed, has been tested at 5 universities and colleges, and is now in revision phase for release before the end of 2016. The course content will be available on the SERC website (http://serc.carleton.edu/integrate/index.html) for anyone to use in their courses.

Many of the CZOs have engaged in NSF-funded Research Experience for Undergraduates (REU) and Teachers (RET) programs. Of note is the collaboration between the Susquehanna-Shale Hills CZO and the Stroud Water Research Center that places 6 undergraduate students and 2 teachers at each locale during each summer since 2014. The results of the summer program of CZ science research are presented at a professional meeting including: the 2014 biennial meeting of CUAHSI entitled Water Across the Critical Zone, the 2015 Ecological Society of America meeting, and the 2016 biennial meeting of CUAHSI entitled Finding your Place in Big Data.

Primary and Secondary Education

CZ science's interdisciplinary nature and its driving questions make it well suited for addressing The Next Generation Science Standards' three-dimensional approach to science (NGSS Lead States, 2013) and for bringing cutting-edge, locally relevant and engaging science more broadly to K-12 classrooms. The CZOs participate in a variety of organizational forums to develop a focused and effective education and outreach presence. For example, CZOs were included in the NSF-sponsored national Science, Technology, Engineering and Mathematics (STEM) best practices conference at Drexel University in Philadelphia, PA in 2011, displaying large format posters, a stream table, and various on-line educational opportunities associated with the CZOs (http://criticalzone.org/national/news/story/crb-czo-featured-at-national-stem-education-event/). The CZO national coordinator traveled to Arizona State University in 2012 to the Earthscope Education and Outreach summit and presented a talk and engaged colleagues from a variety of NSF-sponsored science initiatives (http://www.earthscope.org/blog/earthscope-science-education-and-outreach-provider-summit). The CZOs also strive to educate the general public, for example through participation in the 2nd U.S. Science and Technology Exposition in Washington, D.C. in 2012.

More recently, CZO efforts have focused on training teachers. An on-line open-source course entitled 'Earth Surface Processes in the Critical Zone' is formally offered through The Pennsylvania State University's Masters of Education in Earth Sciences program and aims to educate middle and high school teachers interested in incorporating Critical Zone science into their classroom curriculum (https://www.e-education.psu.edu/earth530/). The course is further described elsewhere in this special issue. The CZO national coordinator has offered a short course entitled "Introduction to Critical Zone Science and Observatories" at the annual meetings of the Geological Society of America, and a CZO Science Teaching Workshop (http://virtualfieldwork.org/CZO_Workshops.html) organized by the CZO National Office has developed to provide K-12 teachers an introduction to CZ science through the creation and use of Virtual Fieldwork Experiences (VFEs).

CZO researchers also cooperate with the American Geosciences Institute's Earth Science Week in 2013 through 2016 providing "hands on" learning exercises that are sent to more than 16,000 teachers nationwide and are ready to be used in a classroom. The AGI hands-on learning exercises include: a LiDAR exercise for high school classrooms (http://criticalzone.org/images/national/associated-files/1National/AGI_handout_Final.pdf), a water resources management simulation (http://criticalzone.org/images/national/associated-files/1National/SSCZO_WaterSim.pdf), exercises on paleoclimate influence on landscape evolution (http://criticalzone.org/images/national/associated-files/1National/ESWcalender2014.pdf) and the Influence of Dry Deserts on Tropical Rain Forests (http://criticalzone.org/images/national/associated-files/1National/AGI_Handout_Dust_Inputs_LCZO.pdf). Related to these AGI handouts are similarly formatted learning exercises developed by two teachers in the CZO RET program: one on Ground Penetrating Radar - Monitoring Soil Moisture, and another on Carbon Storage Measurements in Forests (both available at http://criticalzone.org/national/education-outreach/k-12-education-1national/).

The teachers presented the results of their summer experience at the Pennsylvania State Teachers Association meeting in 2014.

Conclusions

The Critical Zone science and Observatories community continues to develop and improve on earlier and ongoing education and outreach activities. Other opportunities and resources are described through the remainder of this special issue.

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About the Authors

Tim White, coordinator of the CZO National Office, is a classically trained field sedimentary geologist with expertise in stratigraphy, paleoclimatology, paleopedology, chemostratigraphy, organic petrology, and hydrogeology. He teaches the aforementioned course offered through Penn State's M.Ed. in Earth Sciences program, and his responsibilities with the CZO National Office are broad, more recently focusing on education and outreach, and the development of an international CZ science research agenda.

Don Duggan-Haas is Director of Teacher Programs at the Paleontological Research Institution in Ithaca, NY. He is an Earth science educator and is co-coordinator of Education and Outreach for the Critical Zone Observatory Network. Don's especially interested in technology-rich, place-based and inquiry-oriented approaches to teaching and learning that aim to build deep understandings of Earth system science and especially the big ideas that define the discipline. These approaches engage learners in the close study of their local environment and use locally grounded understandings to better understand the global Earth system. With work addressing teaching and learning about hydrofracking, climate change and evolution, he also has expertise in the teaching of controversial issues.

This work was funded by the National Science Foundation Science Across Virtual Institutes (SAVI) Program (EAR 1445246).

International Cooperation in Critical Zone (CZ) Science and Education

Dr. Manoj Menon, University of Sheffield, U.K.
Dr. Tim White, The Pennsylvania State University

Abstract

Soil Transformations in European Catchments (SoilTrEC) project was an international Critical Zone (CZ) project funded by the European Commission (EC) that facilitated collaboration through training programs and other activities (http://www.soiltrec.eu/). This article provides a brief description of SoilTrEC and highlights publicly available resources for teachers developing CZ science curriculum materials.

Critical Zone Science and Observatories: An International Enterprise

From the start, international scientists who aligned to develop and organize the new science of the Critical Zone recognized that international cooperation was a necessary component for success. Critical Zone Observatories (CZOs) bring diverse interdisciplinary communities together to build cross-science alliances to answer complex interdisciplinary questions. Early in the development of Critical Zone science, researchers, educators and science managers recognized the need for 1) international cooperation in the International development of the science; 2) dissemination of societally relevant aspects of the science; and, 3) training of a new cadre of truly interdisciplinary scientists. These goals were approached by building an international collaboration of scientists to engage in science planning meetings beginning in 2003. That cooperation led in 2007 to a special issue of the journal, Elements, entitled "The Critical Zone, Where Rock Meets Life".

Recognizing the importance of international cooperation, the Unites States (U.S.) National Science Foundation (NSF) funded in 2007-2013 a Critical Zone International Scholars program that provided travel and research funds for U.S. based graduate students and postdoctoral researchers to work in international laboratories and field sites focused on CZ science. At about the same time, European Commission funds were obligated to support U.S. scientist participation in the EC's SoilCritZone project from 2007-2009. Shortly after, the SoilTrEC project (see below) was funded. Subsequently, NSF funding of the CZO Science Across Virtual Institutes (SAVI) project, focused on developing international collaborations, provided funds that continued the International Scholars program through 2019.

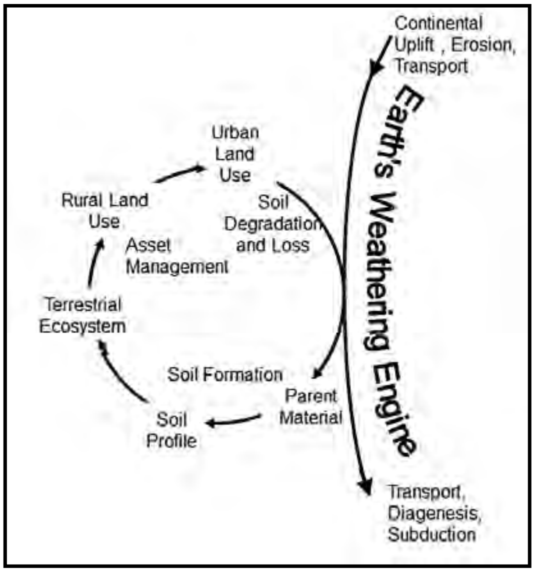

Figure 1. Earth's Weathering Engine exposes bedrock. A portion of this material is colonized by organisms and forms soil. This provides key ecosystem services of economic and social value. Unsustainable soil use leads to depletion of nutrients and mass loss of soil, degraded soil function, and potentially complete physical loss of soil. Damma Glacier, Lysina, Fuchsenbigi, and Koiliaris are CZO site names.

The focus of these projects has by necessity been on graduate students and postdoctoral researchers who perform much of the science. Nonetheless, education and outreach to the greater research community is important to the development of CZ science. Thus, each project includes research and information dissemination to the public. Next, we briefly describe the SoilTrEC project and the publicly available resources for teachers developing CZ science curriculum materials.

What is SoilTrEC?

The Soil Transformations in European Catchments project (SoilTrEC; www.soiltrec.eu) was an international Critical Zone (CZ) project (2009-14) funded by the European Commission in response to the European Union (EU) Thematic Strategy for Soil Protection. The overarching research hypothesis of the project was that soil formation and degradation can be described by a Life Cycle of Soil Function that arises from progressively intensive human use of soil (Figure 1; Banwart et al., 2011). Within this life cycle, soil processes develop and act in combination to provide important soil functions that can be broadly grouped into ecological and non-ecological functions, the former relating to food and fibre production, storage and transmission of water, carbon and nutrients, and biological habitat and gene pool, whereas the latter includes an archive for physical and cultural heritage, a platform for human activities and a source of raw materials (Menon et al. 2014).

The objectives of the SoilTrEC project were to:

1. Describe how soil structure impacts processes and function at a small scale;
2. Establish four CZ Observatories to study soil processes;
3. Develop a CZ Integrated Model of soil processes and functions;
4. Create a GIS-based, modeling framework to delineate soil threats and to assess mitigation in Europe;
5. Quantify impacts of changing land use, climate, and biodiversity on soil function and economic value;
6. Form a global network of CZ Observatories for soil research; and,
7. Deliver a program of public outreach and research transfer on soil sustainability.

The project included field data collection from CZOs, laboratory experiments and integrated modeling using the CZO data. The primary CZOs were: Damma Glacier (Switzerland), Fuchsenbighl (Austria), Lysina-Slavkov Forest (Czech Republic) and Koiliaris (Crete, Greece).

