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Accomplishments

* What are the major goals of the project?

The overall goals of the Southern Sierra Critical Zone Observatory (SSCZO) include: i) expand process-based understanding of the critical zone in a sensitive, societally crucial ecosystem; ii) provide a platform for long-term physical, biogeochemical and ecological studies; and iii) develop a framework for improving Earth System Models. In addressing these goals, the SSCZO has measurements at five main sites spanning a steep elevation gradient in the southern Sierra Nevada. This spatial climate gradient in critical-zone properties and processes permits predicting effects of climate change by substitution of space for time. Building on our work of the prior years, the SSCZO is focused on a cross-disciplinary approach to understanding: i) the current distribution of CZ properties across the mountain front, ii) the processes governing CZ behavior, and iii) the rates that CZ properties can evolve and change. Our scientific goals are centered on 5 research questions and 3

implications (See Figure 2 in Management Plan).

The SSCZO team is committed to advancing both local-CZO and CZO-network science. Our overall goals extend to the broader area of the CZO network, particularly the rapidly changing and stressed western United States. Our core CZO team is becoming increasingly engaged in network science, while continuing to us the unprecedented data and research capabilities provided by investments in the SSCZO. The team is also committed to the goal of continuing to expand our already large and growing set of collaborators in the research community, both on research at the SSCZO and across the network.

The research questions that continue to guide the SSCZO follow.

1. How do regolith properties and process of formation vary over 10-m to 100-km scales? This question of understanding regolith properties and formation across climate (elevation) gradients is key to prediction of both short- and long-time-scale processes. Regolith development over time depends on both parent material and climate. In the case of the Southern Sierra, climate is much more variable over space than is parent material. However, the combined variability results in significantly different biota across gradients of elevation, climate and parent material.
2. How do physics, chemistry, and biology interact to influence critical-zone function over instantaneous to decadal timescales? Questions of critical-zone function, central to understanding and predicting the response of critical-zone services to disturbance, management actions and climate, must consider the highly variable physical, chemical and biological inputs and processing across the range of regolith properties. A common conceptual framework and model must accommodate the different rates and processes of key inputs in order to predict outputs over time.
3. How quickly do regolith properties change in response to climate and biota? Recognizing the importance of regolith-climate-biota feedbacks, predictions of regolith development, formation and properties must consider the integrated changes in climate and biota. Time scales for and magnitudes of change depend on the processes. One example, erosion over annual to millennial to million-year time scales, depends on extreme climate events, as well as disturbance of biota.
4. How do regolith development and properties control, limit or modulate effects of climate change, forest management or disturbance on hydrology, biogeochemistry and ecology? Modulation of climate and disturbance is an essential regulating service of the critical zone. For example, in semi-arid regions, the amount of subsurface water storage during drought is emerging as a key critical-zone attribute, and predicting how this modulation varies across the landscape a central critical-zone-service question. The capacity for modulation over longer time scale may not reflect shorter-term responses of critical-zone biota and biogeochemistry to change. For example, drought versus wildfire both affect biota, which may respond in quite different ways over seasonal, annual and multi-decadal time scales.
5. What measurements of the critical zone at appropriate spatial and temporal scales, using cutting-edge technology, can best advance knowledge of the critical zone? The foundation for advances in the above questions rests on making appropriate, strategic measurements of the critical zone. Both continuing, baseline measurements, as well as shorter-term project or campaign measurements are part of the CZO network. Advances in measurement technology over the past decade have greatly expanded the available observations and data. These advances in measurement can not only support critical-zone research, but also inform longer-term resource management.

Management implications of particular concern include the effects of forest management on: i) plant production and the cycling of carbon and nitrogen through the system, ii) streamwater quality and iii) forest evapotranspiration and streamflow. Of note, we emphasize that these are large, thematic issues; we recognize that while the SSCZO will advance knowledge on these questions, more-complete answers will emerge over the next several years through cooperation with sister CZOs and the broader community. The current generation of students and postdoctoral researchers who are engaged with the SSCZO are already engaged in broader network collaboration.

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

Major Activities: Activities are described following the structure of the five research questions.

Regolith properties and formation. We sampled deep regolith at 115 sites using a geoprobe, backhoe or hand auger; with 25 of the sites reserved for chemical and physical characterization. This brings the total of regolith-depth measurements to 308. Regolith depth was operationally defined as the thickness of material that could be excavated by auger or probe, and thus, potentially accessible by roots. The intensive hand-augering survey at the 1100-m elevation site involved sampling regolith to a maximum depth of 7.25 m or depth of refusal at 67 locations. At each point, we recorded tree diameter, height, species and density within a 10-m radius of the hole.

Further geophysical measurements are in progress.

We continued to characterize chemical, mineralogical and physical properties of soils and deep regolith with the idea of understanding key ecosystem services: carbon sequestration, water storage, water infiltration, and nutrient cycling. Analyses included particle size, bulk density, water-retention curves (to assess plant available water), selective dissolution of iron, aluminum and silica (to understand pedogenic mineral transformations), clay mineralogy, cation-exchange capacity, pH, available phosphorus, phosphorus sorption capacity, exchangeable potassium, fixed potassium. Synthesis of cosmogenic nuclide and U-series isotope data from stream sediment continued, culminating in a manuscript now in preparation on landscape evolution in the region.

In August 2015, we deployed three arrays of 400 geophones to image the critical zone using ambient seismic energy. In addition, WyCHEG assisted with seismic-refraction and ground-penetrating-radar surveys to help constrain the material properties of regolith and unweathered bedrock. Results reveal a correlation between the degree of weathering and remotely sensed ET, with much greater ET at locations with greater weathering, and vice versa.

In fall 2015 we collected and analyzed bedrock, soil, pine-needle samples, and aeolian dust for chemical composition and $^{143}\text{Nd}/^{144}\text{Nd}$ isotopic signatures (ϵNd). Because the ϵNd values of the bedrock and dust are different, the ϵNd values of soils and pine needles can be interpreted to reflect the relative importance of bedrock and dust in nutrient supply to the forest. Our prior research suggests that Sierra Nevada ecosystems receive significant fluxes of phosphorus from aeolian dust; the current aim is to determine how these fluxes influence ecosystem function.

Critical-zone function. We continued measurements and analysis of physical and geochemical data. An eddy-correlation system was redeployed in Long Meadow, to compare measured ET with that estimated from meadow-soil specific-yield values and groundwater fluctuations. We further analyzed geochemical data from meadow wells, snowpack and streams.

We are investigating residence times of water, subsurface water-storage capacity and plant-water strategies at Soaproot and P301 and the integrating sites on P300 and Big Creek. We sampled vegetation, soil, streamwater, precipitation and snowmelt over the course of several seasons for radioactive and stable isotopes. A coupled atmosphere-land-subsurface model (ParFlow) of the SSCZO domain is under development.

Work on annual sediment sources, composition and transport continued, with water and nutrient cycling being tracked in stream and soil water. We investigated nutrient hot spots and hot moments at the 3D grids of ion-exchange-resin capsules. We installed an additional year's-worth of resin for nutrient fluxes. We are using Hydrus 2D to integrate data and determine the role of preferential flow paths on hot-spot and hot-moment formation. We are analyzing soil samples for phosphorus from Short Hair, Soaproot and SJER. Sampling was done multiple times for pre-prescribed fire treatments, including deep soil pits for microbial diversity and function by horizon. DNA has been extracted, and analyses are in progress.

Advances in eco-hydrologic modeling assessed the role of plant-available soil-water storage on both water resources and ecosystem services. We used RHESSys to quantify how spatial variation in soil-water storage can determine whether climate warming will increase or decrease ET and how plant-available soil water and rooting-zone characteristics influence post-disturbance ecosystem recovery. We are also using RHESSys to examine how plant-available water-storage can moderate the loss of snowpack, and influence the partitioning of ET and runoff.

Regolith-climate-biota feedbacks. Using the extensive data noted above, we used our geospatial model to explain relationships between regolith thickness and forest

metrics. This model uses a clustering technique to identify clusters of terrain attributes from input variables, including climate, solar radiation, landform, soil properties (depth, water holding capacity, carbon), and wetness index. The model is being evaluated with field observations of regolith thickness, tree productivity, and tree health metrics. Ultimately we believe that certain combinations of terrain attributes can be used to predict regolith thickness and forest productivity at the watershed scale.

We are analyzing patterns in multi-year soil-moisture measurements, plus RHESSys simulations of those patterns. Data began in 2008 and continue to the present. Simulations focus on effects of vegetation management.

Modulation of climate and disturbance. Our flux-tower measurements at three of the sites provided observations on carbon uptake and ET before and during the drought.

Three papers on scaling the effects of forest thinning and fire on the Sierra Nevada water balance were submitted; they describe how we used RHESSys to integrate multi-year field data and predict effects of vegetation management. We also evaluated how shifts from conifers to shrubs at the rain-snow transition may alter water resources; and we incorporated field data to parameterize species differences in stomatal behavior. A cross-CZO modeling effort was initiated to assess how changes in the timing, rate, and amount of snowmelt influence streamflow production.

An additional cross-CZO research effort was initiated to use flux-tower and other data to assess the variability of the hydrologic response to multi-year dry periods across the mountain west. This includes examining streamflow-subsurface-storage relationships and storage-deficit thresholds across multi-year dry periods.

Measurements of the critical zone. Our catchment-scale time-series measurements of snow, soil moisture, temperature, and matric potential continued, as did streamflow and met-station measurements by the USFS. Additional time-series data came from the flux towers. We resumed operation of Shorthair eddy-flux tower in summer 2015, rebuilding and upgrading sensors. SSCZO data underwent quality assurance and quality control, and were posted in our digital library. The first 5 years were published with a doi. We performed maintenance on the wireless-sensor network and other components.

We installed and initiated operation of a combined optical/thermal imaging system at the P301 flux tower. It is mounted on a pan-tilt mount, which allows nearly 360° sampling. Instruments include a thermal-infrared, near-infrared, and RGB cameras and a terrestrial scanning LiDAR that collects ~10 million observations each run to measure the 3D structure of the site, including snow depth. The entire system is computer controlled and full scans are automatically collected every few hours.

The soil-water sensor network was expanded to include monitoring of water content and water potential in soil and deep regolith (to 250 cm) at all 4 flux-tower sites. We also expanded monitoring of water content to 50-cm intervals in observation wells over the entire deep regolith thickness at each site using a neutron probe.

Specific Objectives: Objectives are described following the structure of the five research questions.

Regolith properties and formation. We are evaluating trends in soil and regolith thickness across the altitudinal gradient of the SSCZO. The regolith is being imaged by drilling and direct sampling, and also indirect seismic imaging. Our goal is to characterize vertical profiles down to the soil-bedrock contact along the transect and constrain weathering and water-storage potential at depth to: i) expand previous 2D information to 3D subsurface data and modeling; ii) explore connections between lithology and different vegetation types; and iii) investigate the role of subsurface fracturing and weathering on aboveground productivity. Rock type and regolith properties such as porosity and water-storage capacity affect the distribution and

productivity of plants inhabiting surface ecosystems.

We aim to understand geospatial patterns in regolith thickness, and quantify the variability in regolith thickness at two scales: ~10-m scale within catchments and ~100-m scale across the elevation gradient. Through the drilling and analysis program we also aim to document the presence of deep carbon and phosphorus pools in regolith.

Additional goals of ongoing work across the altitudinal gradient include: quantifying the relative importance of dust from various sources in the formation of regolith; determining the climatic and geologic factors that influence variations in tree canopy cover across the landscape; and evaluating the evolution of pedogenic processes (additions, losses, transformations, and translocations) in soils and deep regolith.

Critical-zone function. An overarching question is how to manage forested catchments for water and other ecosystem services. Our studies of water and nutrient cycles across the heterogeneous ecosystems and regolith of the SSCZO improves our ability to predict: i) how soil-water holding capacity affects the partitioning of precipitation and snowmelt between ET and runoff; ii) how species change (i.e. conversion from trees to shrub) influences water fluxes; and iii) how hot spots and moments determines larger-scale, longer-term responses of vegetation, weathering, sediment and nutrient export.

Our work on the presence and amount of carbon in deeper regolith complements ongoing work on density fractionation and development of a 2H technique to determine sources of soil organic matter. Objectives include determining: i) how climate regulates the amount, composition, stability and stabilization mechanisms of deep soil organic matter; ii) how topography regulates amount, composition, stability and stabilization of deep organic matter across different climatic zones; and iii) how climate and topography control stocks, stoichiometry and vertical fluxes of carbon, nitrogen and phosphorous in deep soil. Research is being conducted across 3 CZOs.

We are quantifying how phosphorus stock and availability change with climate and regolith depth. We are extending research on hot spots and moments to explain why they are occurring. Our hypothesis is that precipitation travels through the nutrient-rich O horizon, collecting solutes that are transported through preferential flow paths to subsurface pockets of nutrient-rich soil called hot spots (persist over time) or hot moments. Our approach uses an unsaturated-flow model (Hydrus 2D) with field data. Microbially mediated nutrients may occur as both hot spots and hot moments, while those more abiotically controlled tend to be in hot spots.

We initiated investigations of microbially mediated ecosystem consequences of prescribed fire. We hypothesize that prescribed fire will reduce soil respiration because microbial biomass will decrease due to heat-induced mortality. As a result, carbon chemistry will become more recalcitrant, and the fungal composition will change from saprobic to mycorrhizal. A second hypothesis is that prescribed fire will increase nitrogen leaching because microbial assimilation will decrease due to a decrease in microbial biomass.

We are also characterizing deep-soil microbial diversity, and how diversity and biogeochemical function change with depth. We expect that: i) microbial biomass and functional activity will decrease with lower organic carbon, ii) microbial diversity within a profile will be as great as between profiles, iii) microbial metabolism will change from heterotrophic to chemoautotrophic with lower organic carbon, signaled by changes in functional gene abundance, iv) across sites, similar species will appear in similar horizons rather than depth, and v) enzyme activity will also be influenced by geochemical concentrations.

Regolith-climate-biota feedback. Work to understand the relationship between elevation/climate and exchanges of carbon and water is being undertaken using flux-

tower and other data. An objective is also to determine the relationship between regolith thickness and forest productivity and health across the altitudinal gradient and as a function of bedrock geology. Related to this, we also aim to understand factors that influence the presence/absence of soil and vegetation across the landscape.

We want to understand the seasonal variability of soil moisture and temperature. We will continue to look at detailed changes in soil moisture and temperature patterns due to specific local-in-time events. We are monitoring changes in water storage in soils and deep regolith to understand how soil properties may influence storage of water in deep regolith, and water use by vegetation.

Modulation of climate and disturbance. The ongoing drought has provided the opportunity to increase our emphasis on understanding how the water cycle and vegetation will respond to hotter, drier conditions. We aim to develop an understanding of system resiliency, along the steep and variable climate gradient in the Southern Sierra. A more-specific objective is to use the SSCZOs unique, continuous, spatially dense soil moisture and matric potential measurements over the multiyear time period to better understand the cumulative impact of multiple years of drought. These data are also unique in that they are accompanied by coincident measurements of spatially distributed snowpack, solar forcing, temperature, and relative humidity. By developing tools to analyze this data over multiple years, we aim to better understand the cumulative impact of multiple years of drought.

We are extending work on how plant-available water-storage capacity can moderate the loss of snowpack in a warming climate across other CZOs in the western part of the network, i.e. looking at how plant-available water storage affects the partitioning of precipitation into ET and runoff, across the different climates of the network. For example, we are building on current results that suggest that snowmelt rate influences streamflow production via a subsurface mechanism.

Another important relationship we are addressing is between elevation/climate and nutrient cycling. Collaborative efforts of several SSCZO investigators are integrating geophysical measurements of subsurface structure into model parameterization of soil-water holding capacity (and its spatial pattern) into model estimates of vegetation water use and carbon sequestration.

Measurements of the critical zone. One of the hallmarks of the SSCZO has been the development and use of a wireless-sensor network as part of a spatially extensive catchment-scale measurement program. We aim to continue developing improved methods to optimize placements of the sensor clusters, and sensor nodes within the clusters. Through the expanded sensor network and neutron-probe monitoring we aim to reveal trends in regolith water storage in response to forest water use and drought.

Significant Results:

Results are described following the structure of the five research questions. Figures are appended in a pdf file.

Regolith properties and formation. ^{238}U , ^{234}U , ^{230}Th and ^{10}Be in sediment confirm that bare-bedrock slopes erode slower than soil-mantled hillslopes, due to a dominance of physical weathering on bare rock, as expected (Callahan/Riebe). However, bare-bedrock slopes are not common enough in the landscape to explain the “stepped” topography of the region. In addition, patterns of erosion and weathering in the Kings and San Joaquin river basins are inconsistent with the hypothesis that delamination of a dense crustal root in the region has prompted relief growth in the south and relief decline in north.

O’Geen and colleagues found that regolith is thinnest at 400-m elevation, where precipitation is low (Fig. 1). Mean regolith thickness increased at mid elevation (1100 m) where weathering is believed to be highest due to moderately high precipitation and mild temperatures. Mean regolith thickness was lower at 2000-m elevation and even

lower above 3000 m, where glaciation has evidently scoured bedrock, resulting in thinner regolith. These differences in regolith thickness have profound impacts on storage of plant available water, and thus, plant communities and forest density.