The integrated CZ model developed by the project incorporated soil processes ranging from soil structure formation and carbon sequestration, transport of water and nutrients, biotic interactions including plant growth and biomass production (Menon et al. 2014; Banwart et al. 2011; Banwart et al. 2012).

International Outreach Activities of SoilTrEC

The focus of the SoilTrEC project was research and dissemination of those results to policy and decision makers. The initial focus of education and outreach was on graduate students and post-doctoral researchers tied to the project and working to advance the project goals. Following this, education and outreach activities were aimed at a broader audience, including formal and informal educators and the public at large.

International Training Program in CZ science

The broader objectives of SoilTrEC included delivery of an international training program to promote CZ science, and collaboration beyond the project partners. The training program was planned to deepen discipline-specific knowledge and skills as well as to promote understanding of physical and social science links in sustaining the CZ functions. Each training event promoted field, laboratory, analytical and numerical skills in CZ science. A typical event would have classroom activities (presentations, lectures, and modeling exercises), laboratory visits and demonstrations, and hands-on training and field visits.

No	Event name	Date	Venue	Number of participants
1	Critical Zone Biogeochemistry; and International student symposium	1-2 Jun, 2011	Boulder	35
2	International Workshop on Design of Global Environmental Gradient Experiments using International CZO Networks	8-9 Nov, 2011	Delaware	80
3	Social and Economic Frameworks for Natural Resource	16-18 January 2012	Ispra	25
4	Workshop on reactive transport modelling	16-19 Jul, 2012	Crete	41
5	The 2nd Int. Geobiology Conference: critical zone observatories for sustainable soil development and beyond	5-8 September 2012	Wuhan	79
6	Soil aggregation and organic carbon – Sampling, analysis and modelling	10-12 Apr 2013	Vienna	11
7	Land-use practice and sustainable use of soil	30 May-2 Jun, 2013	Sólheimar	27
8	Training Event: Hydrology and Soil Functions	2 – 4 Jul 2013	Zurich	15
9	Training Event: Terrestrial Ecology	18-20 Sept 2013	Prague	11
10	Europe and international policy to address global soil threats (workshop)	3 Oct 2014	Ispra	25

Table 1. A list of training events organized by SoilTrEC project.

On average, two training events were organized each year. Events were organized across different partner institutes or CZOs. Sometimes the events were organized with a conference if it was suitable for the participants and instructors. The list of training activities is shown in Table 1 (for more detailed information: http://www.soiltrec.eu/events/events.html). The project attracted international participants by providing some financial support. The U.S. National Science Foundation provided support for graduate students and postdoctoral researchers at U.S. universities to participate. The materials from the events were made available on the SoilTrEC website.

Figure 2. The Reactive Transport Modeling workshop in Crete showing a hands-on computer session on modeling (top) and a field trip to Koiliaris CZO (bottom).

Other education and outreach activities and resources of SoilTrEC CZOs

Managing Scientific Publications and Open Access

Peer-reviewed scientific publications, and outputs are currently maintained through a Google Scholar link (https://scholar.google.co.uk/citations?user=Ism9760AAAAJ), which updates the publications produced in the project and their citations. With a few exceptions, all articles from SoilTrEC are made available through open-access (requirement for the EC projects) through institutional libraries, academic websites, and local repositories.

Project Highlight Articles and Conferences

The project was also described through highlight articles in journals: Nature (Banwart 2011), Vadose Zone Journal (Banwart et al. 2011), CR Geosciences (Banwart et al. 2012) and Environmental Science and Pollution Research (Menon et al. 2014). For the benefit of international policy makers and stakeholders, an article titled The state of our soils was published in International Innovation.

Website and Resources

The project maintains a website (http://www.soiltrec.eu/) which was regularly updated and used as the primary dissemination portal for the project. The website lists CZ science specific dissemination activities from the project partners.

The website contains comprehensive information about the project and useful resources for anyone interested to know the importance of soils and CZ science. These resources include videos, materials for school children, such as an e-book, fact sheets and other reports and book chapters.

Videos

On the project home page (http://www.soiltrec.eu/), a video prepared at the inception of the project narrates the importance of the Critical Zone. Other videos are collated at the website including International Year of Soils 2015 (Food and Agriculture Organization of the United Nations), Pitch for Nature (World Business Council for Sustainable Development), Let's Talk About Soil (Institute for Advanced Sustainability Studies), The importance of soil (Chicago Botanical Garden), Don't Call it Dirt- A Passion for Soil (Iowa Learning Farm), Soil Security (British Society of Soils), to name a few. The videos can be found at http://www.soiltrec.eu/publications/publicdissemination.html

E-book and Poems for Children

For the pre-university audience, an E-book on soils (Soil: The Life Supporting Skin of Earth) was prepared and edited by Professors Vala Ragnarsdottir and Steve Banwart. The E-book can be downloaded at (http://www.soiltrec.eu/files/PDFs%20uploaded%20by%20the%20cPanel%20support%20team%2024032015/SoilSchoolBook_FinalSubmitted.pdf). The book contains chapters such as soils in the CZ, what soil does, soil threats, global soil supply chain networks and the value of soil ecosystem services. Soil Poems, prepared by U.S. Department of Agriculture's Natural Resources and Conservation Services can also be found on the project website (http://www.soiltrec.eu/publications/publicdissemination.html).

Factsheets

Another important dissemination material is factsheets. The project team prepared 13 factsheets (see: http://www.soiltrec.eu/publications/factsheets.html) on a range of topics evolved from the project. The project also compiled a list of all known (62) CZOs across the world, which can be found at http://www.soiltrec.eu/CZOPages/wfieldSites.html.

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About the Authors

Tim White is the Coordinator of the CZO National Office, which promotes communication among CZO PIs, organizes national meetings, offers graduate/young scientist workshops, and develops electronic delivery of educational resources for Critical Zone science. White's research is predominantly field-based, using the disciplines of sedimentary geology, paleoclimatology, paleopedology, chemostratigraphy, organic petrology, and hydrogeology.

Manoj Menon is a lecturer/assistant professor from the Department of Geography, University of Sheffield, U.K. He worked as an assistant scientific coordinator for the SoilTrEC international project and led the international training program for the project. His research interests are soil hydrology and physics, soil-biotic interactions and modelling soil processes. Web: http://drmenon.staff.shef.ac.uk/index.html

Critical Zone Science, Interdisciplinarity and the NGSS

Dr. Don Duggan-Haas,
The Paleontological Research Institution

Abstract

Scientific study of the Critical Zone (CZ) provides rich opportunities for engaging in teaching and learning aligned with the three dimensional and highly interdisciplinary Next Generation Science Standards (NGSS). Using and creating Virtual Fieldwork Experiences facilitates the inclusion of Critical Zone science into the curriculum in a way that both engages students with in-depth study and maintains the breadth of the curriculum. Critical Zone science also involves the cutting-edge application of engineering, technology, and the applications of science. Since the Critical Zone covers the entirety of Earth's land, it is locally relevant everywhere. As every unit in Earth and environmental science courses is reflected within the Critical Zone, studying the local environment and comparing it to the environments at Critical Zone Observatories can be interwoven throughout the curriculum of one or several courses.

The Next Generation Science Standards (NGSS, NGSS Lead States, 2013) and A Framework for K-12 Science Education (National Research Council, 2012) describe sweeping changes to current common practice in schools and classrooms across the country that are very different from previous reform efforts. This article is intended to help those just starting to think about NGSS implementation as well as those who are already deeply engaged in implementation. It does not offer a nuts and bolts approach, but looks at more conceptual connections between NGSS and CZ Science.

The interdisciplinary and technology-rich nature of Critical Zone (CZ) science offers special promise for satisfying NGSS's expectations. The NGSS clarifies the meaning of inquiry and describes science as a set of relationships between three dimensions: Disciplinary Core Ideas (DCIs), Science and Engineering Practices (SEPs) and Crosscutting Concepts (CCs). See Table 1. Each of the three dimensions is judged to be of roughly equal importance and they are seen as interdependent. To truly, deeply, understand science and how scientific understandings develop, learners must not only understand each dimension, but they must also understand the relationships and connections between them. By understanding these interconnections, teachers and students will also come to better understand the nature of scientific inquiry and complex systems.

Acronyms frequently used in The Next Generation Science Standards (NGSS):

PE: Performance Expectation
DCI: Disciplinary Core Idea
CC: Crosscutting Concept
SEP: Science and Engineering Practice
PS: Physical Sciences
LS: Life Sciences
ESS: Earth & Space Sciences
ETS: Engineering, Technology, and the Applications of Science

Scientific and Engineering Practices	Crosscutting Concepts
1. Asking Questions and Defining Problems	1. Patterns
2. Developing and Using Models	2. Cause and Effect
3. Planning and Carrying Out Investigations	3. Scale, Proportion, and Quantity
4. Analyzing and Interpreting Data	4. Systems and System Models
5. Using Mathematics and Computational Thinking	5. Energy and Matter
6. Constructing Explanations and Designing Solutions	6. Structure and Function
7. Engaging in Argument from Evidence	7. Stability and Change
8. Obtaining, Evaluating, and Communicating Information	8. Interdependence of Science, Engineering, and Technology
	9. Influence of Engineering, Technology, and Science on Society and the Natural World

Disciplinary Core Ideas			
Physical Sciences	*Life Sciences*	*Earth and Space Sciences*	*Engineering, Technology, and the Applications of Science*
PS 1: Matter and its interactions **PS 2:** Motion and stability: Forces and interactions **PS 3:** Energy **PS 4:** Waves and their applications in technologies for information transfer	**LS 1:** From molecules to organisms: Structures and processes **LS 2:** Ecosystems: Interactions, energy, and dynamics **LS 3:** Heredity: Inheritance and variation of traits **LS 4:** Biological evolution: Unity and diversity	**ESS 1:** Earth's place in the universe **ESS 2:** Earth's systems **ESS 3:** Earth and human activity	**ETS 1:** Engineering design **ETS 2:** Links among engineering, technology, science, and society

Table 1. Summary of NGSS's Three Dimensions. For more detailed descriptions, see the relevant appendices in The Next Generation Science Standards at http://nextgenscience.org/.