Dust fluxes from Asian and Central Valley sources are similar in magnitude, highlighting the importance of long-distance transport and delivery of nutrients such as phosphorus to Sierra Nevada ecosystems (Hart/Riebe). Nd isotopes in pine needles and soil measured by Arvin/Riebe imply that 70-80% of the Nd in the soils and 80-90% of the Nd in pine needles is dust-derived (Fig. 2). We are working on converting the inferred Nd contributions from dust into an estimate of its contribution to the ecosystem nutrient pool.

O'Geen et al. found a significant reservoir for carbon in deep regolith. While the highest concentrations of organic carbon occur in soil, small but measureable amounts detected in deeper regolith translate into large pools at locations where regolith is thick (Table 1). The integrated pool of carbon in deep regolith was therefore similar to the carbon stock of a typical rangeland soil found at 400-m elevation. This finding may partly explain missing terrestrial carbon pools in global models. A complementary finding by Behre points to over 40% of total soil C being located in deeper soil layers (below A horizons).

Critical-zone function. Lucas/Conklin found meadow evapotranspiration to be near potential ET rates during summer. Despite these high rates, meadows account for only a small fraction of catchment ET due to their relatively small relative area. Restoring a degraded system to a "pristine meadow" would only increase water loss in a catchment, due to ET, a fraction of a percent. We have used meadow-soil specific-yield values to calculate meadow ET from groundwater-table fluctuations; and are using these results to constrain the highly variable specific yield in several Sierra Nevada meadow systems where ET is currently not measured, and thus scaling meadow ET estimates.

A cross-disciplinary team (Taylor/Riebe/Goulden/O'Geen) coupled geophysical data on subsurface weathering and porosity with remotely sensed estimates of the overlying forest vegetation to explore the effects of subsurface water-storage potential on above-ground productivity. Initial results show a tight coupling of between remotely sensed ET and a geophysically inferred weathering index (Fig. 3).

Lucas/Conklin used end-member mixing of geochemical data to show how/when meadow and stream waters are comprised of snowmelt, rain and multiple groundwater sources, elucidating how the timing and magnitude of a vertical groundwater gradient at the meadow edge and meadow center are reflected in the makeup of the downstream surface water.

Regolith-climate-biota feedbacks. Thaw/Visser/Conklin showed that very dry soil (during drought) led plants to retain water from spring precipitation. Additionally, the snowmelt isotopic signature was influenced by forest-canopy structure; and capturing the changing signature in hydrologic components over the year is important to characterize the plant-water strategies (Fig. 4). Spring-rain tritium concentrations were higher than winter snow due to the "Spring Leak Phenomena". In August, tritium concentrations in both vegetation and shallow soil were similar and elevated above the annual mean. In contrast, meadow groundwater and streams had low concentrations (Fig. 5). The ratio between tritium in streams and snow indicates a residence time on the order of one tritium half-life (12.3 years) (Fig. 6). Sulfur-35 shows the delayed arrival of recent snowmelt at the watershed outlet. Correlations between tritium and streamflow indicate mixing of varying fractions of recent snowmelt and older water.

Modulation of climate and disturbance. Goulden's flux-tower results show a significant decline in ET during the drought at all elevations, with the greatest reduction at the forested Soaproot site (1100 m) (Fig. 7), just above the shrub-to-forest transition. This elevation is thought to be highly vulnerable to climate change, with warming

expected to shift the shrub-to-forest ecotone upslope. The large drop in ET and photosynthesis, and the marked tree mortality that has occurred there over the last 12 months, provide strong evidence for, and an increased mechanistic understanding of, the vulnerability of lower-montane forest to climate change.

Bart/Tague found that tree-to-shrub conversion in the southern Sierra is likely to increase annual streamflow, and depends on the balance between high stomatal conductivity and deep roots of shrubs, and the greater leaf area of trees. This type conversion could have greater hydrologic impacts than increased temperatures; although temperature increases will have a greater impact on streamflow timing.

Tague's analysis of ET response to historic climate variation and warming demonstrates that plant-accessible water-storage capacity can be a dominant control on spatial patterns of vegetation water use. For many locations within the Sierra, we show that the magnitude and even direction of how vegetation water use may change as climate warms depends strongly on subsurface storage (Fig. 8).

Tague/Moritz show that for locations with relatively shallow soils (assumed low plant available water storage capacity), post thinning or fire recovery leads to increases in plant water use, if neighboring plant roots share water (Fig. 9). With deeper soils, thinning leads to minor declines in total water use, even if plant roots share water.

O'Geen and colleagues found that plant-available water-storage capacity in deep regolith can buffer against drought, but not the ongoing multi-year drought that began in 2011. The significant forest die-off at our 1100-m site was due to the absence of usable water in the upper 4 m of regolith (Fig. 10a). At the mixed-conifer tower site (2000 m) there was more plant-available water stored in regolith (Fig. 10b); although mortality in some species is still being observed. While the storage is similar at the two sites, depletion was much greater at the Pine Oak forest as a result of lower precipitation and higher ET.

Measurements of the Critical Zone. Taylor/Riebe have optimized a method to remotely quantify plant-available water using geophysics. Porosity can be derived from field measured seismic velocities using a rock physics model.

Oroza/Glaser developed a machine-learning algorithm for optimal sensor locations that results in better estimates of areal snow cover than traditional expert placements. The algorithm (a Gaussian mixture model) uses LiDAR to remotely identify the independent variables that affect the spatial distribution of snow, and identifies representative sampling locations in the space of independent variables. Oroza also developed an algorithm to predict wireless connectivity in complex terrain.

Key outcomes or Other achievements:

Outcomes cut across the five research questions.

Some of the more-significant research findings from the past year are highlighted below. Together, these give new, integrated insights into the processes determining the differences in regolith formation, weathering, forest density, forest resilience to drought and implications of expected climate change and management actions along the steep climate-ecosystem gradient covered by the Southern Sierra CZO.

1. We documented the effectiveness of digital soil-mapping techniques in explaining soil variation in the Sierra Foothill region. Our findings show that these tools are very effective in granitic terrain but less so in metamorphic rocks in the north. We also found lithologic variability to be greater than expected. These findings will serve as the rationale to explore digital soil-mapping techniques to predict characteristics of deep regolith.
2. We found that relatively light fuels treatments have little effect on runoff in the southern Sierra, but can increase runoff in the higher-precipitation region of the central Sierra. Precipitation and canopy cover controlled the magnitude of runoff

increases, following a relatively light (8%) reduction in vegetation. High-intensity wildfires that result in greater vegetation reductions and can lead to larger runoff increases. The representation of forest vegetation structure in hydrologic modeling is important to capture, and will affect model results of projected changes in vegetation. Simulating reductions by perturbing only leaf-area index resulted in limited impacts on the water balance. Replicating the same reduction by specifically manipulating canopy-cover patterns resulted in a water-balance response of much greater magnitude.

3. Detailed hydro-ecologic modeling (RHESSys) constrained by distributed observations of forest vegetation thinning, precipitation, snowpack storage, soil-water storage, energy balance and stream discharge provide a confident and useful management tool to constrain the water balance and to further project the effects fuels treatments on runoff. Further, a well-constrained headwater model can be effectively used to determine how annual hydrologic fluxes respond to vegetation changes from treatments and fires in larger fireheds, based on geologic and hydrologic similarities.
4. We developed an approach for estimating plant-available water storage at landscape to regional scales based on inverting remote-sensing estimates of annual ET to infer the amount of regolith water withdrawn during the dry season. These results showed that plant-available water peaks at mid elevation and declines at upper and lower elevations, and that it is greatest in locations with wetter and/or warmer climates.
5. Plant-available water-storage capacity is a key variable of equal importance to climate in determining watershed response to perturbations from climate and disturbance. It exerts major controls on partitioning of precipitation into discharge versus evapotranspiration, buffering drought, and post-disturbance ecosystem recovery.
6. The widespread tree mortality observed in 2015 in the 900-1800 m elevation range of the southern Sierra was associated with 4 years of low precipitation, unsustainably high vegetation densities, high evaporative demand that depleted subsurface moisture and lack of recharge below about 1-m depth. Higher precipitation and deeper recharge provide a multi-year drought buffer for fluxes out of southern Sierra basins (discharge and evapotranspiration) in areas with sufficient regolith storage, mainly at elevations well above about 2200 m.
7. We found that temperature also played a key role in controlling site water balance, the rate of below-ground water depletion during the drought, and hence vegetation mortality. Tree death late in the drought was greatest at the comparatively warm 1100-m Soaproot Saddle site and sparse at the cooler 2000-m site. Analyses of the flux tower data and the controls on ET showed that the higher rates of ET observed at 1100 m relative to 2000 m were attributable almost entirely to this temperature difference. Precipitation amounts at the 1100- and 2000-m sites were broadly similar, and hence the greater rate of below-ground water depletion at 1100 m, and ultimately the greater rate of tree death, were attributable in part to this site's warmer climate.
8. Surprisingly, we found no significant difference in rates of erosion and weathering between the Kings and San Joaquin drainages. This is inconsistent with the hypothesis that delamination of a dense crustal root has prompted relief growth in the south and relief decline in the north due to differential uplift. Our results help us interpret other paired measurements of cosmogenic and U-series nuclides from previous work for an improved understanding of landscape evolution both in the Sierra Nevada and in other granitic mountain ranges around the world.
9. The flux of dust to Sierra Nevada soil is on par with the rate of soil formation from underlying bedrock, implying that the dust-derived flux of nutrients to forest ecosystems of the region is significant. Moreover, Nd isotopes in bedrock, dust, soil, and pine needles from forests in the southern Sierra Nevada show that dust contributes ~80% of the Nd in pine needles. To the extent that Nd uptake reflects phosphorus uptake by plants in the region, our results suggest that dust is an

ecologically significant source of nutrients at sites where fluxes from dust are high relative to fluxes from erosion of underlying bedrock.

10. A global synthesis of modeled dust fluxes and measured erosion rates reveals that the supply of nutrients from exogenous dust is on par with the supply from erosion of underlying bedrock across a surprisingly broad range temperate settings around the world. This significantly expands the range of conditions under which inputs from dust flux can be a significant contributor to ecosystem dynamics, with implications for predicting impacts of climate change and land-use intensification.
11. A 3D passive-source geophysical survey of the subsurface at three study areas spanning a range in forest cover indicate that evapotranspiration (inferred from remote sensing) is regulated by subsurface weathering (inferred from shear wave velocities). To the extent that shear-wave velocities reflect porosity, and thus plant-available water, our results suggest that ecosystem function is mechanistically linked to geological, geochemical, and geomorphological processes that influence subsurface weathering processes.
12. The integrated pool of carbon in deep regolith in southern Sierra forests is similar to the carbon stock of a typical rangeland soil found at 400-m elevation. While the largest organic-carbon contents were in soil, small but measureable amounts were detected in deeper regolith, which corresponded to large pools at locations where regolith was thick. These findings may explain part of the missing terrestrial carbon that has been reported in in global models.

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

Students and postdocs associated with the SSCZO receive both formal and informal training in technical issues, and in science communication. At the undergraduate level, students from UC Merced and partnering universities have worked as field and lab technicians. For example, one student worked with the SSCZO field manager in 2015.

This marks the fifth year for the UC Merced surface water methods workshop course, developed by M. Conklin, and the seventh successive year for the UC Davis field methods course, developed by SSCZO researcher P. Hartsough. The SSCZO site visits with Hartsough and Conklin with the SSCZO staff allow students to learn about research and to collect data for use in class. These classes serve both CZO and non-CZO students.

SSCZO research provided material for other university courses as well. M. Conklin and others are part of an InTeGrate team to develop a critical zone processes course, which she taught in fall 2015.

Baseline CZO RHESSys model implementations were used to develop educational materials for two courses: ESM 237 Climate Change Impacts and Adaptation, a graduate course in the Bren School for Environmental Science and Management and ESM 495 Introduction to hydrologic modeling. RHESSys simulation results from CZO were also integrated into a CUASHI Watershed Hydrology Master Class held at Biosphere 2 in Tucson, Arizona. C. Tague was the hydrologic modeling instructor. This Master Class presents work to Ph.D. students and post-doctoral scholars from around the country; and this year included several participants from South America. See <https://www.cuahsi.org/Posts/Entry/27146>.

Ph.D. student R. Lucas served as an instructor at the Sierra Nevada Institute organized by the California Institute for Biodiversity. He presented critical-zone science to K-12 teachers, provided them with ways of bringing field techniques, models, and data visualization to their classrooms. Both R. Lucas and Ph.D. student J. Rungee also presented our research to TEAM-E organized by the Merced County Department of Education, in fall 2015. Co-PI M. Conklin is engaged in guiding this enrichment program for K-12 teachers in the local district, which serves a heavily minority population.

Students regularly work with faculty members to brief visitors to campus, and present off campus to both scientific and public audiences (see Products, and also Dissemination, below).

The societal context that the SSCZO provides for our research also provides lessons that the graduate students embrace, and will take with them to their professional careers when they complete their graduate programs. The SSCZO team mentors students in science communication, and both expects and gets high-quality papers and conference presentations. In addition to presenting at the AGU fall meeting, Ph.D. students participated in cross-CZO and other specialty meetings.

Several graduate students, undergraduates and recent Ph.D. graduates are involved with the SSCZO, and are preparing themselves for independent measurement and data analysis work in field hydrology, biogeochemistry, geophysics, and

modeling. The SSCZO places students in a multi-campus team environment, and creates a sense of community that is manifest through shared resources and collaborations (e.g. shared LiDAR, sensor data, field campaigns for soil pits, analytical tools, programming, modeling). Annual meetings are important for giving graduate students insight into what other researchers are doing, what the big questions are in the field, providing valuable feedback from other investigators on the students' work. It should also be stressed that the field research and opportunity for students to do robust tests of their ideas and hypotheses with rich field data sets in a multi-disciplinary environment will be a major influence on their careers as researchers. The wireless-sensor network remains an uncommon approach to gathering remote field data. The network installed at the Southern Sierra CZO consists of 57 wireless nodes, constituting one of the largest wireless networks for this purpose. Through the work on the wireless sensor network, training and experience continues for both investigators and graduate students.

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

As described in our Management Plan, the SSCZO was planned as a resource for the critical-zone research community; and our team has actively engaged other scientists in using this resource. Public education and outreach are equally important. SSCZO team members – investigators, graduate students and staff – share CZO knowledge and findings with several different audiences, targeting both key decision makers and the public.

Science community. Dissemination to the science community includes alerting potentially interested colleagues of our publications and presentations through our web pages and email, attending scientific meetings and workshops and participating in CZO network activities. Over the past year SSCZO team members have organized sessions, given invited talks and contributed presentations based on SSCZO work at annual meetings of the American Geophysical Union, Geological Society of America, Ecological Society of America and Goldschmidt conference. We also participated in regional scientific meetings and smaller specialty conferences. Our team also contributed to CZO network activities at these and other meetings.

Regional stakeholders and the public. Our communication and sharing of scientific products with stakeholders includes frequent talks around the state, briefings to decision makers, hosting of visits to our laboratories and SSCZO site, news articles in local publications, op-ed pieces in newspapers, radio interviews, television reports and web publications. In addition to stakeholders and decision makers, the SSCZO has an active program of education and outreach to K-16 students and educators and the general public using CZO data and results.

Two products from SSCZO have dominated our engagement with regional stakeholders and the public. Conversations around both have heightened because of the drought, and will impact both drought preparedness and sustainability of Sierra ecosystem (critical zone) services.

First, our work is informing the debate around water benefits of forest management, with emphasis on climate change and runoff from the Sierra. Given the unsustainable forest structures in an area that provides about 60% of California's water supply, there is widespread interest in bringing new resources and tools to watershed management. It is also well recognized that the knowledge base for predicting the effects of different management approaches is insufficient. We share our findings about montane forests and their water supplies with resources managers, students, researchers, and stakeholders at local to international scales.

A second major focus has been on working with water leaders in the state to define and develop prototypes for a new water - information system for California that builds on advances in wireless sensor networks developed at the SSCZO, plus parallel advances in cyberinfrastructure and in measurements by satellite and aircraft.

We also hosted meetings with university trustees, members of the business community, university donors, elected officials, agency staff and others. Two highlights from the past year are meetings with leaders of the Sierra Business Council and with members of USAID Afghan projects.

Within California, 48 Integrated Regional Water Management Groups have formed, aiming to implement regional solutions to the state's water challenges. Beginning in 2017, these groups will have access to a billion dollars of grant funds to upgrade infrastructure, address knowledge gaps, adapt for climate change, and meet other 21st century challenges. Our team has engaged with over 10 groups having an interest in the Sierra Nevada and regularly attended meetings, hosted members and collaborated to bring CZO technology to other parts of the Sierra Nevada through state grants. We also engage with multi-agency groups planning and financing forest-restoration activities. E. Stacy continues SSCZO contributions to the Dinkey Landscape Restoration Project; R. Bales and M. Safeeq contribute to the Tulare Basin Watershed Connections group.

In addition to stakeholders and decision makers, the SSCZO has an active program of education and outreach to K-16 students using CZO research topics, data and results. Our presentations and partnership activities align with several aspects of Next Generation Science Standards and Common Core State Standards. In the past year, students from Fresno Christian High School and the Center for Advanced Research and Technology (CART) executed research projects on soil moisture and snowpack in the Sierra Nevada. We describe our annual projects with CART in an article submitted to educational journal *The Earth Scientist*. Other K-12 presentations this year include Southern California Edison's Science Days for K-8 students, at which we have presented since 2011, and the Society of American Foresters High Sierra Chapter's Conservation Days for 4th and 5th graders. At these events SSCZO colleagues facilitated hands-on activities focusing on Sierra hydrology, ecology and soil science.