Teaching Critical Zone science holds promise for meeting this new vision for science teaching and learning. The Critical Zone – from the tops of the vegetation to the bottom of the water table, where most life resides – provides the services which makes an ecosystem function and upon which life ultimately depends. The study of the CZ is also rich with engineering, technology, and the application of science (see Figure 1). Consider what takes place within the CZ and the ways in which scientists study it as you read through Table 1.

The way scientists engage in studying Critical Zone structures and processes, and the services provided by the CZ can be productively thought of as models for investigations anywhere. Findings from the CZ Observatories (which are set in intentionally different environmental settings; see the map on page 8), can also provide points of comparison for better understanding of the CZ where you and your students live.

Figure 1. A CZ tree at the Southern Sierra Critical Zone Observatory. This is one of the most heavily instrumented trees in the world. PVC pipes in the ground allow access to equipment monitoring soil chemistry and temperature within the root system. Instruments embedded in the tree itself measure the flow of different fluids and monitor temperatures. The image is a screen-capture of a 360° interactive panorama captured using the Google Street View app. The panorama can be found at: https://goo.gl/maps/mHchVLBreVz.

The many processes that shape the Critical Zone are already addressed in existing curricula, albeit independently. For Earth science, biology, and environmental science courses, nearly every unit has its central processes at work outside the school door, but the connections among these units are often not strongly made. Viewing them through the lenses of CZ Science and NGSS's three dimensions has several advantages. It provides an opportunity for an in-depth study of the CZ in the context of the local environment while simultaneously addressing the breadth of the curriculum. In-depth study of one or two science topics in high school science is associated with greater success in college science (Schwartz, Sadler, Sonnert, & Tai, 2008). A coordinated approach to the study of the Critical Zone across units within a single course and across grade levels within multiple courses can lead to a greater depth of student understanding. This deeper understanding pertains not only to the local CZ and the way course topics are represented within it, but also to systems more generally and to the nature and importance of scale, and much more.

Tackling NGSS's Complexity

The NGSS, and its associated resources, A Framework for K-12 Science Education (National Research Council, 2012) layout expectations for the entirety of K-12 science education and how it connects to other disciplines. These documents can be intimidating in scope and complexity. An obvious starting point for working with NGSS is the standards themselves, each a page or two in length, with "Performance Expectations" (PEs) at the top of the first page, followed by "Foundation Boxes" and "Connection Boxes" supporting the PEs. While it is tempting to jump into the discussion of NGSS by starting with PEs or DCIs, looking at the standards in this way facilitates seeing the new standards in old and problematic ways. Appendix K of NGSS notes, "The goal is not to teach the PEs, but rather to prepare students to be able to perform them by the end of the grade band, course sequence" (NGSS Lead States, 2013). It is valuable to understand the three-dimensional and interdisciplinary nature of NGSS and to think about the design of instruction holistically, avoiding a piecemeal or checklist approach.[1] The interpretation of the CZ and its place in the landscape provides just such opportunity, and it does so in ways that are manageable within existing course structures. While CZ science could be a separate instructional unit, it offers more promise as a theme that cuts across the curriculum of several courses.

CZO outreach efforts include Virtual Fieldwork Experiences (VFEs) that are multimedia representations of actual field sites. The Southern Sierra VFE is now online. The Southern Sierra Critical Zone Observatory (SSCZO) is investigating how mountain soils and weathered bedrock develop over geologic time, and how they interact with shorter-term climate variability

[1] Work is now underway to produce "Example NGSS Bundles" that draw together PEs from for organization over the course of the school year and across grade levels. Once complete, these will be shared on the NGSS website's Teacher Resources Page: http://nextgenscience.org/teachers.

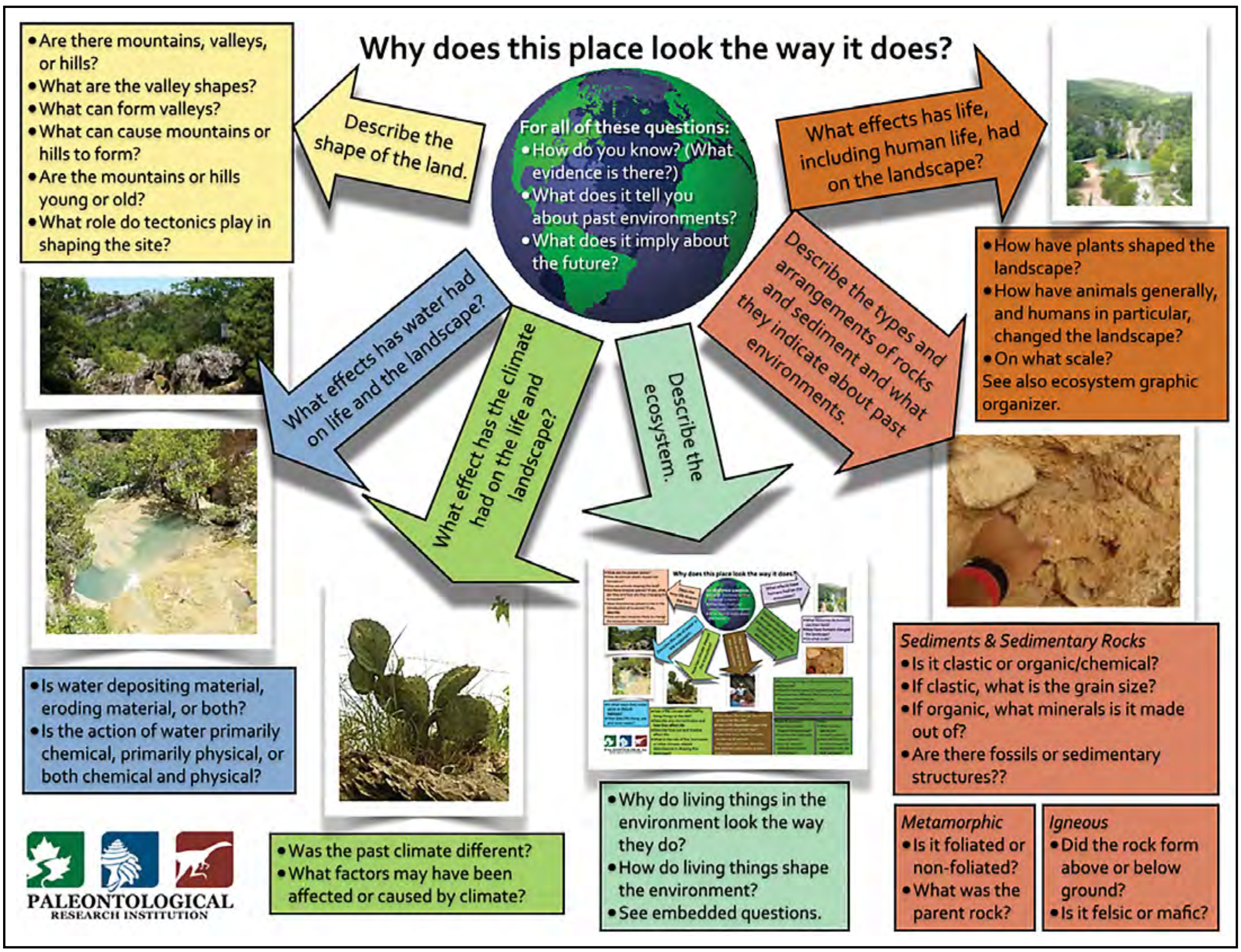

Figure 2. The Virtual Fieldwork Experience Graphic Organizer. The questions can be asked of any site. This work grows out of the earlier NSF-funded ReaL Earth Inquiry Project (NSF DRL733303). Arrow level questions roughly correspond to typical course units. Virtual and actual fieldwork is relevant across the entire curriculum. For more about making and using VFEs, see the fieldwork chapter and the appendix of The Teacher Friendly Guide to the Earth Science of United States at: http://geology.teacherfriendlyguide.org/.

and ecosystem behavior. The Shale Hills/Susquehanna is in development. See: http://virtualfieldwork.org/A_VFE_Database.html. These VFEs share a common set of questions that can be asked of any field site. See the graphic organizer in Figure 2. To build rich explanations of the range of processes at play in a field site requires application of all three dimensions of NGSS, and these VFEs are intended to serve as models for classes to create VFEs of sites within their communities. The "arrow-level" questions roughly align with course units making VFE use and development something that can be revisited throughout the entire course, gradually deepening interdisciplinary understandings of place.

Conclusion

Teaching Critical Zone science addresses the three-dimensional and interdisciplinary approach of the Next Generation Science Standards. By focusing on Critical Zone science in the local environment, coordinated study across a range of topics within a single course or across years of instruction within multiple courses is possible and provides the opportunity for teachers and students to study a topic in depth while also addressing appropriate breadth.

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About the Author

Don Duggan-Haas is Director of Teacher Programs at the Paleontological Research Institution in Ithaca, NY. He is an Earth science educator and is co-coordinator of Education and Outreach for the Critical Zone Observatory Network. Don's especially interested in technology-rich, place-based and inquiry-oriented approaches to teaching and learning that aim to build deep understandings of Earth system science and especially the big ideas that define the discipline. These approaches engage learners in the close study of their local environment and use locally grounded understandings to better understand the global Earth system. With work addressing teaching and learning about hydrofracking, climate change and evolution, he also has expertise in the teaching of controversial issues.

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Drought in the Critical Zone: Engaging Students in Authentic Inquiry Through Data Jam

Steven McGee, The Learning Partnership
Noelia Báez Rodríguez, Luquillo LTER Schoolyard

Abstract

In teaching with socio-scientific issues, it can be challenging to find Critical Zone phenomena with which students have personal experience. A severe drought in Puerto Rico provided one such rich context for high school students to investigate their own questions about weather and climate. Teachers were trained on a teaching strategy called Data Jam. During the subsequent Data Jam, students asked their own research question, used long-term hydrological data from the Luquillo Critical Zone Observatory to investigate the question, and developed a creative display of their results. Students presented their results to scientists at the University of Puerto Rico.

Introduction

The Next Generation Science Standards (NGSS) and the Common Core State Standards (CCSS) in math require significant shifts in how science is taught in schools. A core teaching strategy of the new standards is engaging students in authentic scientific investigations. Students should be asking their own questions and analyzing data to address that question. However, teachers find it challenging to support students in using data as evidence, since it is a statistical process that is largely ignored in schools (Makar & Rubin, 2014). In addition, it can be challenging to find approachable datasets for a wide range of Earth science topics.

In this article, we describe a pilot effort by the Luquillo Critical Zone Observatory (LCZO) to address these challenges by integrating LCZO datasets and a successful teaching strategy called a Data Jam, which was developed at the Asombro Institute for Science Education (Bestelmeyer et al., 2015). The essence of the Data Jam model is to support students in the process of exploring, analyzing, and summarizing long-term data about the environment and then creatively communicating what they discover to non-scientific audiences. To support implementation of Data Jam, we conducted a teacher workshop in fall 2015. Teachers then implemented the Data Jam with their students in the second semester and selected one Data Jam project to submit to the LCZO. Those students were invited to present their findings at the eighth annual Long-Term Ecological Research Schoolyard Symposium at the University of Puerto Rico in May 2016.

[1] **Critical Zone Resources**

Web Links:
http://criticalzone.org/luquillo/education-outreach/k-12-education-luquillo/

Data Jam Preparation

From February to August 2015, Puerto Rico experienced one of the severest droughts on record. Students and their families were subjected to water rationing throughout the summer as the island coped with reduced reservoir levels and low flows in the rivers that feed the island's water supply. Given students' lived experience with the drought, it became a natural theme for the Data Jam. We anticipated that students would have many questions about the drought and that long-term hydrology data from LCZO would provide students with a means to investigate their questions. While all LCZO datasets are available to the general public, we felt it was important to simplify the process of identifying and organizing relevant datasets. Therefore, we worked with the LCZO data manager, Miguel Leon, to combine LCZO data with data from the Luquillo Long-Term Ecological Research program and the U.S. Geologic Survey into one spreadsheet[1]. The dataset included daily data about rainfall, stream flow, and reservoir height for 2015 and 1994 — which was another severe drought year. We also provided the climatic average for all of the variables. For the 2015 dataset only, we included soil moisture data collected by LCZO.

Data Jam Workshop

In November 2015, twenty-two science teachers from Puerto Rican private and public schools participated in a six-hour data jam workshop co-hosted with facilitators at Forward Learning — an educational technology professional development provider in Puerto Rico. The workshop design incorporated the following best practices as suggested by Desimone and Garet (2015). We focused on important scientific content, built coherence through alignment to NGSS, and involved teachers as active participants. The workshop began with a general orientation to Microsoft Excel, including using formulas to summarize data and create graphs. Next, teachers were shown an example of a completed Data Jam project that we developed. The example asked the question of how the drought might affect the shrimp population. The graphs showed a comparison of cumulative rainfall for 1994 relative to average rainfall as well as daily stream flow for 1994 relative to average stream flow. While both rainfall and stream flow were significantly below average, the stream maintained a level of base flow that would stress the shrimp, but would allow them to survive the drought. The teachers were then given time to develop their own questions, explore the data, and develop graphs to address their questions. In the last phase of the workshop, teachers were provided with an orientation to Microsoft PowerPoint, including formatting slides and importing graphs. After the orientation, teachers developed a presentation of their results and then presented their Data Jams to each other (Figure 1). Finally, the workshop ended with a group discussion about strategies for implementing the Data Jam in the classroom.

Figure 1. Teachers presenting their Data Jam project to other teachers at the workshop.

Data Jam Results

Five teachers went on to implement the Data Jam with their students and submit projects for the symposium in May 2016. At the symposium, students presented their Data Jam project for other school participants as well as faculty and students from the University of Puerto Rico (Figure 2). Sample Data Jam topics include: how drought contributes to the propagation of the

Aedes aegypti mosquito (Zika virus carrier), a comparative study of drought effects on stream flow during 1994 and 2015, the relationship between daily rainfall and reservoir height during the 1994 and 2015 rainy and drought seasons, and a comparative study between the cumulative rainfall at El Verde during 1994 and 2015. Along with the graphical representation of their results, students were also encouraged to develop creative approaches to communicating their results. Example creative products included a décima (musical poetry) about El Yunque, a global warming rap, a low stream flow physical model, a TV news hour skit about rainfall data at El Verde, and an informative oral presentation relating the drought data with the Zika, Dengue and Chikungunya viruses.

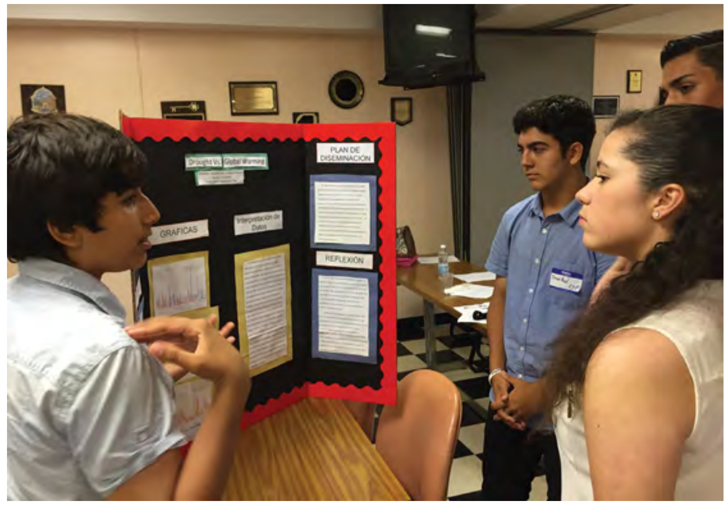

Figure 2. Students presenting their Data Jam project at the eighth annual Long-Term Ecological Research Schoolyard Symposium

Conclusion

The results of our pilot Data Jam program showed that with a relevant research topic, rich critical zone datasets, and high quality professional development, teachers can successfully engage students in authentic inquiry around important critical zone research areas. However, there is room for improvement. As suggested by Desimone and Garet (2015), we hope to extend the duration of the professional development by incorporating additional teacher follow up through periodic webinars. In addition, teachers need more support in how to help students use the spreadsheets to summarize and analyze the data as evidence for their questions. With these continued improvements, the LCZO Data Jam model provides a robust approach for addressing the NGSS with Critical Zone science.

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About the Authors

Steven McGee is president of The Learning Partnership and research associate professor of learning sciences at Northwestern University. He was previously the director of the NASA Classroom of the Future program at Wheeling Jesuit University. His current research interests include (1) engaging students in authentic science experiences that promote both learning and interest and (2) the development of school capacity to support and sustain authentic science in the classroom.

Noelia Báez Rodríguez is the coordinator for the Luquillo LTER Schoolyard program. She was previously a staff scientist for the Johnson Company, an environmental consulting company in Montpelier, VT. Her current work interests include (1) promoting the development of scientific knowledge and analysis skills through computational and outdoor activities in forest ecology, and (2) developing hands-on educational workshops where teachers and students can learn about ecological principles and processes.

This work was funded by the National Science Foundation Award (EAR 1331841).

Earth Surface Processes in the Critical Zone: An Introductory Course Designed for Teachers

Dr. Tim White, The Pennsylvania State University

Abstract

This manuscript describes an open access, online course entitled Earth Surface Processes in the Critical Zone (Earth 530) (https://www.e-education.psu.edu/earth530/). The course was designed to introduce Critical Zone (CZ) science to teachers seeking a graduate degree, but is more broadly usable by anyone with a basic understanding of Earth surface and environmental science. The course is designed for a 12 to 15-week semester and is modular; each unit and lesson stand alone as a cohesive learning exercise. Basic lesson activities and outcomes are described and course relevance to Next Generation Science Standards are briefly considered.

Introduction

Consider a single entity capable of nurturing life, supporting agriculture, cleansing water, and buffering atmospheric gas levels, to name a few processes, and you will have considered the Critical Zone (for more detail see White and Duggan-Haas in this special issue). It is this zone, critical to the maintenance of healthy life on Earth, that is covered in Earth 530, Earth Surface Processes in the Critical Zone, an elective course in The Pennsylvania State University's online Masters of Education in Earth Sciences program.

The course introduces graduate students, mostly teachers, to basic information necessary for understanding Earth surface processes in the CZ, through integration of various scientific disciplines including study of weathering and soils, geomorphology, erosion and sedimentation, hydrogeology, low-temperature geochemistry, and Earth systems. The impetus for developing this CZ course evolved from the national-scale CZ Observatory enterprise described earlier in this special issue (White and Duggan-Haas).

The course is organized into seven units. The structure was chosen to include a focus on the four driving questions of CZ science described earlier in this issue (White and Duggan-Haas). The science lesson in the first unit introduces the basic concept of the CZ. Units 2 through 6 cover issues related to soil, the atmosphere, climate, water, landforms, and ecosystems, respectively, as they relate to CZ studies. Unit 7, integrates the lessons learned in the earlier units into an Earth systems framework, and considers the impacts of human society on the CZ.

Lessons

In Lesson 1 (Unit 1), CZ processes are presented as coupled physical, biological, and chemical processes that involve study by experts in geology, soil science, biology, ecology, geochemistry, geomorphology, and hydrology, to name a few of the relevant sciences. The lesson includes reading assignments, hands-on exercises and activities, and identification of a semester project topic. By the end of this lesson students are expected to be able to: define the CZ and its importance to humanity, list some anthropogenic impacts on the zone, and explain the basic driving questions of CZ science.

While the many various disciplines are equally important for understanding the CZ, they are linked by the presence of soil, the focus in Lesson 2 (Unit 2). Soil and the CZ are presented as existing within the overlapping region between four "spheres": lithosphere, biosphere, hydrosphere, atmosphere. Through short essay responses to questions and a report based on a mapping activity using the Natural Resources Conservation Service's WebSoilSurvey (WSS), by the end of the lesson students are expected to be aware of the importance of soil and its societal relevance, understand how soils form, discuss how soils are described, classified, and geographically distributed, and recognize the major threats to soil.