Our partnerships with educational institutions share research results with educators as well. In September 2015, R. Lucas and J. Rungee presented their work to approximately 60 K-8 teachers who are part of the ongoing TEAM-E Science program. Following up in June, M. Gilmore led additional science-content sessions with TEAM-E on forest-carbon cycling, tree measurement, and ecosystem modeling. L. Sullivan co-led ecosystem modeling activities and presented at another teacher training event the same week, STEM-TRACKS. M. Conklin also remains a member of the NatureBridge Yosemite board, which has provided award-winning, residential outdoor education programs for school groups since 1971.

Public outreach for the SSCZO spans a variety of forms that garner local and national attention, which we frequently share through our Twitter and Facebook accounts. The ongoing drought has brought many requests for media interviews. In February SSCZO was featured in a story on the cover page of the Tuesday Science Times (New York Times), and in an article cross-published in The Desert Sun and USA Today. Many California newspapers have also featured our work, and SSCZO investigators are quoted in national and state press multiple times per month.

Our in-person public engagement has also been active and varied. Graduate student M. Barnes presented artwork inspired by her SSCZO research in two public galleries. K. Moreland, J. Rungee, M. Thaw and M. Gilmore also exhibited at Riverdance Farms' annual Merced River Fair, demonstrating SSCZO instruments and facilitating hands-on soil and water activities. A. O'Geen gives 4-hour Master Gardener short courses in foothill communities each year focused on garden soil management, understanding the variability of soils in mountainous terrain, and documenting vegetative, topographic and lithologic differences that might influence soil variability and properties. He blends SSCZO findings into the courses, in particular topics about deep regolith and its ability supply water and buffer against drought.

Over the next year our outreach using public talks, briefings with decision makers and presentations at scientific meetings will continue along the lines initiated in past years. Some of the additional highlights planned for the next several months follow.

- The Annual Team Meeting will be Aug 2-3 in Shaver Lake. Approximately 30 researchers attend each year to exchange research results, plan field work and strategize for the coming year. Local collaborators join when schedules allow.
- We have been asked by producers to collaborate on a feature film on San Joaquin Valley water and agricultural sustainability.
- California artist Todd Gilens will visit our sites and shadowing our researchers this summer, fall, or winter as part of his ongoing *Confluence* project.
- We will follow up with Merced County educators on incorporating more CZO-related activities in classrooms.

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

The next period will include the balance of year 3 and extend through part of year 4. Several graduate students, postdocs and senior investigators have completed their research, and are submitting papers based on their work. Field research and modeling are proceeding, including several subsurface investigations. The new cohort of graduate students, who joined the SSCZO in fall 2014, which the first full academic year after the cooperative agreement began, should complete field work this year and be well into analysis and modeling. New collaborators are also joining the SSCZO. Plans for research over the next year are described following the structure of the five research questions.

Regolith properties and formation. We will complete instrumenting the excavations in soil and weathered bedrock that were done in summer/fall 2015. Geochemical analyses of samples will continue at three sites along the altitudinal transect. R. Callahan will synthesize geochemical data on weathering with cosmogenic nuclide data on erosion. Work also continues on understanding factors that influence the presence/absence of soil and vegetation across the landscape. We will continue sampling and analysis of aeolian dust. L. Arvin is seeking a mechanistic understanding of the observed bimodality in soil and

vegetative cover controlled by soil chemistry. Grad student N. Taylor will continue exploring critical -zone architecture using the passive-source seismology data.

We will investigate the extent to which soil-forming factors, (time, topography, parent material, organisms, and climate) can explain spatial variability of weathered bedrock characteristics, and which factors are more important. Along with this we will study the degree to which digital soil mapping techniques and their digital proxies (terrain attributes, airborne gamma ray mapping, remote sensing) can explain weathered bedrock thickness and mineralogical, chemical, biological and physical characteristics. We also aim to model how the degree of soil development influence processes in weathered bedrock. This will come together with aboveground landscape characteristics, as we seek a fundamental scaling relationship between the depth of regolith, canopy height, and depth of chemical alteration of bedrock.

Work will also continue work on quantitative models that describe watershed-scale patterns in weathered bedrock and its relationship to forest productivity. With most field sampling complete, much of the next year will focus on analyzing data and modeling. This includes completing three papers on regolith characteristics across the elevation gradient: i) depth trends and water storage, ii) carbon stocks in soils and regolith, and, iii) nutrient pools and mineralogical transformations in regolith relative to overlying soils. Three additional papers are: i) evaluating the relationship between forest die-off, water and regolith thickness in the forested sites, ii) documenting controls on variability in regolith thickness at the 10-m scale, and iii) Lidar and other remote sensing technique to infer below-ground root biomass.

Critical-zone function. We will analyze and disseminate data from the recently deployed remote-sensing package that was developed over the past year at the P301 site. This system includes separate Vis/NIR and thermal-IR cameras, along with a terrestrial-scanning LiDAR. We will continue operating the flux-tower network; and we will continue exploring possible sites above tree-line for a higher-elevation flux tower.

We will complete analysis of surface-groundwater exchange of Sierra Nevada montane meadows in the context of greater watershed processes (R. Lucas). We will collect a second year of stream, vegetation, soil, precipitation and snowmelt samples to examine vegetation-water sources (M Thaw).

We will continue collecting soil samples from the SSCZO transect and developing plans for work in the CJCZO (A. Moreland) and Inyo (M. Barnes) and continuing data analysis on the water samples we have been working on. We will establish productivity plots (for measuring above and belowground productivity and soil respiration) along the SSCZO transect. We will sample soils to evaluate changes in soil microbial communities (focusing on mycorrhizae) 2.5 y after forest disturbance (N. Dove). Graduate student Dove will also visit a series of wildfire sites across the mixed conifer zone of the Sierra looking for suitable sites to expand his mycorrhizal disturbance work. E. McCorkle (SSCZO alum), M. Barnes (new CZO grad student), Newman (REU researcher), Berhe, Hart, and Hunsaker are currently analyzing the steam geochemical data and plan to submit a manuscript focusing on dissolved C and N fluxes.

One modeling focus will be on understanding the effect of plant-available soil-water storage on ET, allowing us to better predict changes in vegetation under a warming climate. We will first look at how precipitation across the Sierra and a range of water storage would impact both the magnitude and direction of ET under climate warming. Second, we are using the same analysis, across all CZOs, to look at how different climates around the U.S. and a range of water storage will impact ET under climate warming. Finally, we plan to use the subsurface mapping of the SSCZO to look at how water storage will affect lateral redistribution of water and ET.

We also consider how hydrologic impacts of thinning are likely to differ across the landscape due differences in subsurface water accessible by trees. We will evaluate the spatial neighborhood defining how individual trees compete for available water (i.e, local versus diffuse competition), which determines whether water made available through the removal of transpiring biomass can be used by nearby remaining trees. We will analyze treatment impacts on water use and forest productivity for a range of biomass mass removal scenarios, across a variation in climate drivers.

Regolith-climate-biota feedbacks. Sediment sampling, soils analyses, and hydrologic/biogeochemical analyses will continue, in concert with tasks described above under regolith properties and formation, and critical-zone function. We will continue sampling of gas wells and soils from the entire climosequence during the summer and fall 2016. We plan to complete a manuscript on based on analysis of 8 years of distributed soil-moisture data, including investigations the rate and seasonality of water infiltration, and drying behavior of the soil and saprock.

Continuing investigations are documenting the role of storage hydrology, and phosphorus pools in Sierra soils. We will document soil phosphorous pools across lithologic and climatic gradients throughout the Sierra Nevada. We are assembling a time series of water balances for major Sierra catchments to assess how storage may influence runoff and forest water use

in response to climate change. Finally, we aim to complement hydrologic research to study how hydrologic monitoring and physical characterization of deep weathered bedrock reflect trends in forest response to drought.

We are developing and testing a fire-effects model, coupling a fire-spread model to RHESys, to investigate the effects of changes in forest management on forest health and runoff. We will also examine how changes in forest productivity feedback to affect fire-return intervals and forest management by further coupling the firespread/ecohydrologic model with a model of how fuels-treatment decisions are made (collaborative with NSF-HAZARDS).

Measuring the critical zone. The summer months in 2016 are critical to our SSCZO measurement program. Several upgrades were made in 2015, and those will be evaluated and adjusted this summer as needed. One set of soil excavations are planned, and we are assessing broader-scale geologic data from drilling logs to plan for deeper regolith and bedrock drilling. We will continue hydrologic measurements (both fluxes and water chemistry).

Supporting Files

Filename	Description	Uploaded By	Uploaded On
Accomplishments_table_figs3.pdf	Tables and figures for accomplishments section.	Roger Bales	06/29/2016
Additional_2016a.pdf	Additional reporting requirements, including budget information.	Roger Bales	06/29/2016
SSCZO_Mgmt_Plan_2016.pdf	Southern Sierra CZO Management Plan	Roger Bales	06/29/2016

Products

Books

Book Chapters

Inventions

Journals or Juried Conference Papers

Aciego, S. M., Riebe, C. S., Hart, S., Blakowski, M. A., Carey, C., Aarons, S. M., Dove, N., Austin, P., & Aronson, E. (). Dust outpaces bedrock in nutrient supply to forest ecosystems. *Science*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Bart, R., Tague, C., Mortiz, M. (). Effect of tree-to- shrub type conversion in lower montane forests of the Sierra Nevada on streamflow. *PLOS ONE*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Beaudette, D.E. and A.T. O'Geen (2016). Topographic and geologic controls on soil variability in California's Sierra Nevada Foothill Region. *Soil Science Society of America Journal*. 80 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/sssaj2015.07.0251

Blankinship, J.C., McCorkle, E.P., Hart, S.C. (). (in prep.) Moving soils in the rain-snow transition zones: effects on greenhouse gas emissions and nitrogen cycling. *Journal of Geophysical Research Biogeosciences*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Blankinship, J.C., McCorkle, E.P., Meadows, M.W., Hart, S.C. (). (in prep.) Quantifying the legacy of earlier snowmelt on soil greenhouse gas emissions in a high-elevation forest. *Global Change Biology*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Brooks, P. D., Chorover, J., Fan, Y., Godsey, S. E., Maxwell, R. M., McNamara, J. P., Tague, C. (2015). Hydrological partitioning in the critical zone: Recent advances and opportunities for developing transferable understanding of water cycle dynamics. *Water Resources Research*. 51 (9), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer

Reviewed = Yes ; DOI: 10.1002/2015WR017039

Carey, C.J., N.C. Dove, J.M. Beman, S.C. Hart, E.L. Aronson (2016). Meta-analysis reveals ammonia-oxidizing bacteria respond more strongly to nitrogen addition than ammonia-oxidizing archaea. *Soil Biology and Biogeochemistry*. 99 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.soilbio.2016.05.014

Carey, C.J., S.C. Hart, S.M. Aciego, C.S. Riebe, M.A. Blakowski, E.L. Aronson (). Microbial community structure of subalpine snow in the Sierra Nevada, California. *Arctic, Antarctic, and Alpine Research*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

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Garcia, E.S., Tague, C.L. (2015). Subsurface storage capacity influences climate–evapotranspiration interactions in three western United States catchments. *Hydrology and Earth System Sciences*. 19 (12), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/hess-19-4845-2015

Hayes, J. L., Riebe, C. S., Holbrook, W. S., Flinchum, B. & Hartsough, P. C. (). Porosity production in saprolite: Where volumetric strain dominates over chemical mass loss. *Geology*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

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Lukens, C. E., C. S. Riebe, L. S. Sklar, and D. L. Shuster (2016). Grain size bias in cosmogenic nuclide studies of stream sediment in steep terrain. *Journal of Geophysical Research: Earth Surface*. 121 (5), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/2016JF003859

McCorkle, E.P., Berhe, A.A., Hunsaker, C.T., Johnson, D.W., McFarlane, K.J., Fogel, M.L., Hart, S.C. (2016). Tracing the source of soil organic matter eroded from temperate forest catchments using carbon and nitrogen isotopes. *Chemical Geology*. . Status = AWAITING_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.chemgeo.2016.04.025

Oroza, C.A., et al. (). (in prep.) Repeater Placement Strategy for Environmental Wireless Sensing. *Undecided Journal*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Oroza, C.A., Zheng, Z., Glaser, S., Bales, R.C. (). VOptimizing embedded sensor network design for catchment-scale snow-depth estimation using LiDAR and machine learning. *Water Resources Research*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

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- Riebe, C.S., Sklar, L.S., Lukens, C.E., Shuster, D.L. (2015). Climate and topography control the size and flux of sediment produced on steep mountain slopes. *Proceedings of the National Academy of Sciences*. 112 (51), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1073/pnas.1503567112
- Safeeq, M. and Hunsaker, C. (2016). Characterizing Runoff and Water Yield for Headwater Catchments in the Southern Sierra Nevada. *Journal of the American Water Resources Association*. . Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Safeeq, M., Hartsough, P., Bales, R. (). (in prep.) Stand-level variability in water storage and evapotranspiration from a White Fir (*Abies concolor*). *Undecided Journal*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Saksa, P.C., Conklin, M.H., Battles, J.J., Tague, C.L., Bales, R.C. (). Forest thinning impacts on the water balance of Sierra Nevada mixed-conifer headwater basins. *Water Resources Research*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Saska, P.C., Bales, R.C., Tague, C.L., Battles, J.J., Conklin, M.H. (). Fuels-treatment and wildfire effects on runoff in Sierra Nevada mixed-conifer forests. *Water Resources Research*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Son, K. and Tague, C. (). (in prep.) Importance of soil parameter uncertainty in assessing climate change projections in small two Sierra Nevada watersheds. *Water Resources Research*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Son, K., Tague, C., Hunsaker, C. (). Effects of model spatial resolution on ecohydrologic predictions and their sensitivity to inter-annual climate variability in California's Sierra Nevada watersheds. *Water*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
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- Tague, C., and Moritz M. (). (in prep.) Testing common assumptions associated with thinning as a fire-hazard reduction treatment in water limited forests. *Ecological Applications*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Tague, C., Heckman, C., Flint, A. (). How plant accessible water storage interacts with changing snowpacks in Mediterranean Environments. *Nature Climate Change*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Webb, R.W., Fassnacht, S.R., Gooseff, M.N. (2015). Wetting and Drying Variability of the Shallow Subsurface Beneath a Snowpack in California's Southern Sierra Nevada. *Vadose Zone Journal*. 14 (8), . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.2136/vzj2014.12.0182
- Zhang, Z., et al. (). (in prep.) Connectivity Model through Ensemble Regression- Tree on Large-Scale Deployment Traces. *Undecided Journal*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Zhang, Z., Glaser, S., Bales, R., Conklin, M., Rice, R., Marks, D. (). Design and evaluation of a basin-scale wireless sensor network for mountain hydrology. *Water Resources Research*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes
- Zheng, Z., Kirchner, P. B., and Bales, R. C. (2016). Topographic and vegetation effects on snow accumulation in the southern Sierra Nevada: a statistical summary from lidar data. *The Cryosphere*. 10 (1), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: doi:10.5194/tc-10-257-2016

Licenses

Other Conference Presentations / Papers

Aronson, E.L., Carey, C., Riebe, C., Aciego, S., Blakowski, M., Hart, S.C. (2015). *Aeolian and soil microbial communities differ at multiple elevations in the Southern Sierra CZO*. Soil Ecology Society Biennial Meeting. Colorado Springs, Colorado.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Aronson, E., Riebe, C.S., Aciego, S., Blakowski, M., Hart, S.C., Carey, C. (2015). *Aeolian transported and deposited microbial communities differ along an elevation gradient in the Southern Sierra CZO*. Ecology Society of America Annual Meeting. Baltimore, Maryland. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Bart, R., Anderson, S., Moritz, M., Plantinga, A., Tague, C. (2015). *An Integrated Model for Identifying Linkages Between the Management of Fuel Treatments, Fire and Ecosystem Services*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Fogel, M., Berhe, A., Williams, E. (2015). *Can $\delta^{2}H$ of Organic Matter in Soils be Used for Understanding Organic Matter Sources and Cycling?*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Safeeq, M., Hunsaker, C. (2015). *Characterizing Runoff and Water Yield from Headwater Catchments in the Southern Sierra Nevada*. American Geophysical Union Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Tian, Z., O'Geen, A., Hartsough, P., Deng, J. (2015). *Climatic Controls on Soil and Deep Regolith Development in Southern Sierra CZO*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Bales, R., Goulden, M., Hunsaker, C., Conklin, M., Hartsough, P., O'Geen, A., Hopmans, J., Safeeq, M. (2015). *Drought effects on evapotranspiration and subsurface water storage in the southern Sierra Nevada*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Biederman, J., Scott, R., Goulden, M., Litvak, M., Kolb, T., Yépez, E., Oechel, W., Meyers, T., Papuga, S., Ponce-Campos, G., Krofcheck, D., Maurer, G., Dore, S., Garatuza, J., Bell, T., Krishnan, P. (2015). *Ecosystem carbon balance in a drier future: land-atmosphere exchanges of CO₂, water and energy across semiarid southwestern North America*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Berhe, A., Newman, A., Hunsaker, C. (2015). *Erosional distribution of metal oxides and its implication for soil carbon dynamics*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Mazzi, J., Grigsby, S., Goulden, M., Ustin, S. (2015). *Estimating CO₂ Fluxes Pre and Post Drought Using Remote Sensing Data in the Sierra Nevada Range*. American Geophysical Union Annual Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hayes, J., Riebe, C., Holbrook, S., Hartsough, P. (2015). *Generating Porosity in the Critical Zone: Does Volumetric Strain Dominate Chemical Mass Loss?*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Dove, N. (2016). *Geospatial techniques for field-based research: case studies in NW Baja California & Yosemite NP*. California Geographic Information Association Annual Geosummit. Merced CA. Status = PUBLISHED; Acknowledgement of Federal Support = No

Jepsen, S., Harmon, T., Meadows, M., Hunsaker, C. (2015). *Hydrogeologic Influence on Changes in Snowmelt Runoff with Climate Warming: Numerical Experiments on a Mid-Elevation Catchment in the Sierra Nevada, USA*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Lukens, C., Riebe, C., Sklar, L., Shuster, D. (2015). *If Rocks Could Talk: Origin Stories of Stream Sediment Told by Apatite Helium Ages and Cosmogenic Nuclides*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Oroza, C., Zheng, Z., Zhang, Z., Glaser, S., Bales, R., Conklin, M. (2015). *In-situ monitoring of California's drought: Impacts on key hydrologic variables in the Southern Sierra Nevada*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Heckman, C. (2016). *Managing forests in an era of drought*. Graduate Research Advocacy Day. Sacramento, California.

Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Tague, C. (2015). *Modeling the complex interactions among wildfire, fuel treatments and hydrology*. EARSeL Forest Fire Special Interest Group Workshop. Limassol, Cyprus. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Lucas, R., Conklin, M., Goulden, M. (2015). *Montane meadow evapotranspiration: implications for restoration and impacts on downstream flow*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Zheng, Z. (2016). *Multi-platform data fusion for more accurate forecasting of water supply from the Sierra Nevada snow*. Western Snow Conference. Seattle, Washington. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Arvin, L., Riebe, C., Aciego, S., Blakowski, M. (2016). *Nd Isotopes in Soils and Pine Needles Trace Aeolian Inputs to Sierra Nevada Ecosystems*. Goldschmidt Abstracts. Yokohama, Japan. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Oroza, C., Zheng, Z., Zhang, Z., Glaser, S., Bales, R., Conklin, M. (2015). *Optimization methods for multi-scale sampling of soil moisture and snow in the Southern Sierra Nevada*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Safeeq, M., Grant, G. (2015). *Patterns of Hydrologic Sensitivity to Climate in the Western US: Implications for Future Predictions*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Boisrame, G.F.S, Thompson, S.E., Stephens, S., Collins, B., Tague, N. (2015). *Resilience Through Disturbance: Effects of Wildfire on Vegetation and Water Balance in the Sierra Nevadas*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Martin, S., Conklin, M., Liu, F. (2015). *Source Water Flow Pathways In Forested, Mountain, Headwater Streams: A Link Between Sediment Movement Patterns And Stream Water Chemistry*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Ferrell, R., Ferrell, P., Hartsough, P., O'Geen, A. (2015). *Spatial Patterns between Regolith Thickness and Forest Productivity in the Southern Sierra CZO*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hart, S., Barnes, M., Johnson, D., Meadows, M. (2015). *The Median Isn't the Message: Elucidating Nutrient Hot spots and Hot Moments in a Sierra Nevada Forest Soil*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Carey, C.J., Hart, S.C., Riebe, C.S., Aciego, S., Blakowski, M., Aronson, E. (2015). *The role of elevation and time in structuring soil microbial communities in the Sierra Nevada, California*. Ecology Society of America Annual Meeting. Baltimore, Maryland. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Gallery, R., Aronson, E., Fairbanks, D., Murphy, M., Rich, V., Hart, S. (2015). *Tools and perspectives for a unified approach to understanding microbial ecology in the critical zone*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Bart, R. R. (2015). *Type Conversion, Fire and Ecosystem Services*. Western Mountain Initiative Annual Meeting. Three Rivers, California. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Callahan, R., Riebe, C., Dosseto, A. (2016). *Using Cosmogenic and U-Series Nuclides in Stream Sediment to Test Hypotheses About Mountain Landscape Evolution*. Goldschmidt Abstracts. Yokohama, Japan. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Taylor, N., Dueker, K., Riebe, C., Chen, P., Flinchum, B., Holbrook, S. (2015). *Using Three-Dimensional Passive Seismic Imaging to Capture Near-Surface Weathering and Its Influence on Overlying Vegetation*. American Geophysical Union Fall Meeting. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Visser, A., Thaw, M., Stacy, E., Hunsaker, C., Bibby, R., Deinhart, A.L., Schorzman, K., Egnatuk, C., Conklin, M., Esser,

B. (2015). *Variability of Residence Time tracer Concentrations at the Southern Sierra Critical Zone Observatory during the California Drought*. American Geophysical Union Fall Meeting.. San Francisco, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

O'Geen, A. T. (2015). *Visions for the future of Soil Survey and soil information delivery*. Soil Science Society of America International Meeting. Minneapolis, Minnesota. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Bales, R. (2015). *Water and Sierra Nevada forests*. The State Bar of California Environmental Law Conference at Yosemite. Fish Camp, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Other Products

Educational aids or Curricula.

Rhodea, J., and Gilmore, M. (2016). *Stomata printing: Seeing the small parts and spaces in plants*. Activities adapted from California Academy of Sciences. Presented at the Merced County Office of Education TEAM-E workshop, June 2016, Wawona CA.

Educational aids or Curricula.

Sullivan, L., and Gilmore, M. (2016). *Grass, Rabbits, and Wolves – Oh My! Understanding Food Chains and Ecosystem Interactions*. Activities adapted from Shodor. Presented at the Merced County Office of Education TEAM-E workshop, June 2016, Merced CA.

Educational aids or Curricula.

Gilmore, M. (2016). *Carbon's adventures around the forest*. Presented at the Merced County Office of Education TEAM-E workshop, June 2016, Wawona CA.

Educational aids or Curricula.

Gilmore, M. (2016). *Tools of the Trade: Methods for Measuring Trees*. Presented at the Merced County Office of Education TEAM-E workshop, June 2016, Wawona CA.

Educational aids or Curricula.

Rhodea, J., and Gilmore, M. (2016). *Invent an Insect!* Activities adapted from California Academy of Sciences. Presented at the Merced County Office of Education TEAM-E workshop, June 2016, Wawona CA.

Artwork.

Barnes, M. (2015). *Oak Woodlands at San Joaquin Experimental Range*. Oil on canvas. Publicly displayed at Merced Multicultural Arts Center, August 2015, Merced, CA.

Artwork.

Barnes, M. (2015). *Soil Madness*. Mixed media. Publicly displayed at Merced Art Hop Epekel Gallery, March-April 2016, Merced CA.

Other Presentation.

Bales, R. (2016). *Sierra Nevada tree die-off: Lessons learned & future challenges*. Presented at Tulare Basin Watershed Connections Group, January 10, 2016, Fresno CA.

Other Presentation.

Gilmore, M., Thaw, M., Moreland, K., Rungee, J. (2016). *Where Rock, Soil, Water, Air, and Life Connect: Understanding and Measuring the Critical Zone*. Presented at Riverdance Farms Annual Merced River Fair and Pick 'n' Gather, June 4, 2016, Livingston CA.

Other Presentation.

Lucas, R. (2015). *Science Content Seminar*. Presented at Merced County Office of Education TEAM-E Science workshop,

September 2015, Merced, California.

Other Presentation.

Rungee, J. (2015). *Sierra in a Box*. Presented at Merced County Office of Education TEAM-E Science workshop, September 2015, Merced, California.

Other Presentation.

Tague, C. (2015). *Fire, Water, and Ecosystems in a Changing Climate*. Presented at Zuckerberg Institute for Water Research (ZIWR), part of the Jacob Blaustein Institute for Desert Research, October 28, 2015, Ben-Gurion University of the Negev, Be'er Sheva, Israel.

Other Presentation.

Tague, C. (2016). *Ecohydrology and Informatics: Seeing water in the Trees!* Presented at Arizona State University, April 13, 2016, Tempe, Arizona.

Other Presentation.

Tague, C. (2016). *Fire, Water, and Ecosystems in a Changing Climate*. Presented at Water Resources Graduate Program Winter Seminar, Oregon State University, February 2016, Corvallis, Oregon.

Other Presentation.

Bales, R. (2015). *Water and Sierra Nevada forests*. Presented at the Tuolumne County Alliance for Resources & Environment Annual Meeting, September 21, 2015, Pinecrest CA.

Other Presentation.

Bales, R. (2015). *Water Information System*. Presented at UC Merced to USAID Group from Afganistan, Dec 7, 2015, Merced CA.

Other Presentation.

Bales, R. (2016). *Water Security in a Changing Climate: California Drought and Sierra Nevada Response*, Presented at Invited Seminar, Lawrence Berkeley National Laboratory, April 14, 2016, Berkeley CA.

Other Presentation.

Bales, R. (2016). *Water & carbon balances in the Southern Sierra: measurements, drought and scaling*. Presented at NASA Jet Propulsion Laboratory, Jan 13, 2016, Pasadena CA.

Other Presentation.

Bales, R., (2015). *Drought impacts on subsurface water storage, evapotranspiration, and vegetation mortality in the Southern Sierra Nevada, 2009-2015*. Presented at the Yosemite Hydroclimate Meeting, Oct 8, 2015, Yosemite Valley CA.

Other Presentation.

Barnhart, T.B., N.P. Molotch, and C. Tague, (2015). *Hydrologic partitioning sensitivity to snowmelt rate, timing, and amount*. Presented at Boulder Creek Critical Zone Observatory Annual Meeting, August 29, 2015, Ward, Colorado. Oral presentation.

Other Presentation.

Blankinship, J. (2016). *The brown belowground*. Presented at University of California Sedgwick Reserve, March 25, 2016, Santa Ynez, California.

Other Presentation.

Blankinship, J.C. (2016). *Soil microbes on a changing world: from quantification to prediction to cooperation*, Presented at

University of Arizona, April 25, 2016, Tucson, Arizona.

Other Presentation.

Gilmore, M., Barnes, M., Rungee, J., Thaw, M., Lash, B., Castro, M., Ayala-Astorga, M. (2016). *How do trees eat, drink, and breathe?* Presented at Southern California Edison Science Days, May 20 and June 3, 2016, Shaver Lake CA.

Other Presentation.

Gilmore, M., Stacy, E., Barnes, M. (2016). *Soil formation, composition, and infiltration.* Presented at Society of American Foresters High Sierra Chapter's Conservation Days, April 21, 2016, Tollhouse CA.

Other Presentation.

Moreland, K. (2016). *Topsoil versus subsoil isotopic carbon and nitrogen along a climosequence.* Presented at University of California Merced EnviroLunch, May 2016, Merced CA.

Other Presentation.

O'Geen, A. T. *Nature and Properties of Soil.* Presented at the Sonora, Tuolumne and Calaveras Counties' Master Gardners Programs.

Other Presentation.

Safeeq M. (2016). *Combining in situ and remotely sensed data to understand the interactions between forests and water in the Sierra Nevada.* Presented at Perspectives Across the Hydrologic Cycle, Water Resources Seminar Series, Oregon State University, Corvallis, OR.

Other Presentation.

Safeeq, M. (2015). *Managing water in forested landscapes under climate change: An integrated view.* Presented at Mariposa County Health Department, Mariposa, CA.

Other Presentation.

Safeeq, M. (2015). *Forests and Water in the Sierra Nevada: Kings River Experimental Watershed and Ecosystem Monitoring Project.* Presented to Sierra Nevada Alliance.

Other Presentation.

Safeeq, M. (2015). *Climate Change & Water: Impact and Adaptation for Agriculture.* Presented at Climate & Agriculture Summit, UC Davis, Davis, CA.

Other Presentation.

Safeeq, M. (2015) *Forests and Water in the Sierra Nevada: Kings River Experimental Watershed and Ecosystem Monitoring Project.* Presented at 22nd Annual California Aquatic Bioassessment Workgroup Meeting, October 20-21, 2015, Davis CA.

Other Presentation.

Tague, C., Heckman, C., Flint, A. (2016). *How plant accessible water storage interacts with changing snowpacks in Mediterranean environments.* Presented at CUAHSI Watershed Science Master Class, January 17-22, 2016, Biosphere2, Oracle, Arizona. Poster.

Workshop.

Cross-CZO SAVI Biogeochemistry Workshop held at University of California, Riverside, CA on 28-29 September 2015. Organizing Committee: Emma L. Aronson, Stephen C. Hart, and Rachel E. Gallery. Funded by NSF Science Across Virtual Institutes (SAVI) CZO Network.

Other Publications

Bales, R. (2015). *Roger Bales: Climate talks in Paris are important for the Valley.* Op-ed published in The Fresno Bee.

Status = PUBLISHED; Acknowledgement of Federal Support = No

Bales, R. (2016). *Roger Bales: Sierra is white with snow, but more drought solutions needed*. Op-ed published in The Modesto Bee. Status = PUBLISHED; Acknowledgement of Federal Support = No

Patents

Technologies or Techniques

Neomote Wireless Sensor Network: The Glaser-Bales team has been installing the new generation of wireless sensor stations. The new WSN boards provides a platform that provides the capacity for a wide range of sensors, up to forty analog and/or digital, to be added to the current twelve. The network is comprised of 27 sensor nodes and 30 data relay nodes.

Thesis/Dissertations

Son, K.. *The importance of sub-watershed variability for predicting ecohydrologic response to inter-annual climate variability and climate warming in California's Sierra Nevada watersheds*. (2015). University of California, Santa Barbara.

Acknowledgement of Federal Support = Yes

Websites

Critical Zone Observatories Instagram

<https://www.instagram.com/criticalzoneorg/>

SSCZO contributes photos and captions to the new CZO Instagram account, activated in spring 2016. @CriticalZoneOrg is the official instagram of all critical zone observatories in the U.S. CZO network. The account currently has 52 followers.

SSCZO Digital Library

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW

The major foci of SSCZO's online presence are the National CZO Program website and the Sierra Nevada San Joaquin Hydrologic Observatory (SNSJHO) digital library. Data, metadata, photos, reports, and other documents are catalogued in the SNSJHO digital library. Access to public data and files is available to anyone. Additional permissions can be obtained through registration and individual requests. Links for viewing and downloading data on criticalzone.org/sierra/data connect to this repository. In spring 2016 we initiated using Google Analytics for page visits and downloads on this site.

SSCZO Facebook

<https://www.facebook.com/SSCZO/>

The Southern Sierra Critical Zone Observatory maintains a Facebook page. This page is slowly growing with 72 likes. Our Facebook activity reaches a local cross-disciplinary audience of researchers (broader than environmental science, hydrology, or the CZO network), along with some friends and family of SSCZO colleagues. The URL and account name for our Facebook page was updated this year for consistency with our Twitter URL and account name.

SSCZO Twitter

<https://twitter.com/SSCZO>

The Southern Sierra Critical Zone Observatory was the first CZO in the National CZO Program with an active Twitter account. Now that the network has expanded and other CZOs are active on Twitter, it is a space for SSCZO to connect with other observatories and researchers interested in critical zone science. SSCZO posts events, photos, videos, and links to pertinent stories and blog posts on the Twitter page. This avenue has been useful in reaching researchers, media and other professionals, particularly in publicizing research presentations during professional conferences. A majority of our 292 followers are members of the research community, including researchers unaffiliated with the National CZO Program.

Southern Sierra Critical Zone Observatory

<http://criticalzone.org/sierra/>

This website is the home of the Southern Sierra Critical Zone Observatory. In the past year, SSCZO staff have worked with National Office staff to publish 28 news articles and opportunities online. Upcoming events and publications lists are regularly updated. Our staff are currently updating static webpage content for improved long-term management and planning to add interactive site maps. We are also part of the CZO network's newly formed Website Committee to continue improving content consistency, layout, features, and accessibility on criticalzone.org.

Twitter - Roger Bales
<https://twitter.com/rbalesuc>

Since SSCZO PI Roger Bales started a Twitter page in December 2014, he has garnered 731 followers and posted 931 tweets. His page is active in conversations regarding water usage, hydrologic technology and infrastructure, and the ongoing CA drought.

Twitter - SSCZO Researchers
<http://twitter.com>

Several researchers from SSCZO - students, investigators, and collaborators - actively share SSCZO activities, publications, presentations, upcoming events, and stories and conversations related to the critical zone. Some of our researchers' accounts are listed below:

Lindsay Arvin (@lj_arvin), Ryan R. Bart (@ryanrbart), Asmeret Asefaw Berhe (aaberhe), Russell Callahan (@russ_buss), Rachel Gallery (@rachelgallerys), Steve Holbrook (@WyoGeoProf), Cliff Riebe (@sedimentMatters), Mohammad Safeeq (@safeeqkhan), Naomi Tague (@naomi_eco_hydro), Melissa Thaw (@MelissaThaw).

Supporting Files

Filename	Description	Uploaded By	Uploaded On
SSCZO 2016 Media Coverage_Part2.pdf	Media Coverage of Southern Sierra CZO -- Part 2	Roger Bales	06/29/2016
SSCZO 2016 Media Coverage_Part1.pdf	Media Coverage of Southern Sierra CZO -- Part 1	Roger Bales	06/29/2016

Participants/Organizations

Research Experience for Undergraduates (REU) funding

Form of REU funding support: REU supplement

How many REU applications were received during this reporting period? 2

How many REU applicants were selected and agreed to participate during this reporting period? 0

REU Comments: We had REU students in 2015, but not 2016.