To properly understand the varying effects of climate on the CZ, basic knowledge of Earth's atmosphere and the range of phenomena that occurs within it are presented in Unit 3; Lessons 3, 4, and 5. Lesson 3 describes the basic structure and chemistry of the atmosphere, the carbon cycle, atmospheric carbon dioxide and greenhouse gases, radiative forcing, and physical climate processes and feedbacks. An exercise in comparing various carbon footprint calculators is used to help students consider their role in humanity's perturbation of atmospheric carbon dioxide content. In Lesson 4, topics covered include: the evolution of Earth's atmosphere and ocean system through geologic time, specifically focused on paleoclimatology (ancient climates), and the relevance to society's considerations of the not-too-distant future. In Lessons 4 and 5, paleoclimatology and present-day regional climate issues, are explored, culminating in an examination of how knowledge of past, present, and future climate processes are linked to soil formation and the CZ, a topic returned to in the final lesson (12) of the course. Lesson 5 includes a discussion about regional climate issues and how predicted climate changes may differently effect the CZ in various regions of the U.S.

Water covers ~70% of Earth, mostly in the oceans. The global ocean is more than peripheral to the Critical Zone. Ultimately, all of the water that bathes the CZ is derived from the ocean. Unit 4 covers water's role in the CZ. The water cycle is described in Lesson 6, first through a revisit of some aspects of atmospheric processes, demonstrating the intimate link between the various "spheres" that overlap in the CZ. The water cycle involves much more than the transfer of water from the ocean to the land surface - once precipitated. Water can flow across the land surface, infiltrate into the subsurface as soil pore water or groundwater, or be evaporated or transpired by plants back to the atmosphere. Thus Lesson 6 also considers the many processes involved in the flow of water through the CZ. By the end of the lesson students are able to: describe the water cycle, obtain and interpret online surface water data using the U.S. Geological Survey's StreamStats program, and discuss the basic chemistry of some natural water and human influences on the availability and quality of water. Finally, in Unit 4, Lesson 7, various aspects of groundwater flow are covered, with consideration of the many links between water, the water cycle, and CZ science. Students read about and consider soil moisture in the unsaturated zone, and then progress to read about and study groundwater. They access, use, and interpret online groundwater data from the U.S. Geological Survey's Ground-water Data for the Nation program.

Figure 1. Soil profile showing soil horizons from the Cambrian Gatesburg Formation, near State College, PA.

Figure 2. Top carnivore, Alaska Peninsula—How would the presence or absence of the brown bear affect CZ (Critical Zone) processes?

Geology and landforms are the focus of Unit 5, and include topical coverage of other state factors of soil formation: parent material, topography, and time. In Lesson 8, basic concepts of geology are reviewed to remind the student that rocks and sediments have widely ranging textures and compositions formed in a wide range of environments. These variations in turn can affect soil formation and CZ processes. The landforms and topography of a region control a variety of CZ processes with plate tectonic setting being a first-order control in determining the topography of a site and thus in determining whether soils develop and accumulate or are subject to erosion. Students use the U.S. Geological Survey's National Geological Maps Data Base as part of this lesson.

In Lesson 9, geomorphic environments and the processes that can move and shape them are described to understand links between landforms, soils, and the CZ. Students consider the CZ as a weathering engine along with the concept of a soil catena and the influence of slope and aspect on soil formation. They learn to differentiate between fluvial, eolian, periglacial and karst environments and to describe and identify some features and processes characteristic of these generalized geomorphic environments. The students learn to access online remotely sensed imagery, specifically aerial photographs, to interpret landscapes and potential surface processes associated with their observations.

Figure 3. Tropical deforestation disrupts global Critical Zone processes.

In Lesson 10 (Unit 6), the various means by which biologists and other natural scientists classify life is considered. Basic concepts of ecology and biodiversity are introduced, examining some of the interactions and processes between organisms and their environment (ecology)— gradually focusing on the CZ and soil processes that involve biota. Lesson 10 culminates in a discussion of the merits of placing financial value on ecosystem processes. In Lesson 11 (Unit 6), students more closely examine various expansive ecosystems, or biomes, and consider their character and relationship to climate and the rest of the CZ. Access to land cover maps available through the U.S. Geological Survey is utilized to determine the natural character and human land use of a chosen site.

The final Unit 7 and Lesson 12 considers the term Earth system science, primarily used to describe the science of interactions between the atmosphere, hydrosphere, cryosphere, and biosphere. The point is made that the addition of lithosphere to that list provides all the components ("spheres") of the CZ. Students consider systems and system modeling and create a qualitative CZ system model of a chosen field site. The lesson and course culminates with consideration of the various environmental consequences of human-induced land-use and climate change, as well as adaptive actions humanity can take to lessen those impacts on the CZ.

Next Generation Science Standards

Earth 530 is directly responsive to Next Generation Science Standards. The course reviews Disciplinary Core Ideas from the domains of physical, life and Earth science. A strength of CZ science in general and this course lies is the application of multiple Crosscutting Concepts. The course uses Science and Engineering Practices through hands-on learning exercises involving student interpretation of online accessible data, and includes system design in the final lesson of the course.

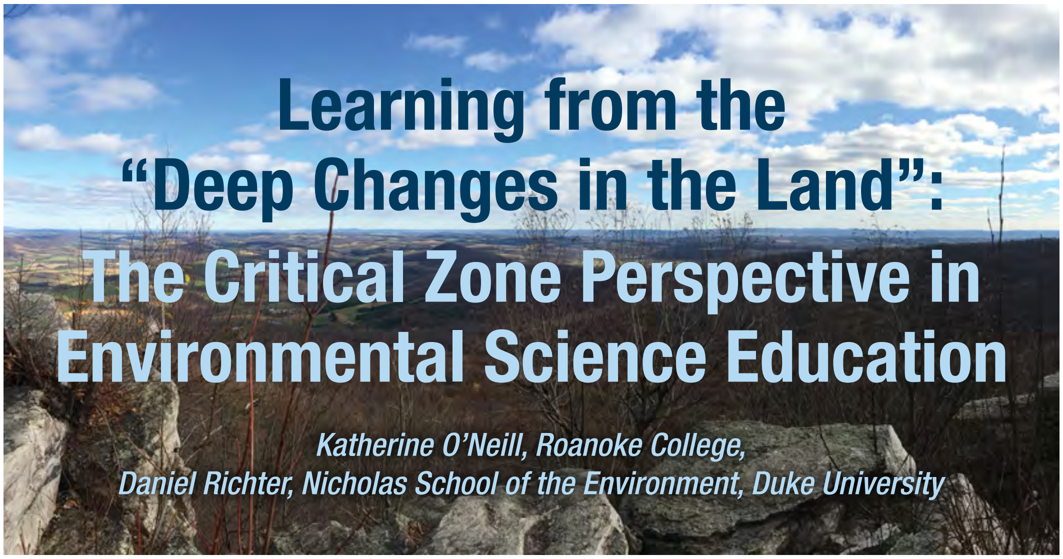
Conclusion

The Critical Zone (see White and Duggan-Haas, this special issue), critical to the maintenance of healthy life on Earth, is covered in Earth 530, Earth Surface Processes in the Critical Zone. An elective course in The Pennsylvania State University's online Masters of Education in Earth Sciences program, the course introduces graduate students, mostly teachers, to basic information necessary for understanding the Critical Zone. The course is directly responsive to Next Generation Science Standards.

About the Author

Tim White is the Coordinator of the CZO National Office, which promotes communication among CZO PIs, organizes national meetings, offers graduate/young scientist workshops, and develops electronic delivery of educational resources for Critical Zone science. White's research is predominantly field-based, using the disciplines of sedimentary geology, paleoclimatology, paleopedology, chemostratigraphy, organic petrology, and hydrogeology.

This work was funded by the National Science Foundation Award (EAR 1360760).



Learning from the "Deep Changes in the Land": The Critical Zone Perspective in Environmental Science Education

Katherine O'Neill, Roanoke College,
Daniel Richter, Nicholas School of the Environment, Duke University

Abstract

Ongoing research at the Calhoun Critical Zone Observatory (CCZO) in South Carolina seeks to integrate natural and human factors into our conceptions of Critical Zone (CZ) dynamics in the southern Piedmont. This line of inquiry is inherently interdisciplinary and place-based, creating a rich venue for the exploration of human-landscape interactions. This article describes an educational partnership that illustrates how the emerging science and environmental narrative of the CCZO has informed the teaching of coupled human-natural systems in an undergraduate Environmental Studies program. It also discusses how this Critical Zone perspective may be adapted for use in AP Environmental Science courses.

Introduction

Critical Zone science bridges many of the learning objectives in interdisciplinary environmental education and undergraduate geoscience education (Figure 1; Woodhouse et al., 2000; Kastens and Manduca, 2012). Curriculum materials derived from ongoing research at the CCZO can contribute to environmental science education by engaging students in questions that: (1) address complex, dynamic systems, (2) are derived from observations and experimentation, and (3) cross the boundaries between the natural sciences, social sciences, and environmental humanities.

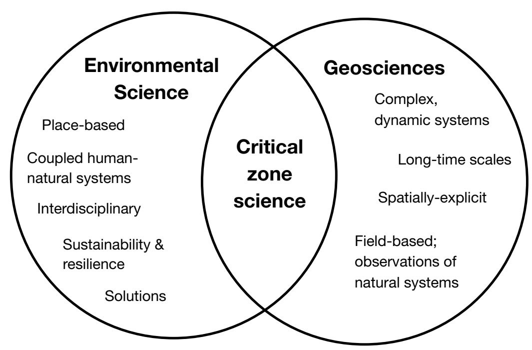


Figure 1. Critical zone science bridges many of the educational goals for undergraduate environmental studies and geoscience.

Perspective of Earth's Critical Zone in Environmental Studies

The southern Piedmont was severely impacted by soil erosion and water degradation resulting from intensive agriculture on erodible uplands. By the mid-20th century, more than 10 million hectares of land had been severely eroded and cultivation of many agricultural crops was no longer viable, spurring the migration of struggling farmers to urban areas or to more productive farmlands (Richter & Markewitz, 2001; Richter et al., 2014). Despite the often lush appearance of the contemporary landscape, the imprint of past management practices can still be found today, as eroded soil from historical cotton farms continues to impair the region's waterways and many riparian wetlands lie blanketed by thick deposits of displaced upland "legacy sediment" (James, 2013; Richter, 2016). The abandonment of row crop agriculture and subsequent transition to secondary forests raise compelling questions about long-term soil productivity, hydrologic function, and ecosystem services. Together, on-going research at the Calhoun Experimental Forest and the CCZO provide a 60-year window into how the Critical Zone of the southern Piedmont has both influenced and responded to human management (Richter et al., 2014).

For educators and students of environmental science, the narrative of environmental degradation and forest regeneration at the CCZO provides a rich opportunity for exploring the interconnections between human well-being and the health of the land itself. Over the past three years, the CCZO has partnered with the Environmental Studies program at Roanoke College, a 4-year undergraduate liberal arts institution, to develop materials and programming that are, in a very real sense, "grounded" in the Earth's Critical Zone. In 2015, the Environmental Studies major was redesigned with the Critical Zone selected as one of the cross-cutting themes to integrate the three introductory courses: Environmental Science (natural science), Environment and Society (social science), and Environment and Culture (environmental humanities). The emphasis on CZ science is further reflected in the title for the natural sciences track, which has been renamed "Conservation and the Earth's Critical Zone." The major also features a new, upper-level course in CZ science that is based, in large part, on ongoing research at the CCZO. Although this course emphasizes the natural science perspective and quantitative reasoning skills, it also fulfills a requirement for students of the environmental social sciences and humanities. As such, this course has been designed without a steep science pre-requisite structure and engages broader societal themes such as land management, soil and water conservation, interactions between the land and socio-cultural institutions, and the valuation of ecological services. Following additional classroom testing, the materials piloted in this course (including lecture notes, class, and lab activities) will be published as a modular curriculum organized around the emerging environmental narrative of the Calhoun landscape and made available for use by undergraduate and AP Environmental Science educators throughout the region.

> *"A southern history is all about the transformation of soils and ecosystems, and if we are content to view the secondary green blanket as a restoration, we have much more to learn from these deep changes in the land"*
>
> (Richter et al., 2014)

Critical Zone Linkages in AP Environmental Science

The Critical Zone perspective and on-going research across the Critical Zone Observatory (CZO) network directly align with many of the unifying themes and topic areas for AP Environmental Science allowing many of the materials and approaches described earlier to be adapted for this audience (College Board AP, 2013; Table 1). Datasets from the CZO network provide a valuable resource for developing inquiry-based labs and virtual field experiences that frame observations about the natural world within a broader social and cultural context. For example, at Roanoke College, students explore the physical factors contributing to historically-high erosion rates in the southern Piedmont (e.g. slope, rainfall intensity, soil texture), discuss how historical land management practices contributed to soil and water degradation, and then evaluate options for minimizing erosion in their home community. CZO-based explorations may be coupled with field and lab investigations that complement the concepts learned in class through firsthand observation in a local setting and that ask students to apply a Critical Zone perspective towards the development and testing of their own hypotheses (Table 1).

Summary

Critical Zone science is inherently interdisciplinary and place-based, reflects a long-term perspective, and uses a systems approach to address complex phenomena within social and cultural contexts. As such, study of the Earth's Critical Zone can provide a valuable framework for environmental education that engages students in exploration of coupled human-natural systems across the natural sciences, social sciences, and environmental humanities. Through this example of a partnership with an undergraduate Environmental Studies program, the Calhoun CZO hopes to model the potential for expanding the teaching of critical zone science beyond the research university to the broader community of Environmental Science educators engaged in the interdisciplinary study of human-landscape interactions.

AP Environmental Science Unifying themes	Topics relevant to Critical Zone science	Example inquiries based on CCZO research
Science is a process		How do researchers test hypotheses?
Energy conversions underlie all ecological processes	Net primary productivity	How does ecosystem productivity change over time?
	Ecological succession	How does the composition of species change as forests regrow?
	Photosynthesis and respiration	How do microbial and root respiration contribute to ecosystem CO_2 emissions?
The earth itself is one interconnected system	Soil and soil dynamics	How do soil chemical and physical properties change as forests grow?
	Natural biogeochemical cycles	How are soil minerals changed by weathering?
	Surface and groundwater	How does soil erosion impact the chemistry of streams?
Environmental problems have a cultural and social context	Human population and demographics	What social and economic forces contributed to accelerated soil erosion?
	Impacts of land management	How did soil erosion impact human populations?
Human survival depends upon developing practices that will achieve sustainable systems	Land use (agriculture, forests)	How does soil erosion impact food production? Forest growth?
	Soil and water conservation	How does erosion alter soil carbon storage?
	Ecosystem services	How does soil erosion impact water quality?

Table 1. Critical Zone science aligns with unifying themes and topics addressed in AP Environmental Science courses (College Board AP, 2013).

Acknowledgements

Many thanks to the Calhoun investigators, Roanoke College students and faculty that contributed to this effort (including Valerie Banschbach, Marwood Larson-Harris, Daniel Sarabia, Andreea Mihalache-O'Keef, Alexandra Ramey, and Kimberly Johnson).

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About the Authors

Katherine O'Neill is an Associate Professor of Environmental Studies at Roanoke College and serves as a lead for Education and Outreach at the Calhoun CZO. She may be contacted at oneill@roanoke.edu.

Daniel Richter is a Professor of Forest Soils and Ecology at the Nicholas School of the Environment, Duke University and the lead Principal Investigator for the Calhoun CZO. He can be reached at drichter@duke.edu.

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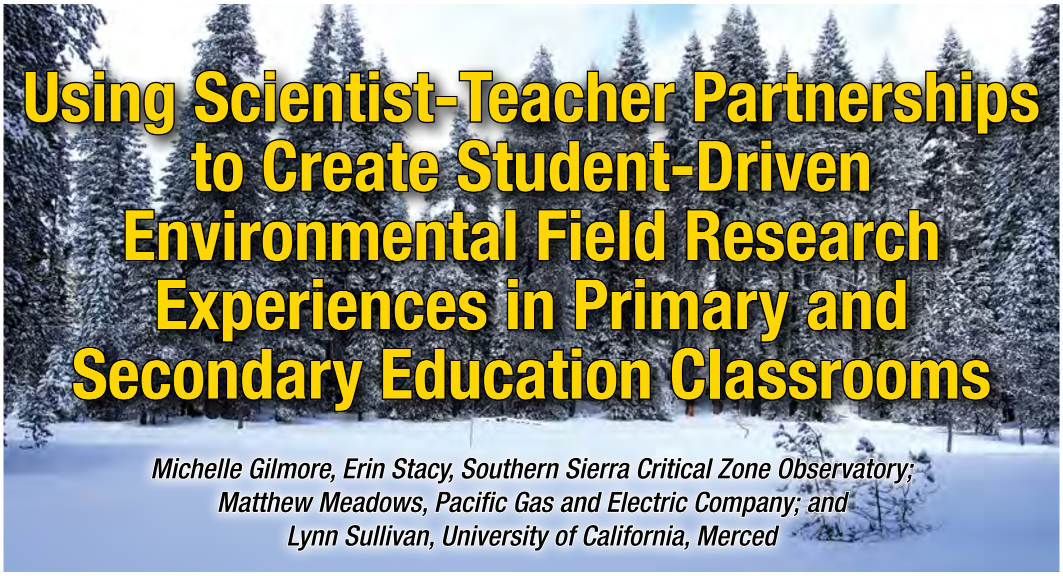

Using Scientist-Teacher Partnerships to Create Student-Driven Environmental Field Research Experiences in Primary and Secondary Education Classrooms

Michelle Gilmore, Erin Stacy, Southern Sierra Critical Zone Observatory;
Matthew Meadows, Pacific Gas and Electric Company; and
Lynn Sullivan, University of California, Merced

Abstract

Teachers can partner with environmental professionals to create real-world research experiences for students answering field-based scientific questions. A partnership between staff from the Southern Sierra Critical Zone Observatory (SSCZO) and the Center for Advanced Research and Technology has resulted in six years of inquiry-based mentored research projects in the Sierra Nevada. While project background and mentoring are provided by professional scientists, our partnership empowers students to gain experience in the process of professional research through research question and hypothesis formulation, data collection and analysis, and communication of findings. This hands-on approach combining scientific research with learning supports the goals of the Next Generation Science Standards (NGSS). This article shares SSCZO's approach to student-driven environmental research projects and advice for teachers to start their own scientist-teacher partnership.

Overview of Project Partnership

Professional mentors can be a valuable resource for incorporating NGSS through the development of inquiry-based learning opportunities for students. Since 2011, SSCZO has partnered with a secondary school in Clovis, California, to mentor and empower students as they develop and implement environmental research projects. Students formulate research questions and hypotheses that fit within the scope of SSCZO research and test their hypotheses by directing their own field experiments. After collecting and analyzing data, students communicate their findings through research papers and conference-style presentations. Throughout the mentorship, students are kept accountable for their work as in a professional setting and exposed to potential career options in environmental science.

Mentored research projects align with the goals and approaches of NGSS (NGSS, 2013). Students' active participation in the scientific process can directly address the science and engineering practices of NGSS. Projects require students to apply multiple crosscutting concepts, including scale, proportion, and quantity; cause and effect; and patterns. Teachers can cover disciplinary core ideas in-depth with this project-based structure and use the project to assess performance expectations.

Our scientist-teacher partnership is based at the Center for Advanced Research and Technology (CART) [http://www.cart.org], a half-day 11th and 12th grade school with semester-based block scheduling that serves Fresno and Clovis Unified School Districts. SSCZO mentors one of several student research teams each spring in CART's Environmental Science and Field Research Career and Technical Education Program. Mentors meet with CART teachers prior to the project semester and submit research project proposals. Students review project descriptions, prepare a resume and cover letter, and interview in groups for their top project choices. Students' project interests and mentors' ratings of interviewees are used by the class' teachers to form project groups. Our approach with CART student research teams is detailed below, along with advice on creating your own scientist-teacher partnership.

Student Research Project Development

At CART, a group of six to nine students collaborate with one or two SSCZO staff mentors to develop a research project. Mentors meet with the student team to provide background information related to a general project topic. While the SSCZO conducts multi-disciplinary science, we typically develop projects focused on the water cycle of the Sierra Nevada. Based on this background, students work with mentors to identify potential questions to test, relationships to explore, or phenomena to quantify. The student team formulates their scientific question either through class brainstorming or out of a selection of predesigned questions. Hypotheses are developed from the overarching question based on student understanding of the subject.