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Bales, Roger	PD/PI	2
Conklin, Martha	Co PD/PI	2
Goulden, Michael	Co PD/PI	2
Riebe, Clifford	Co PD/PI	2
Tague, Christina	Co PD/PI	1

Berhe, Asmeret Asefaw	Co-Investigator	2
Glaser, Steven	Co-Investigator	1
Hart, Stephen	Co-Investigator	3
O'Geen, Anthony	Co-Investigator	3
Safeeq, Mohammad	Co-Investigator	1
Bart, Ryan	Postdoctoral (scholar, fellow or other postdoctoral position)	3
Blankinship, Joseph	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Fellows, Aaron	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Jefferson, Jennifer	Postdoctoral (scholar, fellow or other postdoctoral position)	1
Williams, Elizabeth	Postdoctoral (scholar, fellow or other postdoctoral position)	9
Aciego, Sarah	Other Professional	1
Busse, Matt	Other Professional	0
Chen, Po	Other Professional	1
Choate, Janet	Other Professional	1
Davis, Frank	Other Professional	0
Dueker, Ken	Other Professional	1
Esser, Brad	Other Professional	3
Fogel, Marilyn	Other Professional	1
Gilmore, Michelle	Other Professional	9
Graham, Bob	Other Professional	0
Guo, Qinghua	Other Professional	1
Hayes, Jorden	Other Professional	2
Holbrook, Steve	Other Professional	1
Hopmans, Jan	Other Professional	1
Hunsaker, Carolyn	Other Professional	1
Johnson, Dale	Other Professional	1

Kelly, Anne	Other Professional	1
Maxwell, Reed	Other Professional	1
McCorkle, Emma	Other Professional	1
McCormick, Cyril	Other Professional	2
Meadows, Matt	Other Professional	1
Meng, Xiande	Other Professional	10
Son, Kyongho	Other Professional	1
Stacy, Erin	Other Professional	12
Sullivan, Lynn	Other Professional	2
Visser, Ate	Other Professional	3
Womble, Patrick	Other Professional	1
Hartsough, Peter	Staff Scientist (doctoral level)	4
Arvin, Lindsay	Graduate Student (research assistant)	5
Barnes, Morgan	Graduate Student (research assistant)	6
Callahan, Russell	Graduate Student (research assistant)	9
Chen, Xiaoli	Graduate Student (research assistant)	2
Collins, Caitlin	Graduate Student (research assistant)	4
Devine, Scott	Graduate Student (research assistant)	3
Dove, Nicholas	Graduate Student (research assistant)	8
Ferrell, Ryan	Graduate Student (research assistant)	6
Flinchum, Brady	Graduate Student (research assistant)	1
Heckman, Christopher	Graduate Student (research assistant)	3
Keifer, Ian	Graduate Student (research assistant)	2
Lucas, Ryan	Graduate Student (research assistant)	6
Lukens, Claire	Graduate Student (research assistant)	4
Moreland, Kimber	Graduate Student (research assistant)	9

Oroza, Carlos	Graduate Student (research assistant)	10
Rungee, Joe	Graduate Student (research assistant)	9
Taylor, Nicholas	Graduate Student (research assistant)	9
Thaw, Melissa	Graduate Student (research assistant)	12
Tian, Zhiyuan	Graduate Student (research assistant)	9
Wilson, Stu	Graduate Student (research assistant)	2
Zheng, Zeshi	Graduate Student (research assistant)	1
Araiza, David	Non-Student Research Assistant	2
Everhart, Anthony	Non-Student Research Assistant	4
Jimenez, Ricardo	Non-Student Research Assistant	1
Ayala-Astorga, Maria	Undergraduate Student	3
Castro, Madeline	Undergraduate Student	2
Dziegiel, Abby	Undergraduate Student	3
Elias, Oscar	Undergraduate Student	3
Huang, Jennifer	Undergraduate Student	3
Vang, Mai	Undergraduate Student	2

Full details of individuals who have worked on the project:

Roger C Bales

Email: rbales@ucmerced.edu

Most Senior Project Role: PD/PI

Nearest Person Month Worked: 2

Contribution to the Project: PI, oversight, planning, team lead, hydrologic balance

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Martha H Conklin

Email: mconklin@ucmerced.edu

Most Senior Project Role: Co PD/PI

Nearest Person Month Worked: 2

Contribution to the Project: CZO coPI, InTeGrate Critical Zone course, groundwatersurface water interactions, especially in meadows

Funding Support: SSCZO, UC Merced, other funding

International Collaboration: No

International Travel: No

Michael L Goulden

Email: mgoulden@uci.edu

Most Senior Project Role: Co PD/PI

Nearest Person Month Worked: 2

Contribution to the Project: CoPI, flux towers, development of tovertop remote sensing system

Funding Support: SSCZO, UC Irvine, other funding

International Collaboration: No

International Travel: No

Clifford S Riebe

Email: criebe@uwyo.edu

Most Senior Project Role: Co PD/PI

Nearest Person Month Worked: 2

Contribution to the Project: CoPI, geophysics, regolith formation and erosion, vegetation-landscape interactions

Funding Support: SSCZO, U. of Wyoming, other funding

International Collaboration: No

International Travel: No

Christina Tague

Email: ctague@bren.ucsb.edu

Most Senior Project Role: Co PD/PI

Nearest Person Month Worked: 1

Contribution to the Project: CoPI, system modeling especially with RHESSys

Funding Support: SSCZO, UC Santa Barbara, USGS, WSU

International Collaboration: No

International Travel: No

Asmeret Asefaw Berhe

Email: aaberhe@ucmerced.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 2

Contribution to the Project: Sediment transport & nutrient cycling

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Steven Glaser

Email: glaser@berkeley.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 1

Contribution to the Project: University of California, Berkeley; Investigator; monitoring technology

Funding Support: UC Berkeley

International Collaboration: Yes, France

International Travel: No

Stephen Hart

Email: shart4@ucmerced.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 3

Contribution to the Project: Sediment transport, nutrient cycling

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Anthony O'Geen

Email: atogeen@ucdavis.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 3

Contribution to the Project: Controls on weathering & regolith formation

Funding Support: other funding

International Collaboration: No

International Travel: No

Mohammad Safeeq

Email: msafeeq@ucmerced.edu

Most Senior Project Role: Co-Investigator

Nearest Person Month Worked: 1

Contribution to the Project: Adjunct Professor on the project, working collaboratively between UC Merced and Pacific Southwest Research Station (Forest Service)

Funding Support: other funding

International Collaboration: No

International Travel: No

Ryan Bart

Email: ryanbart@berkeley.edu

Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)

Nearest Person Month Worked: 3

Contribution to the Project: Post-doctoral student working with Tague and collaborator M. Moritz on shrubs, modeling,

and vegetation-water interactions

Funding Support: SSCZO, WSU, SESYNC

International Collaboration: No

International Travel: No

Joseph Blankinship

Email: joseph.blankinship@lifesci.ucsb.edu

Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)

Nearest Person Month Worked: 1

Contribution to the Project: UC Santa Barbara; former UC Merced Hart lab group member; soil biogeochemistry; preparing findings for publication

Funding Support: other funding

International Collaboration: No

International Travel: No

Aaron Fellows

Email: afellowswork@gmail.com

Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)

Nearest Person Month Worked: 1

Contribution to the Project: Analysis and data QA/QC for flux tower data

Funding Support: Others

International Collaboration: No

International Travel: No

Jennifer Jefferson

Email: jejeffer@mymail.mines.edu

Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)

Nearest Person Month Worked: 1

Contribution to the Project: Colorado School of Mines PhD alumna, current postdoctoral researcher with Maxwell; hydrologic modeling

Funding Support: Lawrence Livermore National Laboratory, other funding

International Collaboration: No

International Travel: No

Elizabeth Williams

Email: ewilliams22@ucmerced.edu

Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)

Nearest Person Month Worked: 9

Contribution to the Project: Postdoctoral researcher working with senior personnel Berhe and collaborator Fogel on project for OM retention and stabilization in the subsurface

Funding Support: Other funding

International Collaboration: No

International Travel: No

Sarah Aciego

Email: aciego@umich.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: U. of Michigan; isotope geochemistry, Sierra Nevada dust analysis

Funding Support: external

International Collaboration: No

International Travel: No

Matt Busse

Email: mbusse@fs.fed.us

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 0

Contribution to the Project: USFS Pacific Southwest Research Station, advisory board

Funding Support: Other; CZO funds for travel for Advisory Board duties

International Collaboration: No

International Travel: No

Po Chen

Email: pchen@uwyo.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: U. of Wyoming collaborator; pSin seismic data cross-correlation and processing code

Funding Support: other funding

International Collaboration: No

International Travel: No

Janet Choate

Email: jsc.eco@gmail.com

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: University of California, Santa Barbara; Techno II/Tague Lab Manager; RHESSys technical support staff

Funding Support: SSCZO, USGS, WSU, other NSF funding

International Collaboration: No

International Travel: No

Frank Davis

Email: fd@bren.ucsb.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 0

Contribution to the Project: Advisory Board; University of California, Santa Barbara

Funding Support: Other; CZO funds for travel for Advisory Board duties

International Collaboration: No

International Travel: No

Ken Dueker

Email: dueker@uwyo.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: U. Wyoming; geophysical seismic array

Funding Support: other funding

International Collaboration: No

International Travel: No

Brad Esser

Email: esser1@llnl.gov

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 3

Contribution to the Project: LLNL collaborator; isotope geochemistry and hydrology

Funding Support: Lawrence Livermore National Laboratory

International Collaboration: No

International Travel: No

Marilyn Fogel

Email: mfogel@ucmerced.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: UC Merced faculty; ecology and biogeochemistry

Funding Support: other funding

International Collaboration: No

International Travel: No

Michelle Gilmore

Email: mgilmore2@ucmerced.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 9

Contribution to the Project: full-time staff, outreach manager; began September 28, 2015; outreach facilitation and coordination for multiple audiences; website and social media management; annual meeting coordination; external and internal communications

Funding Support: SCZO

International Collaboration: No

International Travel: No

Bob Graham

Email: robert.graham@ucr.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 0

Contribution to the Project: University of California, Riverside; advisory board

Funding Support: Other; CZO funds for travel for Advisory Board duties

International Collaboration: No

International Travel: No

Qinghua Guo

Email: qguo@ucmerced.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: University of California, Merced; Collaborator; remote sensing and GIS

Funding Support: UCM, other funds

International Collaboration: No

International Travel: No

Jorden Hayes

Email: hayesjo@dickinson.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 2

Contribution to the Project: U. of Wyoming PhD; began new position at Dickinson College in spring 2016; geophysical analysis of near-surface processes, including chemical and physical weathering and landscape evolution

Funding Support: other funding

International Collaboration: No

International Travel: No

Steve Holbrook

Email: steveh@uwyo.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: U. of Wyoming; geophysics and seismology

Funding Support: external

International Collaboration: No

International Travel: No

Jan Hopmans

Email: jwhopmans@ucdavis.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: University of California, Davis; Collaborator, Alumni Investigator

Funding Support: Other funds

International Collaboration: No

International Travel: No

Carolyn Hunsaker

Email: chunsaker@fs.fed.us

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: USFS Pacific Southwest Research Station; Sr. Personnel; stream and watershed ecology and hydrology

Funding Support: Forest Service

International Collaboration: No

International Travel: No

Dale Johnson

Email: forestrangesoils@gmail.com

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: University of Nevada, Reno; Collaborator, Alumni Investigator

Funding Support: Other funds

International Collaboration: No

International Travel: No

Anne Kelly

Email: a.kelly@uci.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: Previous graduate student, writing and preparing papers for publication

Funding Support: other funding

International Collaboration: No

International Travel: No

Reed Maxwell

Email: rmaxwell@mines.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: Colorado School of Mines collaborator; ParFlow hydrologic modeling

Funding Support: Lawrence Livermore National Laboratory, other funding

International Collaboration: No

International Travel: No

Emma McCorkle

Email: mccoemma@isu.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: Determining sources of carbon in eroded sediments and nutrient (carbon and nitrogen) fluxes of natural waters; Working on publication preparation

Funding Support: other funding

International Collaboration: No

International Travel: No

Cyril McCormick

Email: mccormic@uci.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 2

Contribution to the Project: UC Irvine project engineer; Goulden research group instrumentation

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Matt Meadows

Email: mmeadows@ucmerced.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: Former SSCZO staff; continuing work on publication preparation

Funding Support: other funding

International Collaboration: No

International Travel: No

Xiande Meng

Email: xmeng@ucmerced.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 10

Contribution to the Project: SSCZO Staff - Data Manager

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Kyongho Son

Email: kson@bren.ucsb.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: UC Santa Barbara PhD alumnus; core CZO measurements, data management and

integration; working on publications

Funding Support: other funding

International Collaboration: No

International Travel: No

Erin Stacy

Email: estacy@ucmerced.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 12

Contribution to the Project: SSCZO Staff, Field Manager; Covered outreach duties until 28 September 2015

Funding Support: SSCZO

International Collaboration: No

International Travel: No

Lynn Sullivan

Email: lsullivan3@ucmerced.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 2

Contribution to the Project: Part-time staff for Outreach and Education projects through September 2015; volunteer for outreach programs through present

Funding Support: other funding

International Collaboration: No

International Travel: No

Ate Visser

Email: visser3@llnl.gov

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 3

Contribution to the Project: Lawrence Livermore National Laboratory collaborator; Isotope hydrology

Funding Support: Lawrence Livermore National Laboratory

International Collaboration: No

International Travel: No

Patrick Womble

Email: pwomble@ucmerced.edu

Most Senior Project Role: Other Professional

Nearest Person Month Worked: 1

Contribution to the Project: University of California, Merced; occasional field assistance at SSCZO; primarily other projects in SNRI

Funding Support: UCM, other funds

International Collaboration: No

International Travel: No

Peter Hartsough

Email: phartsough@ucdavis.edu

Most Senior Project Role: Staff Scientist (doctoral level)

Nearest Person Month Worked: 4

Contribution to the Project: Relationships between soils and weathered bedrock in the O'Geen lab

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Lindsay Arvin

Email: larvin@uwyo.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 5

Contribution to the Project: U. of Wyoming PhD student; geochemical linkages between vegetation, bedrock, and erosion

Funding Support: NSF GRFP

International Collaboration: No

International Travel: No

Morgan Barnes

Email: mbarnes@ucmerced.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 6

Contribution to the Project: Graduate student in the Hart lab, phosphorus in the subsurface

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Russell Callahan

Email: rcallaha@uwyo.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 9

Contribution to the Project: U. of Wyoming PhD student; regolith formation, chemical weathering, and erosion rates

Funding Support: SSCZO

International Collaboration: No

International Travel: No

Xaoli Chen

Email: xiaoli_chen@umail.ucsb.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 2

Contribution to the Project: UC Santa Barbara graduate student; ecohydrologic systems modeling with RHESSys

Funding Support: SSCZO, WSU, USGS, NSF

International Collaboration: No

International Travel: No

Caitlin Collins

Email: collins@mymail.mines.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 4

Contribution to the Project: Colorado School of Mines graduate student; ParFLOw hydrologic modeling

Funding Support: Lawrence Livermore National Laboratory; other funding

International Collaboration: No

International Travel: No

Scott Devine

Email: smdevine@ucdavis.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 3

Contribution to the Project: UC Davis; soil hydrology characterization

Funding Support: other funding

International Collaboration: No

International Travel: No

Nicholas Dove

Email: ndove@ucmerced.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 8

Contribution to the Project: Graduate student in the Hart lab, mycorrhizal study

Funding Support: SSCZO, UCM, other funding

International Collaboration: No

International Travel: No

Ryan Ferrell

Email: rmferrell@ucdavis.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 6

Contribution to the Project: Graduate student in O'Geen lab, work on neutron probe, saprock investigations, and others

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Brady Flinchum

Email: bflinch1@uwyo.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 1

Contribution to the Project: U. Wyoming PhD student; seismic data collection and interpretation

Funding Support: other funds

International Collaboration: No

International Travel: No

Christopher Heckman

Email: checkman@bren.ucsb.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 3

Contribution to the Project: UC Santa Barbara; ecohydrologic modeling

Funding Support: SSCZO, USGS

International Collaboration: No

International Travel: No

Ian Keifer

Email: ikeifer@uwyo.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 2

Contribution to the Project: U. of Wyoming graduate student; geophysical data processing code

Funding Support: other funding

International Collaboration: No

International Travel: No

Ryan Lucas

Email: rlucas@ucmerced.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 6

Contribution to the Project: UC Merced PhD student; Surface-groundwater interactions

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Claire Lukens

Email: clukens@uwyo.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 4

Contribution to the Project: Regolith formation and erosion; near-surface geophysics; vegetation-landscape interactions

Funding Support: other funding

International Collaboration: No
International Travel: No

Kimber Moreland

Email: kmoreland@ucmerced.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 9

Contribution to the Project: Graduate student in the Hart and Berhe labs working on nitrogen in the subsurface

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Carlos Oroza

Email: coroz@berkeley.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 10

Contribution to the Project: Graduate student on developments for the wireless sensor network and site selection

Funding Support: SSCZO, other funding

International Collaboration: Yes, France

International Travel: Yes, France - 0 years, 2 months, 0 days

Joe Rungee

Email: jrungee@ucmerced.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 9

Contribution to the Project: University of California, Merced; Ecohydrology, data modeling