Most students initially propose large-scale questions such as, "How much snow is needed to provide water for the farms in California?" It is important for teachers and mentors to channel creativity toward a project that students can handle based on time commitment, grade level, and project logistics. To help develop projects that students can complete, we start from a broad disciplinary core idea, such as cycling of water through an ecosystem, and funnel the topic toward a narrowly scoped project with real-world application (Figure 1). Chosen questions are often relevant to ongoing research at SSCZO and the management of Sierra Nevada watersheds and forests (e.g., Bales et al., 2011; Blankinship, Meadows, Lucas, and Hart, 2014).

Some examples of previous student project questions are:

- How much water is contained in a one-hectare area of snow?
- What are the effects of canopy closure on snow depth, snow water content, and snow density?
- How does vegetation density affect soil moisture in a forest?

Together, students and mentors develop an experimental design to test their hypothesis. Data collection for each hypothesis varies in spatial coverage and design (Figure 2). Protocols are developed based on established environmental field methods (e.g., Lemmon, 1956; Savage, 2003; Osterhuber, 2014).

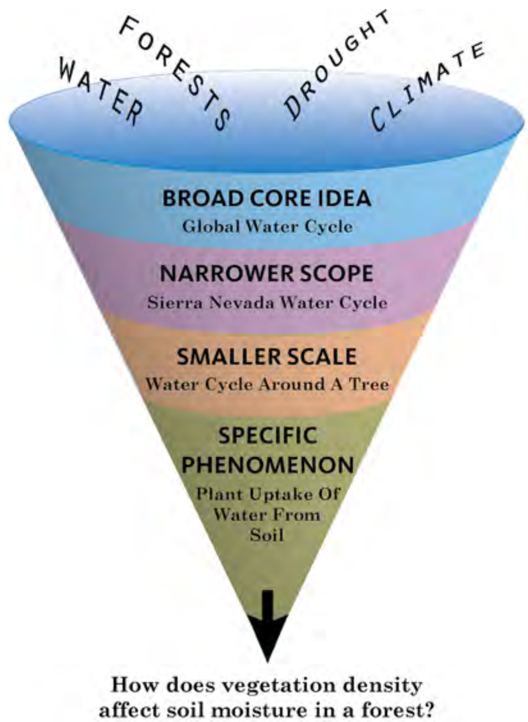

Figure 1. A funneling approach moves student research teams from broad environmental science topics to narrow final research questions as they brainstorm for their project.

Data Collection and Analysis

CART projects typically involve one day of data collection; some projects require multiple field days, such as topics exploring temporal changes or involving multiple field sites. In the field, mentors and teachers monitor student safety and ensure effective measurement technique, sampling coverage, and time management. Students collect and record data themselves, often collecting the same data as professionals, such as GPS information, snow water content, and soil moisture.

Before collecting data, mentors train students to use field instruments, such as snow water content samplers, soil moisture meters, and spherical canopy densiometers. Mentors can provide

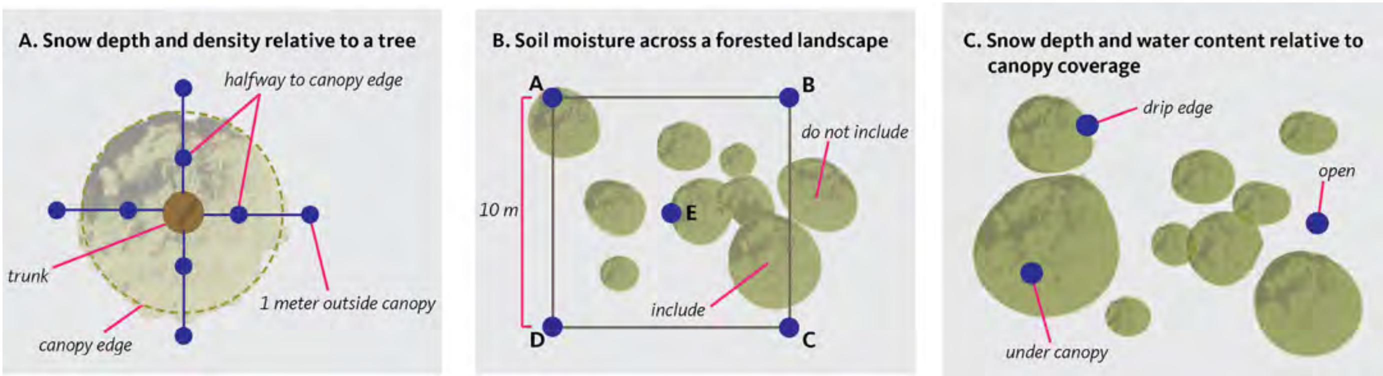

Figure 2. Examples of protocols for students' research projects. Blue circles represent measurement sites. A. Students recorded snowpack measurements under and outside tree canopies. Ground slope and tree species information were also recorded. B. Students conducted soil moisture and vegetation surveys in several square plots categorized as "dense", "medium" or "sparse". Teams measure soil moisture at the corners and center of the plot, tally tree and shrub species, and measure trunk circumference for all trees and large shrubs. C. Students recorded canopy closure and snowpack measurements at several sites in a forested area, classified as open sky, canopy drip-edge, or under-canopy zones.

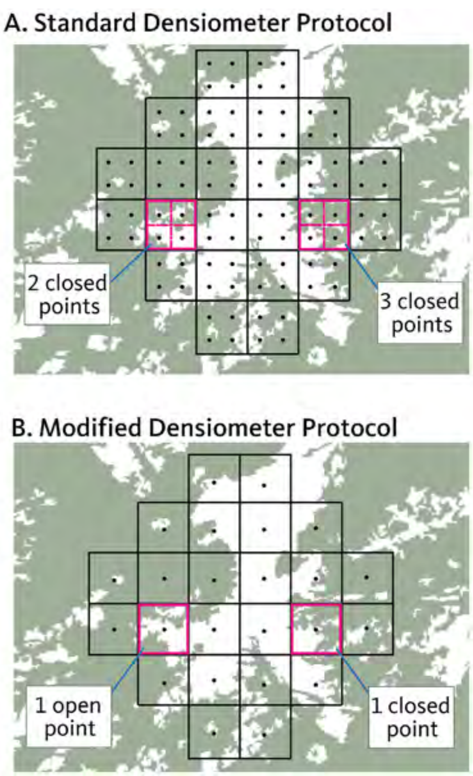

Figure 3. A. The standard spherical densiometer protocol requires mentally dividing each of the 24 squares engraved on the densiometer into four quadrants. B. A modified the protocol allows students count each engraved square as a single point.

a professional data recording format or work with students to design a data recording format tailored for their project. Depending on time available, method complexity, and student skill level, it may be helpful to simplify some measurement protocols. For instance, one CART team used a simplified approach to measure tree canopy closure percentage with a spherical canopy densiometer. Spherical densiometers contain 24 engraved squares on a mirror, which users usually divided into quadrants. The number of quadrants, or points, covered by canopy, are counted out of 96 total points (Lemmon, 1956) (Figure 3a). This protocol was modified, counting each square on the densiometer as a single point and determining coverage out of 24 (Figure 3b). The procedure modification reduced precision of canopy closure measurements but allowed students to save time and sample more sites.

After data collection, students transfer field data into spreadsheets and mentors advise the team on data analysis techniques and visualizations. Depending on research topic, students may incorporate additional pre-existing data into their project, either from previous student projects or other data libraries. Teachers and mentors support students as they learn and practice technological skills to analyze their data, such as graphing in a spreadsheet, manipulating data through computer coding, or importing GPS data into mapping software. The team uses online spreadsheets, slideshows, and other documents during and between research team meetings to collaboratively edit, answer questions, and offer feedback on project progress.

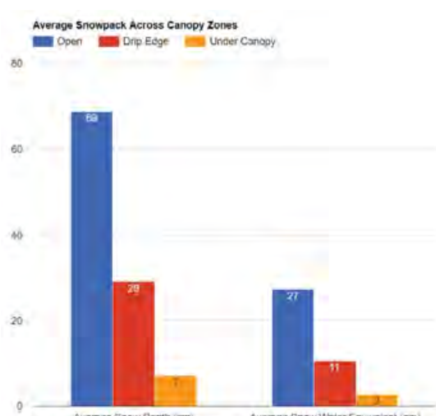

Figure 4. A graph created by CART students illustrating differences in average measured snow depth and snow water content in open, canopy drip edge, and under canopy areas.

During data analysis, mentors facilitate discussion with students to help them understand their findings and draw conclusions from their work. For instance, one team discussed how interception, albedo, and heat transfer contribute to observed patterns between canopy closure and snow distribution (Figure 4). Teachers can deepen student understanding of new concepts and processes and relate project activities to other ongoing classwork.

Communicating Research with Peers and Others

Explaining project concepts, workflow, and findings through papers and presentations allows students to show understanding of their work and experience the research project to completion. CART students write a research paper and present their project to their peers, parents, and public attendees at a research symposium. Mentors and teachers advise and collaborate with each team to generate their presentations. Students may also design figures for their presentation to explain their research (Figure 5). Student teams are encouraged to seek feedback from peers and mentors through practice presentations with other groups and mentors in a mock symposium.

Teams also have the opportunity to present their findings to the broader science community and public through science fairs, scientific conferences with student research sessions, and presentations to stakeholders or colleagues of a mentor. Journals focused on student research are another potential outlet for sharing students' work.

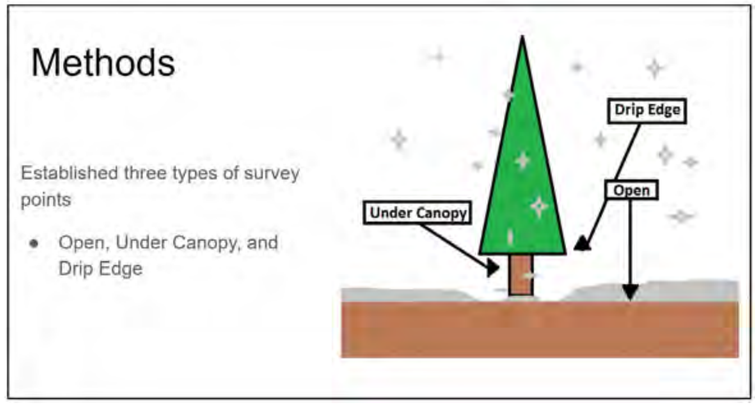

Figure 5. A student-made figure used in a CART symposium explaining three canopy zones and sample site selection.