Funding Support: UC Merced, other funding

International Collaboration: No

International Travel: No

Nicholas Taylor

Email: ntaylor9@uwyo.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 9

Contribution to the Project: Graduate student at U. of Wyoming, geophysics and subsurface remote sensing

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Melissa Thaw

Email: mthaw@ucmerced.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 12

Contribution to the Project: Graduate student in the Conklin lab; isotope hydrology, ecohydrology

Funding Support: SSCZO, Lawrence Livermore National Laboratory, UC Merced, Southern California Edison, others

International Collaboration: No

International Travel: No

Zhiyuan (Tina) Tian

Email: ztian@ucdavis.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 9

Contribution to the Project: Graduate student in O'Geen group, neutron probe, spatial work, soil chemistry, and others

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Stu Wilson

Email: stuwilson@ucdavis.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 2

Contribution to the Project: Graduate student at UC Davis; soil characterization and chemistry

Funding Support: Other funding

International Collaboration: No

International Travel: No

Zeshi Zheng

Email: zeshi.z@berkeley.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 1

Contribution to the Project: Graduate student work on LiDAR ground-truthing, Wireless data at Providence

Funding Support: Other funding

International Collaboration: No

International Travel: No

David Araiza

Email: daraiza@ucmerced.edu

Most Senior Project Role: Non-Student Research Assistant

Nearest Person Month Worked: 2

Contribution to the Project: UC Merced research assistant in Fogel lab

Funding Support: other funding

International Collaboration: No

International Travel: No

Anthony Everhart

Email: aeeverhart@ucmerced.edu

Most Senior Project Role: Non-Student Research Assistant

Nearest Person Month Worked: 4

Contribution to the Project: volunteer January-June 2016; part-time employee as of 6 June 2016; soil, snow, precipitation, and vegetation sampling with M. Thaw

Funding Support: other funding

International Collaboration: No

International Travel: No

Ricardo Jimenez

Email: ricardoj@uci.edu

Most Senior Project Role: Non-Student Research Assistant

Nearest Person Month Worked: 1

Contribution to the Project: UC Irvine junior specialist research assistant; Goulden research group

Funding Support: SSCZO, other funding

International Collaboration: No

International Travel: No

Maria Ayala-Astorga

Email: mayalaastorga@ucmerced.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 3

Contribution to the Project: undergraduate field assistant, summer 2016

Funding Support: SSCZO

International Collaboration: No

International Travel: No

Madeline Castro

Email: mcastro29@ucmerced.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 2

Contribution to the Project: outreach program assistant; website updates, outreach materials drafting and event assistance, data entry

Funding Support: SSCZO

International Collaboration: No

International Travel: No

Abby Dziegiel

Email: adziegiel@ucmerced.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 3

Contribution to the Project: Undergraduate student assistant for Hart

Funding Support: CZO & other

International Collaboration: No

International Travel: No

Oscar Elias

Email: oelias2@ucmerced.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 3

Contribution to the Project: undergraduate assistant in Hart Lab

Funding Support: other funding

International Collaboration: No

International Travel: No

Jennifer Huang

Email: jhuang26@ucmerced.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 3

Contribution to the Project: Undergraduate assistant in Hart Lab

Funding Support: other funding

International Collaboration: No

International Travel: No

Mai Vang

Email: mvang25@ucmerced.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 2

Contribution to the Project: Undergraduate assistant in Hart Lab

Funding Support: other funding

International Collaboration: No

International Travel: No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
Lawrence Livermore National Laboratory	Other Organizations (foreign or domestic)	Livermore, CA
US Forest Service, Pacific Southwest Research Station	Other Organizations (foreign or domestic)	Fresno, CA

Full details of organizations that have been involved as partners:

Lawrence Livermore National Laboratory

Organization Type: Other Organizations (foreign or domestic)

Organization Location: Livermore, CA

Partner's Contribution to the Project:

Financial support

In-Kind Support

Facilities

Collaborative Research

More Detail on Partner and Contribution: Collaboration with Co-PI M. Conklin on SSCZO meadows

US Forest Service, Pacific Southwest Research Station

Organization Type: Other Organizations (foreign or domestic)

Organization Location: Fresno, CA

Partner's Contribution to the Project:

In-Kind Support

Facilities

Collaborative Research

More Detail on Partner and Contribution:

What other collaborators or contacts have been involved?

Molly Blakowski [U. of Michigan grad student] with Sarah Aciego

Singleton Thibodeaux-Yost; Daniel Carlson; Bethany Soto [California Regional Water Quality Control Board] – Post-fire monitoring plan for Rough Fire area (S Fork Kings River, Hume Lake, Mill Flat Creek) with an emphasis on water quality on turbidity, DO, EC, temperature, pH, metals, and nutrients; potential collaboration with Forest Service too. Spoke/emails (Feb 16, 2016) with them about available CZO data, connected with KREW (Hunsaker, Safeeq) regarding KREW data as a baseline.

Joost Iwema [graduate student, University of Bristol, United Kingdom] – using data from tower/Irvine soil sensors in conjunction with COSMOS evaluation, especially at Soaproot. (Emails, Feb 2016)

Yufang Jin and Toby O'Geen [UC Davis] – parameterizing cost-effective rangeland biomass measurement tool (remote sensing), at SJER; help from CZO staff with permitting and scouting

Sarah Hall [Faculty, College of the Atlantic] – establishing undergraduate environmental field course that will spend 1-2 days at SSCZO in summer 2017; scouted in June 2016

NASA Cal/Val – groundtruthing satellite near-surface water quantification; adding additional soil moisture sensors; 2017 implementation?

Jeff Lauder [grad student, UC Merced] and Emily Moran [faculty, UC Merced] – vegetation productivity, vegetation surveys, and pine species adaption to climate change and elevation movement (Providence, Soaproot, Short Hair – inquiries with SCE and private landowners about research there)

Jill Marshall [postdoctoral scholar, UC Berkeley] Tree root instrumentation and root pressures at root-rock interface. Instrumentation depending on my budget and time (dime-sized force sensors at the root-rock interface, maybe data loggers and maybe wind sensors and tilt meters (Providence, Soaproot– inquiries with SCE and private landowners about research there).

Impacts

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

From the outset the Southern Sierra CZO was planned as a resource for the critical-zone research community, and our team has actively engaged others in using this resource. Three levels of users are represented at the Southern Sierra CZO: the core CZO team, research collaborators and cooperators. Our core team represents six universities plus the USFS. Over 20 research groups are collaborators. These collaborator groups are not formally part of the Southern Sierra CZO grant, but work with the core team using largely other resources and are an important part of the SSCZO. In addition, several additional cooperators use Southern Sierra CZO data, collect samples at the Southern Sierra CZO or make use of other CZO resources in their own work.

Modeling holds an important role in disseminating research results. Modifications by C. Tague to the Regional HydroEcologic Simulation System (RHESSys) serve as mechanisms for encoding advances made by our field based analyses. Ongoing refinement of the RHESSys code and RHESSys parameterization are part of the CZO, and provide tools that are made accessible to a broader earth-system-science modeling community. RHESSys code and parameter libraries are made available through github (<https://github.com/RHESSys/RHESSys>). In this 2015-16 year we emphasized:

- a) the development of new physiological parameters for chaparral and conifer species derived from field measurements, and
- b) development of new routines within RHESSys that support testing of different assumptions about how neighboring trees share water.

We note that RHESSys is used by eco-hydrologists throughout the world – and results from this tool development will be particularly useful for researchers in other semi-arid and snow-dominated systems.

A. O'Geen, C. Riebe and colleagues are implementing empirical geophysical modeling, which will also be linked with the RHESSys modeling.

In collaboration with the Wyoming Center for Environmental Hydrology and Geophysics (WyCEHG), we have developed a workflow can be applied to other landscapes across the world to study the link between regolith properties and ecosystem processes. Optimizing and integrating geophysical methods allowed us to model the subsurface composed of various weathered rock types and quantify the water holding capacity and plant available water used by Sierra Nevada vegetation. These rock properties were compared to remotely sensed and ground-truth ET values. We observed a correlation between bedrock lithology and plant productivity, as indicated by ET. The data suggest that environments with a relatively thin weathered zone cannot support plant life, even if the climate is ideal for vegetation growth.

What is the impact on other disciplines?

We used a seismic geophysical method, known as ambient seismic interferometry, combined with an adapted Hertz-Mindlin rock physics model to image porosity in 3-D across three compositionally distinct granites that underlie a gradient in vegetation cover and evapotranspiration (ET). The integration of these methods provided a foundation for future studies of deep critical zone structure, currently difficult and expensive to model with more traditional methods (e.g. drilling).

We collaborate with work carried out on several other research grants, including three other NSF awards at UC Merced:

- WSC Category 3: Propagating climate-driven changes in hydrologic processes and ecosystem functions across extreme biophysical and anthropogenic gradients, Award 1204841, PI: T. Harmon.
- MRI: Development of a basin-scale water balance instrument cluster for hydrologic, atmospheric and ecosystem science, Award 1126887, PI: R. Bales.
- REU Site: Yosemite environmental science research training, Award 1263407, PI: S. Hart.

It is planned that the proposed NEON core site and relocatable sites be co-located with the SSCZO; and permitting and planning work is underway by NEON.

The SSCZO works with the U.S. Forest Service and U.S. Park Service as they plan and implement forest- restoration strategies for the Sierra Nevada. Our work is central to informing the water-cycle impacts, drought resilience and other aspects of how the forest will respond to management actions and disturbance.

Tague received a SESYNC (National SocioEnvironmental Synthesis Center) grant that supports a two-year working group on integrating economic and biophysical models to examine pre and post ecosystem service impacts of wildfire and fuel treatment (title: Wildfire Management, Ecosystem Dynamics, and Climate: The Role of Risk Salience in Driving Ecological Outcomes). The SESYNC working group uses several Western U.S. case-study sites, including the SSCZO. RHESys is the core biophysical model used in coupled analysis, and its parameterization and application is being based on the CZO. Model-based analysis of the sensitivity of forest hydrology and carbon cycling to climate variability and to forest management is increasingly of interest to both forest managers and water-resource managers in the Sierra. Both the SESYNC working group and a dissertation supervised by Tague (Kastl) explicitly involve resource management stakeholders. Kastl is investigating how science-based model presentation influences how stakeholders understand the complex watershed dynamics studied by scientists at the CZO. The SESYNC working group will involve forest managers from agencies as well as communication expertise through COMPASS a group that specializes in science based communication for the public (<http://www.compassonline.org/>).

Our spatially dense soil-moisture and matric-potential measurements over an 8-yr time period, plus the coincident measurements of snowpack, solar forcing, temperature, and relative humidity will be analyzed to better understand the multi-sector, cumulative impact of multiple years of drought in CA.

We believe the discovery of deep carbon in weathered bedrock will have a significant impact on the knowledge base of carbon stocks in terrestrial environments.

We have made several advances in wireless-sensor-network optimization, which are both important to the CZO network and have applications well beyond the CZOs. Existing algorithms in computer science do not have the data necessary to inform real-world deployments of wireless monitoring technologies. We have shown that field-hardened optimization needs to incorporate the long term evolution of signal strength (RSSI) and packet delivery ratio (PDR) along each link in the wireless network, as well as understanding how environmental factors (such as trees, changes in humidity etc.) impact wireless performance. By analyzing historical signal strength data from the CZO and combining with classification algorithms, graph theory etc., we were able to produce an approach that combines insights from multiple disciplines to create a standard approach to establishing new wireless observatories. We worked with our collaborators at INRIA Paris (French National Lab) to develop a new data architecture for remote environmental monitoring systems. This architecture simplifies the data coming across wireless-sensor networks by dividing each packet into a "sensor object" with a defined type and MAC address. These packets can be easily transmitted through base station and unpacked at remote servers. SOL has the potential to be used across multiple disciplines in environmental sensing and our collaborators at INRIA are working to make the system open source so anyone can use and develop upon it. The SOL architecture will facilitate real-time data transfer and archiving. Our collaborators are also working on real-time data visualization and archiving tools for the SOL architecture based on InfluxDB, Grafana, and Google maps, which I am currently working to adapt for the SSCZO wireless-sensor network.

We have integrated techniques from machine learning to develop more-rigorous approaches to observatory design. Specifically, we employed unsupervised and semi-supervised learning algorithms (a Gaussian Mixture model and Gaussian Process, respectively) to find representative sensor locations for spatially distributed snow observatories. We then analyze the long-term accuracy of these methods using shared SSCZO data and collaboration with LiDAR data. Our results suggest that adopting these techniques can result in observatory designs that produce more accurate estimates of spatially distributed variables such as snowcover (relevant to the primary disciplines of Hydrology/Environmental Sensing). These techniques are not limited to snowcover or wireless sensor networks; they can be applied broadly in the field of environmental sensing.

P. Chen's pSin code, initially written to run cross-correlations on our SSCZO seismic data, will provide services to other researchers attempting to process large-scale data (several terabytes). The code was published in *Computers and Geosciences* and is available to the public.

What is the impact on the development of human resources?

SSCZO staff and students have engaged in four curriculum-development or teacher training partnerships this year. Members of our team have given interactive presentations to, among others, TASTES, a local teacher training program; and at STEM Tracks, a two-year teacher-development program covering three mountain counties. The interactive Next Generation Science Standards activities included field trips through forests and several climatic biomes in the Sierra Nevada. It should be noted that UC Merced is a Hispanic Serving Institution, and the region around UC Merced has a very high proportion of underrepresented students who could be the first in their family to attend college.

SSCZO student R. Lucas was an instructor at the California Institute for Biodiversity (CIB) Climate Change Workshop. He

communicated CZO science in the context of climate change to K-12 teachers that attended the workshop. He also participated in an additional institute through CIB that focused on bringing field investigations into K-12 classrooms in the intent to help facilitate the implementation of Next Generation Science Standards. [ems1] M. Goulden used CZO research results to help train K-12 instructors attending a summer workshop at UC Irvine.

An activity simulating water resource management decisions, developed by R. Lucas and E. Stacy, was adapted for the American Geosciences Institute for teachers, and distributed by the National office in June 2014. We have answered inquiries from teachers making use of the exercise in their classroom. In conjunction with D. Duggan Haas, (CZO National Office), a SSZCO Virtual Field Experience was created to stimulate a field visit and present results. Instructors are able to take their students to the SSCZO P301 site and, using an inquiry approach, acquire information regarding our most pressing scientific questions.

SimWater products were updated by E. Stacy and M. Gilmore after R. Lucas testing the existing exercise material with the UC Merced Critical Zone class taught by M. Conklin.

What is the impact on physical resources that form infrastructure?

The Glaser-Bales team has been installing the new generation of wireless sensor stations. The new WSN boards provide a platform that provides the capacity for a wide range of sensors, up to forty analog and/or digital, to be added to the current twelve. The network is comprised of 27 sensor nodes and 30 data relay nodes. Through an NSF MRI grant, plus state and local support, that technology is being applied at the river-basin scale (American River basin) in the Sierra Nevada. The wireless-sensor network can be viewed as a platform for real-time, spatially distributed environmental monitoring. It is flexible, in that we can add different types of sensors to it, and nodes can be moved around if researchers ever want to use it for more than the current applications of snowcover, energy-balance and soil monitoring.

What is the impact on institutional resources that form infrastructure?

The SSCZO infrastructure and data are a resource for both UC and the community. We receive frequent requests for access to both the data and site. We are planning to make the data availability sustained over the long term.

What is the impact on information resources that form infrastructure?

Data and information. Data-management policies and procedures for the SSCZO are laid out in the management plan. The SSCZO continues to maintain a current and thorough digital library. This is the main repository for data, metadata, protocols, photos and presentations. Raw data are freely available after upload at multiple points per year, and processed data are made available according to CZO data policies. The SSCZO team also participates in the CZO data-management project.

SSCZO Digital Library data catalog

https://czo.ucmerced.edu/dataCatalog_sierra.html and direct link to files:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW

Web and social media. Online efforts complement our written and oral presentations. The main SSCZO online presence is through the CZO website and the SNSJHO digital library. Facebook and Twitter accounts provide an informal counterpart where we share field activities, real time information on conference presentations, and pertinent updates on research and current events. Descriptions for each site follow.

Southern Sierra Critical Zone Observatory (www.criticalzone.org/sierra). This website is the home of the Southern Sierra CZO. In the 2015-2016 year, SSCZO staff expanded the research field areas, added data, posted multiple opportunities, and regularly updated field and research activities. In the coming months, we will focus on

SSCZO Facebook (www.facebook.com/SouthernSierraCZO). The Southern Sierra CZO is the only active CZO Facebook page that we are aware of. This page is slowly growing, and reaches a local cross-discipline audience (broader than environmental science, hydrology, or the CZO network). The audience is more location based, centered around Merced.

SSCZO Twitter (<https://twitter.com/ssczo>). The Southern Sierra CZO was the first CZO in the network with an active Twitter account. Now that the network has expanded and other CZOs are active on Twitter, it is a space for the SSCZO to connect with others observatories and researchers interested in critical zone science. Southern Sierra CZO posts events, photos, and links to other pertinent stories and blog posts on the Twitter page. This avenue has been useful in reaching researchers, media and other professionals, particularly in publicizing research presentations during professional conferences

R. Bales Twitter (<https://twitter.com/rbalesuc>). PI R. Bales also uses Twitter regularly to disseminate and comment on issues related to the SSCZO and the CZO network.

What is the impact on technology transfer?