Initiating a Scientist-Teacher Partnership

You might be saying, "I don't know any researchers or environmental professionals!" Finding a scientist mentor might be easier than you think. CART has gradually built partnerships with mentors from SSCZO, USDA Forest Service, Pacific Gas & Electric Company, and other diverse groups spanning a range of STEM disciplines. Consider searching at local colleges or universities, research programs, non-governmental organizations, State and Federal agencies, as well as private companies. You may narrow your mentor search based on the NGSS disciplinary core ideas that apply to your grades and subjects. All you need is one mentor to get things started; they can help build and diversify your mentor base over time.

SSCZO is one of ten observatories around the United States in the National Science Foundation's Critical Zone Observatory Program [http://www.criticalzone.org]. Each observatory researches multidisciplinary science topics upon which your class could build. There may be an observatory or other research program nearby that could mentor your class.

Additional considerations for a scientist-teacher partnership include time commitment of the work, both during and between mentor meetings; fit of project within a class' curriculum; and size of your research team or classroom. CART projects usually have less than 10 students on a research team, with multiple mentored research projects happening in class at once. Larger classroom projects may require different approaches to keep student teams engaged and productive. It is important to keep students motivated and empowered throughout the research project.

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We thank Staci Bynum, Ashley Howell, and Steve Wilson, the teachers who instruct, motivate, and inspire our student research teams from CART's Environmental Science and Field Research Regional Occupational Program. We also greatly appreciate article feedback provided by high school biology teacher Jennifer Meadows from Clovis Unified School District and Jennifer Williams from Susquehanna Shale Hills Critical Zone Observatory.

About the Authors

Michelle Gilmore is the Outreach Manager for the Southern Sierra Critical Zone Observatory and enjoys creating science and engineering experiences for learners of all ages. She received M.S. and B.S. degrees in Geology from the University of Pittsburgh and is interested in landscape evolution. Michelle can be reached at mgilmore2@ucmerced.edu.

Erin Stacy is the Field Manager for the Southern Sierra Critical Zone Observatory. She facilitates research endeavors in the field for this project and has the pleasure of working with research groups in geology, geophysics, soil science, ecohydrology, microbial ecology, and snow hydrology. Over the past several years, she has worked on curriculum development and outreach for community building and sharing science, including through Science Cafe Merced. Erin is interested in how humans interact with and impact their environment, and how those interactions alter ecosystem health, stability and resilience. She has a Master's of Science from UC Merced in Environmental Systems. She can be reached at estacy@ucmerced.edu.

Matthew Meadows is a Hydrographer with Pacific Gas and Electric Company. He holds a Professional Forester License in California; with a M.S in Forest Engineering from Oregon State University and B.S. in Forestry from Humboldt State University. Matt can be reached at MoMr@pge.com.

Lynn Sullivan is a lecturer for the School of Engineering at University of California, Merced. She has been an educator for Southern Sierra Critical Zone Observatory and participated in coordinating STEM content for professional development programs for 4 counties in California. She received her M.S. in Environmental Systems from the School of Engineering at University of California, Merced. Lynn may be reached at lsullivan3@ucmerced.edu.

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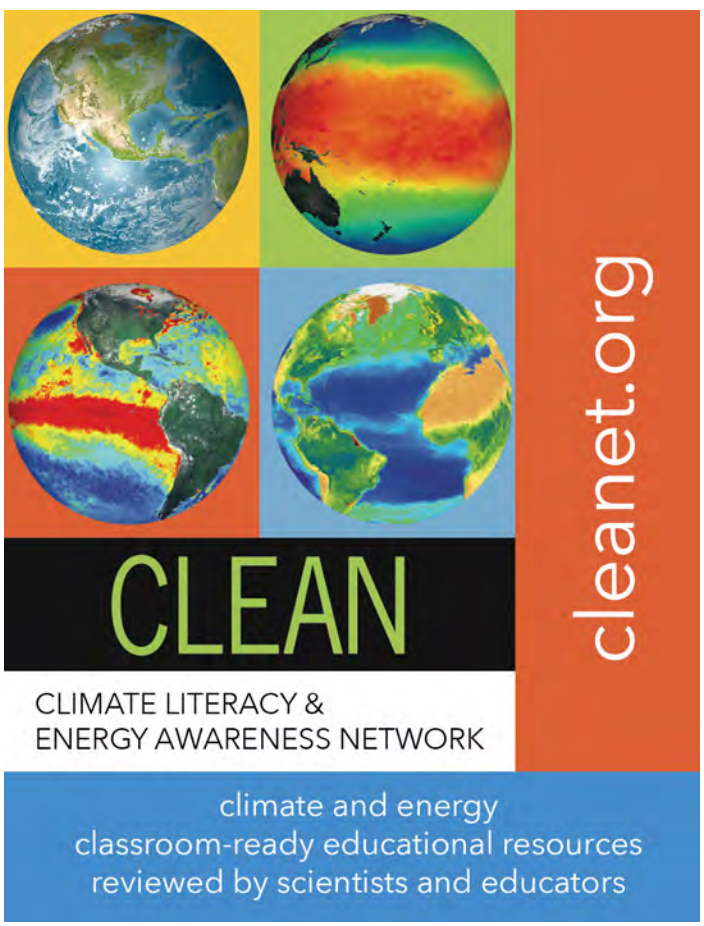

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NESTA's monthly E-News comes to your computer and provides brief summaries of stories and projects that have a direct link to the Earth Sciences and or the teaching of Earth Science. Many of these short articles provide links to more information or complete websites that those interested can follow. The E-News also contains information regarding teacher opportunities for research, professional development, and even grants. The reader will also find a calendar with items that have time critical information or may be occurring later that month or the next. Each month, the E-News provides links to a selected state's Earth Science sites. For example in the November 2012 issue we focused on Earth Science resources in Arizona, the state where in December, 2012 the NSTA Area Conference was held.


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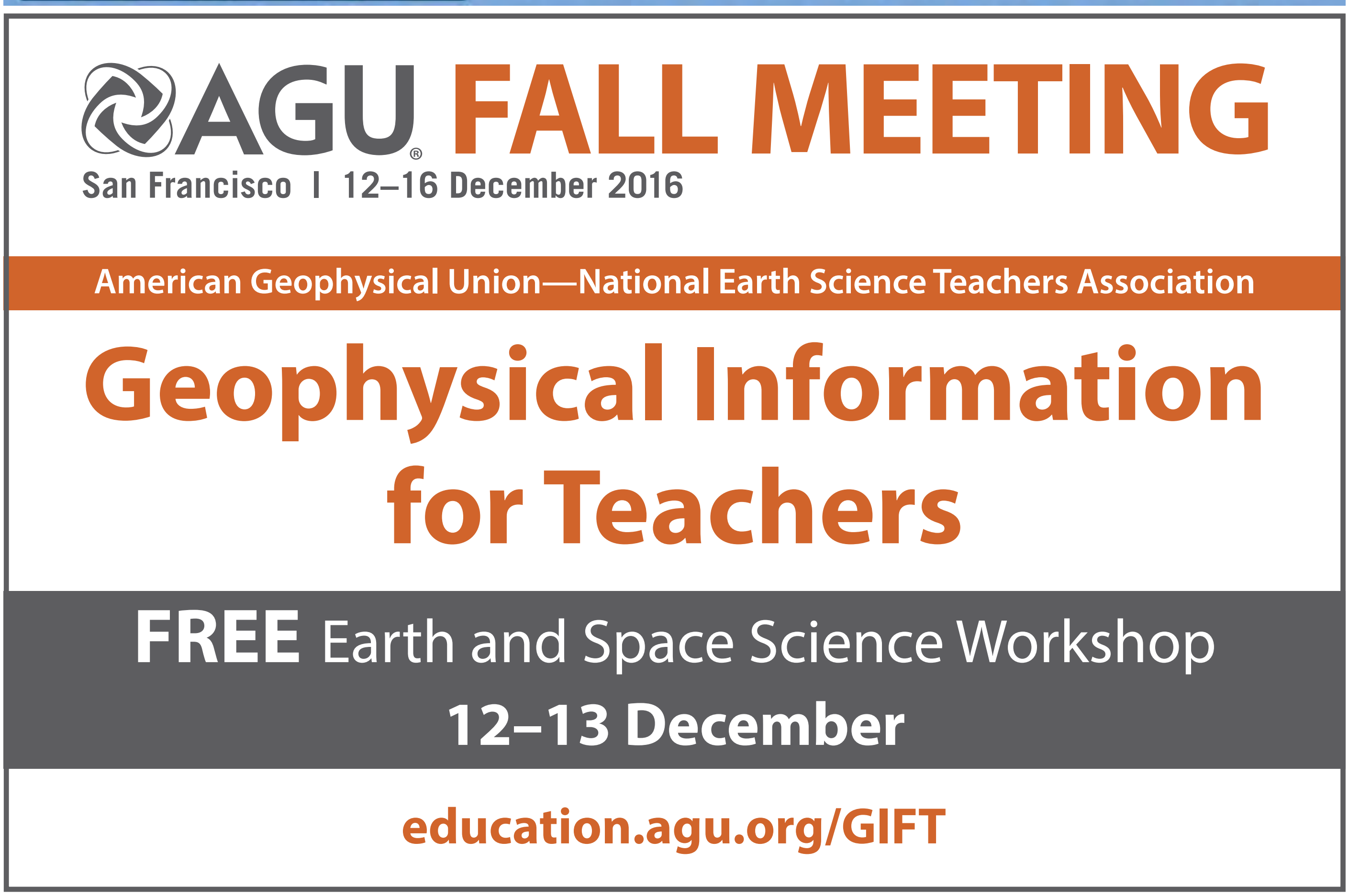
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  - References to photo/chart placement may be made in the body of the article identified with some marker: <Figure 1 here> or [Figure 1 in this area].
- Website screen shots: If you wish to include "screen shots" within your article, please also supply the direct link to the site, so TES can go online and grab the same screen shots at as high a resolution as possible. ***Note:*** When used, screen shots will produce a poorer image than a digital photograph, thus their inclusion in your article will produce an image that will look less crisp and bitmapped.
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David Thesenga, EDITOR
dthesenga@gmail.com

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