The Southern Sierra CZO has a high profile with resource-management stakeholders in California and the broader region. Our research addresses fundamental knowledge gaps around management of water supplies, forests, hydropower and integrated ecosystem services. The enhanced predictive capabilities that we are developing provide much needed tools to understand the effects of management actions, disturbance and climate warming on ecosystem services. Adapting to climate change basically involves managing ecosystem services, with water related ecosystem services being an early if not primary focus. Having a CZO with major capability to inform and influence adaptation around water supply in California is very timely given the state's global leadership role in implementing climate solutions.

California is grappling with many challenges at the intersection of water, forests and climate. Water security is the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water related risks. Water security in semiarid regions is founded on adequate water storage. Four consecutive dry years have emphasized the significance of the problem in California. In some cases, management actions can in part offset the effects of climate warming, and can lower the risk of severe disturbance, e.g. wildfire. Both the knowledge and technology developed by the SSCZO are informing decision making around water storage and ecosystem services.

In addition to broad outreach to resource managers and stakeholders, the SSCZO attends to other audiences. The general public is the audience for many of our communications, including press reports and newspaper opinion pieces. We have given public talks in local communities, as well as presentations to civic organizations. The Southern Sierra CZO has been employing internet tools as part of its outreach program. SSCZO presences on Twitter and Facebook have gained more followers. These social-media platforms are available to the public, and also provide a way to disseminate information about events and activities to CZO and non-CZO researchers and students. E. Stacy has organized a monthly Science Café for the City of Merced, drawing on SSCZO as well as other science issues of public interest. SSCZO PI R. Bales, Co-PI M. Conklin, collaborator M. Safeeq and others have presented to local groups in the region and across the state.

We are making make the wireless-sensor network methods we're developing open source so anyone can use them, including the sensor-placement algorithm, the SOL architecture for wireless-sensor networks, and the tool to predict RSSI discussed above. See <http://github.com/realms-team/sol>.

What is the impact on society beyond science and technology?

Building on the success of the SSCZO in bringing a multi-campus collaboration to address knowledge gaps that are critical to California and the Western United States, several UC faculty from 5 campuses, including 3 SSCZO investigators, last year started the UC Water Security and Sustainability Research Initiative (<http://ucwater.org>) that links headwater research under the SSCZO with complementary research on valley groundwater systems and water policy. UC Water is supported by the UC Office of the President, and aims to focus UC resources on key problems and working alongside California's water leaders to achieve a water-secure future and build the knowledge base for better water-resources management. This multi-campus initiative blends UCs technical advances in water resources with parallel innovations in policy analysis and decision support to meet the state's water-security challenges. Three elements of water security underpin the research. First, salient, credible and legitimate water information at the proper spatial and temporal scale is a bottleneck for sound decision making. UC Water will develop innovative, quantitative water accounting and analysis methods that replace century-old technology and provide the foundation for better decisions under increasing uncertainties. Embedding modern information systems into both natural and engineered infrastructure is feasible, affordable and timely. Second, understanding the way water flows through the natural environment, and how it is extracted, conveyed and stored in built and natural infrastructure is fraught with uncertainties. UC Water will make immediate research contributions by developing understanding of land-cover changes on source-water areas, and tools and techniques for better groundwater management. Third, water-management institutions in California have not kept pace with yesterday's scientific and engineering developments, let alone developed the capacity to adapt to 21stcentury stressors. UC Water will tightly weave legal and policy research through its scientific agenda to create an integrated whole. Through integration of measurement and modeling technologies, and drawing on UC expertise across disciplines, UC Water aims to make rapid progress towards filling the gaps.

Our SSCZO results developing a viable method to quantify groundwater storage over a large-scale area (several acres) could influence water policies towards more sustainable practices.

Changes/Problems

Changes in approach and reason for change

The California drought has led the SSCZO to focus more directly on understanding related to the resiliency of California's critical Sierra Nevada headwaters. Essentially all aspects of the CZO research agenda, as outlined in the five areas presented in the Accomplishments section, are contributing to the focus.

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

Our subsurface drilling plans were postponed from year 1 until geophysical surveys could be completed to inform the drilling effort. A particularly insightful round of geophysical surveys was completed in summer and fall 2015, in work led by a graduate student who started in fall 2014. The geophysical work was supplemented by Geoprobe coring and by trenching of large soil pits, allowing us to obtain direct observations of physical and chemical properties of the subsurface. Though most cores were collected and most pits were completed last fall, some of this work was postponed until this spring and summer owing to wildfires and early snow in the area.

Together, results from the coring, pit digging, and geophysical imaging have helped us focus on several exciting new questions about how regolith thickness and development vary across landscapes and how they influence overlying ecosystems. For example, the data collected thus far are consistent with the hypothesis that evapotranspiration, and thus ecosystem productivity, is coupled to the depth and degree of weathering of regolith across mountain slopes spanning a wide range in land cover, from bare rock to dense forest. As trees continue to die in the ongoing California drought, our data may also help us test the hypothesis that the sensitivity of ecosystems to water stress is ultimately regulated by water holding capacity in the subsurface, which is in turn influenced by regolith thickness and degree of weathering.

In the next year, with the help of the remaining drilling funds – which we will need to carry over into year 4 – we plan to conduct a deeper-reaching program of drilling to explore the emerging hypothesis that regolith thickness is set by the interaction of topographic and tectonic stress fields, which allow fractures to open in the subsurface. Thus, our use of the drilling funds has evolved into a test of the exciting hypothesis that tectonic stresses in Earth's crust influence ecosystem response to drought stress at Earth's surface through their effects on regolith thickness.

Changes that have a significant impact on expenditures

We postponed hiring of a postdoc due to the longer-recruitment needed to bring in someone with the well-developed integrated-modeling background and skills needed. This will result in the need for carryover funds, as it was budgeted for year 3.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.

Table 1. Carbon stock (kg C m⁻²) in soil and regolith (soil + weathered bedrock).

Site	Regolith			Soil		
	Minimum	Median	Maximum	Minimum	Median	Maximum
Elevation (m)	(kg C m ⁻²)	(kg C m ⁻²)	(kg C m ⁻²)	(kg C m ⁻²)	(kg C m ⁻²)	(kg C m ⁻²)
400	4.04±0.67	4.14±0.66	4.40±0.70	3.98±0.62	4.07±0.60	4.32±0.63
1100	10.90±3.51	11.60±3.74	13.11±4.21	8.70±3.20	9.21±3.39	10.27±3.72
2000	29.32±16.3	32.07±17.6	33.37±18.1	23.47±15.5	25.47±16.7	25.82±16.9
	2	8	0	0	3	0
All sites	13.62±13.0	14.67±14.3	15.75±14.7	11.12±11.1	11.89±12.1	12.51±12.2
	5	0	1	8	6	2

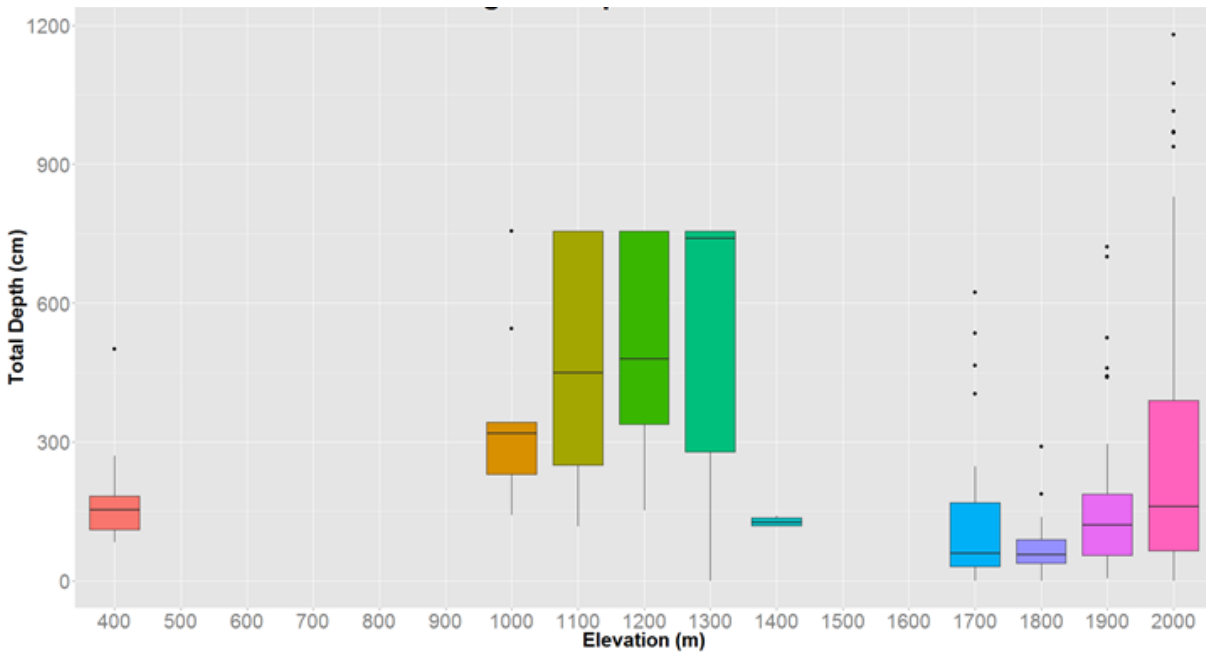


Figure. 1. Regolith thickness across the Sierran elevation gradient. Glaciated terrain above 3000 m was not included in this analysis.

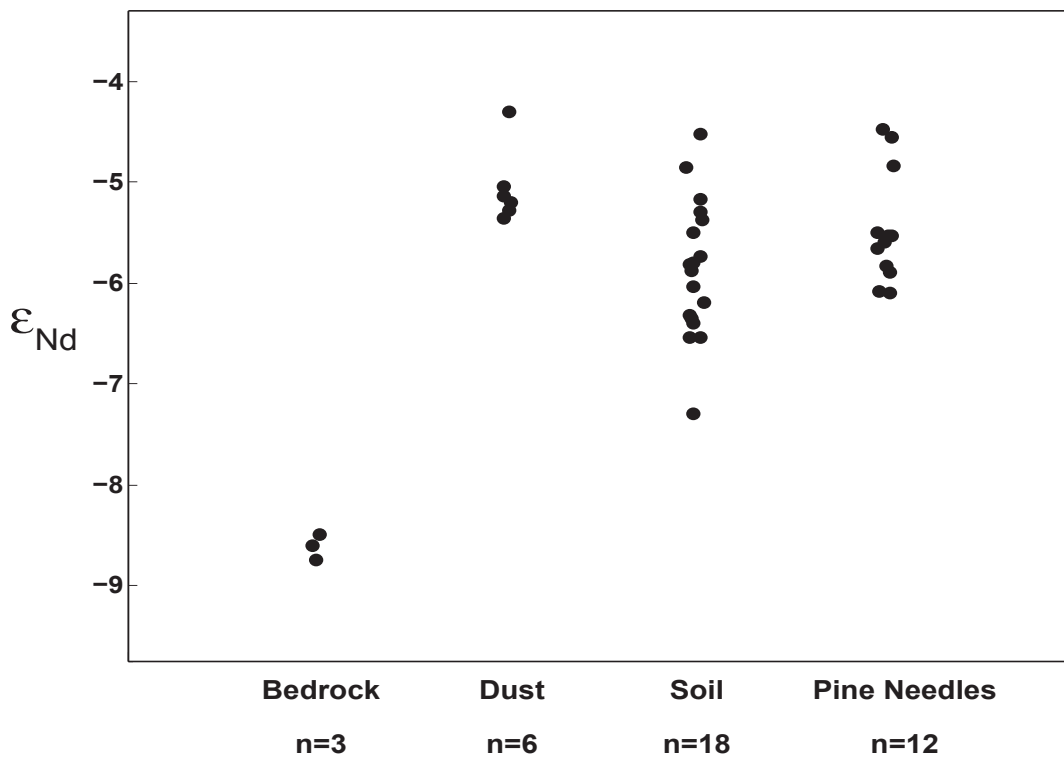


Figure 2: ϵ_{Nd} values of bedrock, dust, soil, and pine needle samples from the Bald Mountain Granite. Individual data points are displayed with horizontal jitter for clarity. These results indicate that dust accounts for between 70 and 80 percent of the Nd in soils and pine needles, assuming that dust and bedrock are the two sources of the element in each case.

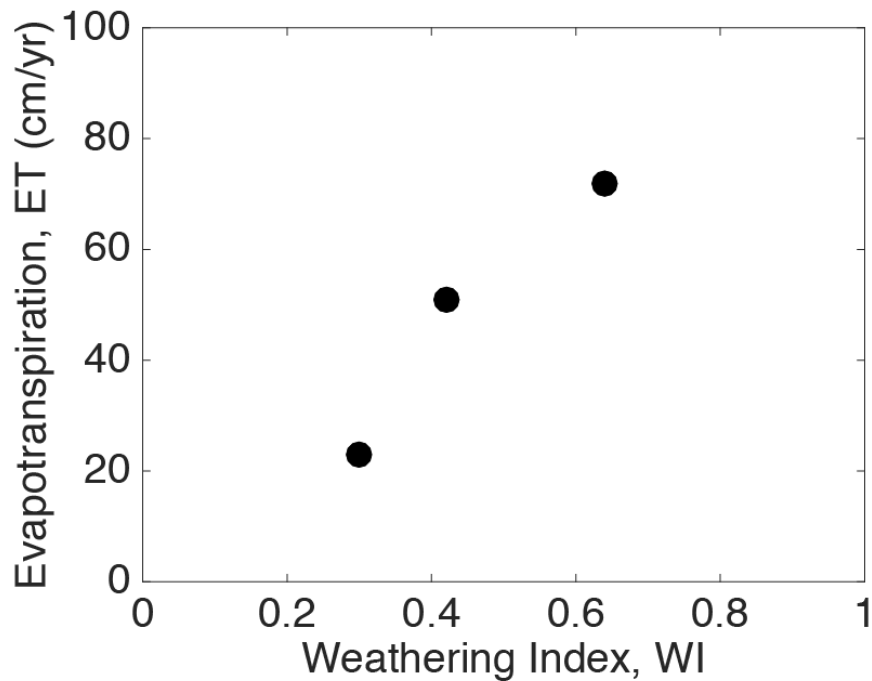


Figure 3. Weathering index (WI) is averaged over the 3.6 ha area of each geophysical survey and is calculated as the normalized difference between the theoretical maximum and measured shear-wave velocity at each point on the landscape. (Note: this means that low values of WI imply little water storage capacity and high values of WI imply large water storage capacity.) Evapotranspiration (ET), a measure of ecosystem productivity, is inferred from remotely sensed NDVI using regression relationship of Goulden and Bales (2014).

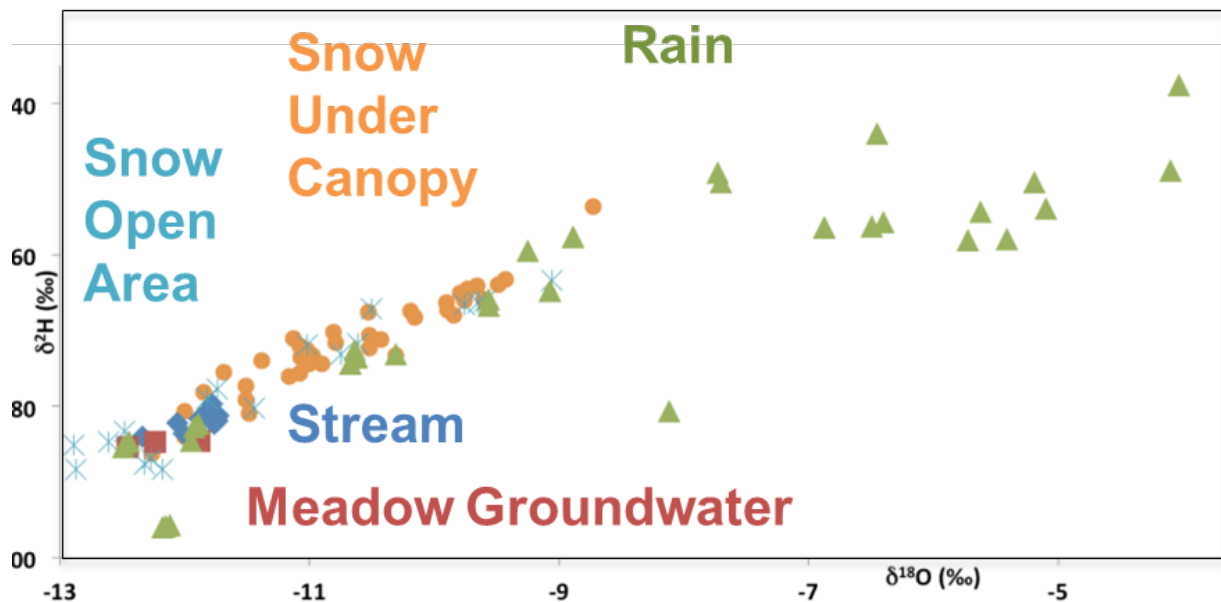


Figure 4. The changing isotopic signature of hydrological compartments – snow, rain, groundwater, stream – over the year.

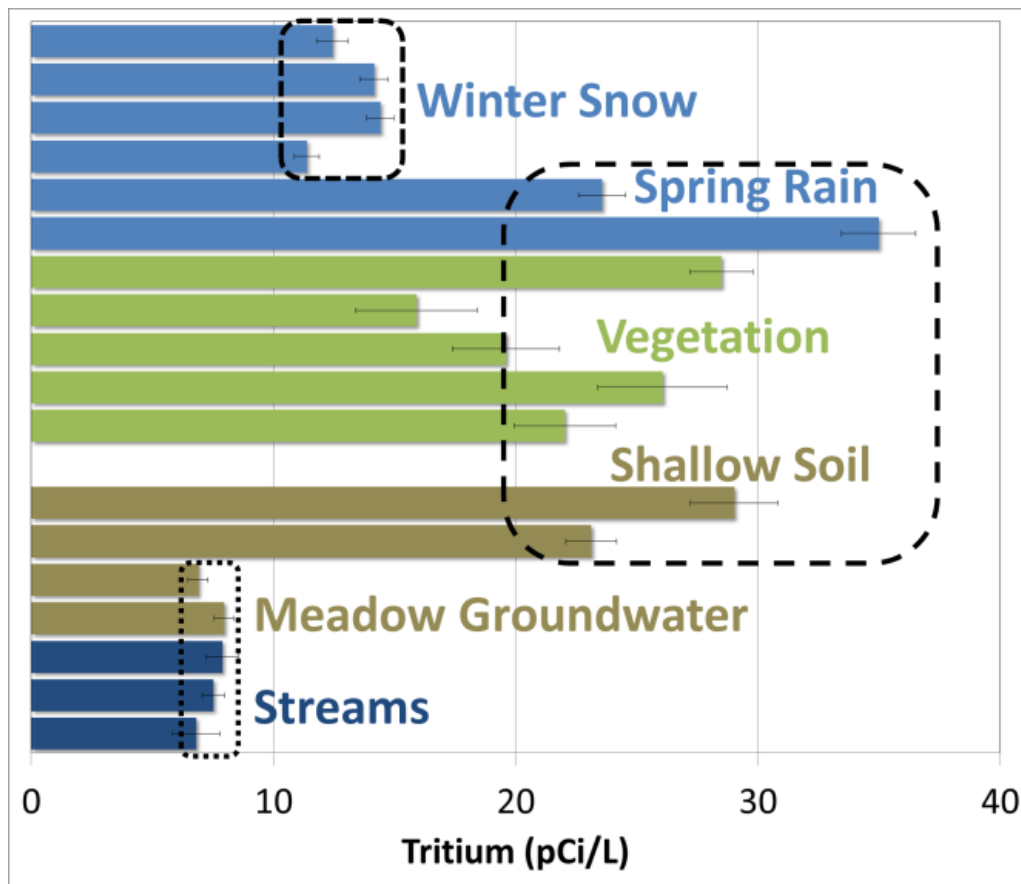


Figure 5. Tritium activities in snow, rain, vegetation, shallow soil, groundwater and streams show disconnect between snow, spring rain, vegetation and shallow soil and meadow groundwater and streams.

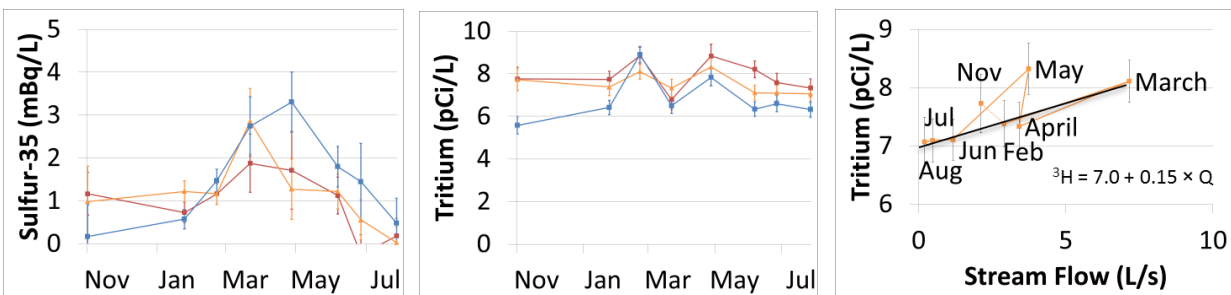


Figure 6. Monthly variation of residence time tracers sulfur-35 (left, $t_{1/2} = 87$ days) and tritium (middle, $t_{1/2} = 12.3$ years) in P301 (red), P300 (orange) and Big Creek (blue), and correlation between tritium and stream flow (P300).

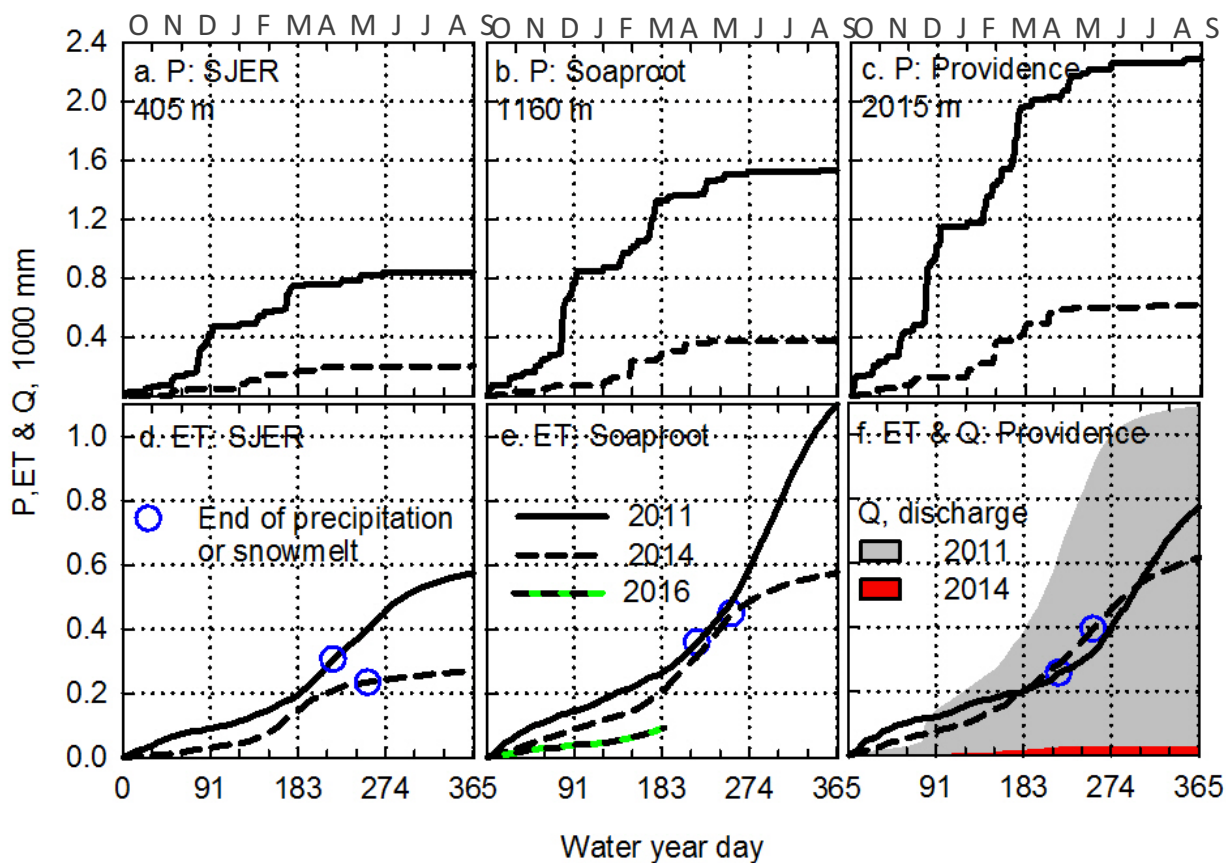


Figure 7. Cumulative daily precipitation (a-c) and ET (d-f) measured by eddy correlation for 2011 and 2014, for San Joaquin (Oak Savannah) and two forested sites, Soaproot and Providence. Discharge for one catchment at Providence also shown on panel (f). Vertical lines on ET graphs indicate last day of precipitation and snowmelt for 2011 and 2014, marking the day after which all ET and streamflow came from storage that was not replenished until the next rain (right after end of water year). ET for Soaproot in first half of 2016 shown is black/green dashed line. Months indicated at top. Manuscript in preparation..

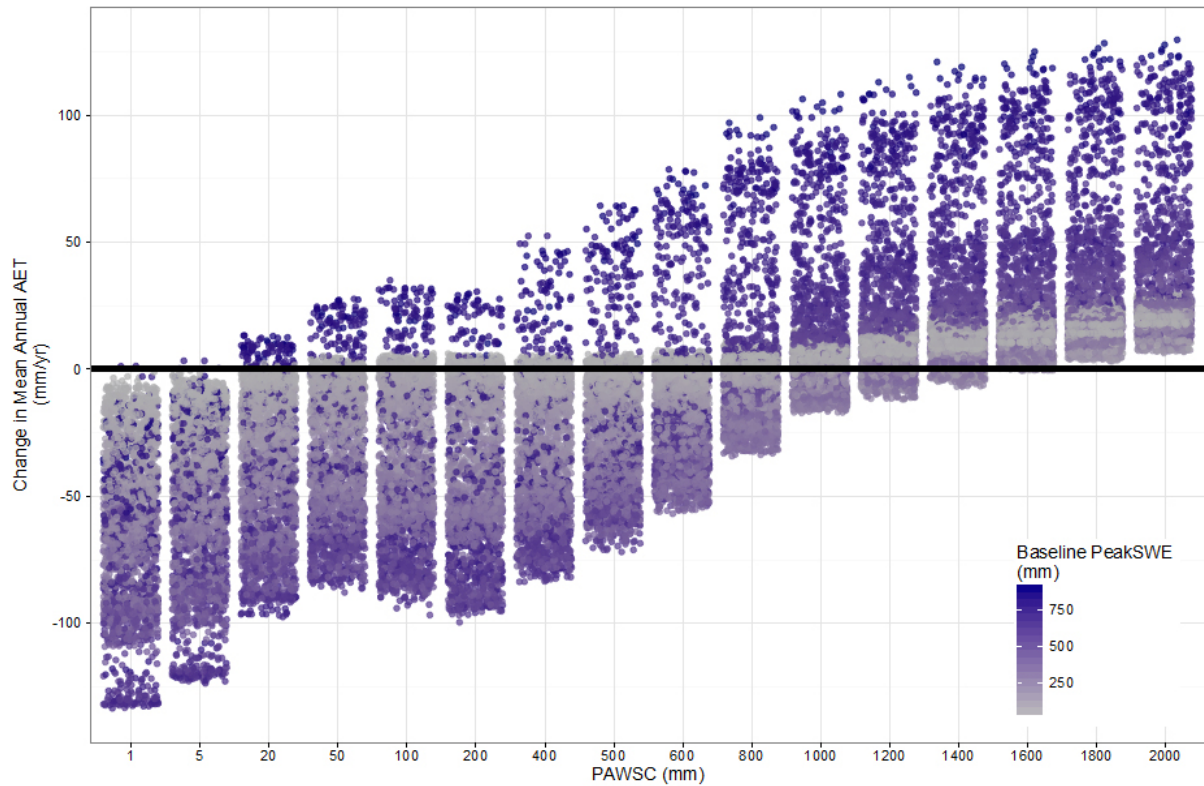


Figure 8. Estimates of changes in actual ET (AET) with 2°C warming for more than 2000 locations along elevational transects in the Sierra Nevada, based on RHESSys modeling. Each point is a change for a given site, with the color shading indicating the mean annual peak snowpack. Abcissa is plant available water storage capacity (Tague et al., in review).

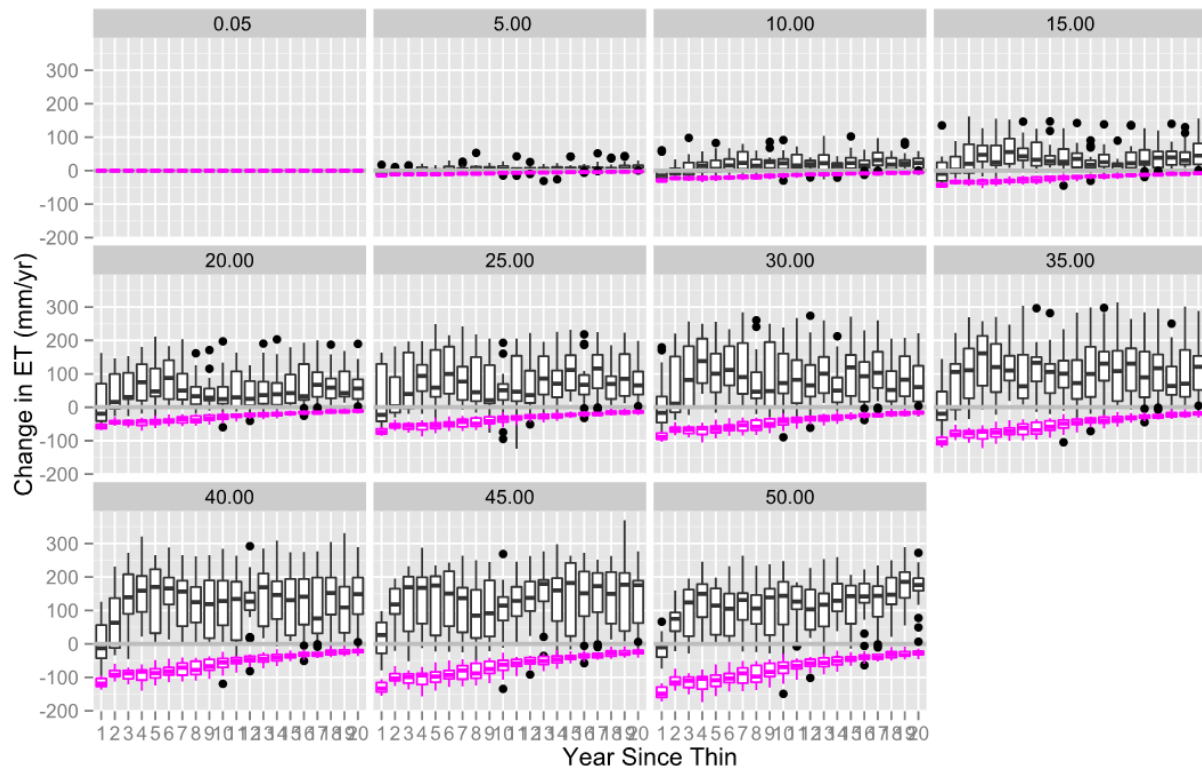


Figure 9. Estimated post-thinning recovery trajectories, shown as change in ET, relative to undisturbed baseline. Boxes depict the impact of inter-annual climate variation. Black boxes show recovery if we assume that neighboring trees share water. Pink symbols show results assuming tree roots are isolated. Panels show increasing levels of biomass removal during thinning (Tague and Moritz, in review).

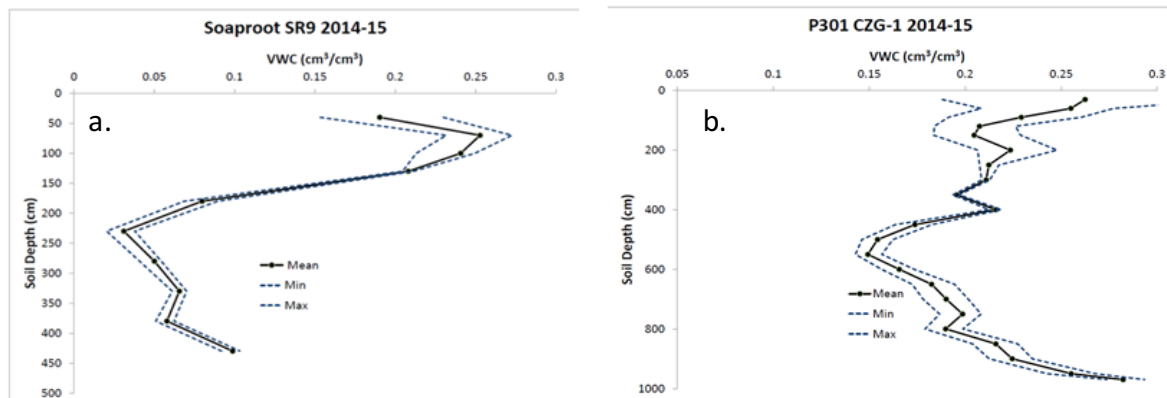


Figure 10. Regolith water content at a) 1100 m and b) 2000 m elevation.

Additional Reporting Requirements

Metrics. Performance metrics for the SSCZO fall under three categories: output metrics, outcome metrics, and impact metrics. Output metrics include the publication of data and results online in our digital library and through peer-reviewed publications. The amount of data and number of publications are tracked.

During the past year the core SSCZO team had 34 journal papers citing the SSCZO published and in review in leading peer-reviewed journals. This does not include papers by SSCZO cooperators. SSCZO research was also highlighted by team members in presentations at many conferences over the past year, and many more seminars and public talks. We are implementing tracking for publications by collaborating and cooperating investigators, but those data are not yet available. In the past year, we know of at least two peer-reviewed articles published using data obtained from SSCZO that do not list any SSCZO core team members as authors (Webb et al., 2015; Chen et al., 2016).

Data are housed in an online digital library that is hosted on UC Merced servers and also accessible through the new website portals. Core measurements, including water-balance instrument clusters, soil moisture and flux-tower data, are posted in raw format promptly after retrieval from the field. Processed data, including full QA/QC procedures are posted at least annually for core measurements. SSCZO staff (the data manager and the field manager) help coordinate the compilation of data and appropriate metadata in the digital library. In accordance with the cross-CZO data-management policy, data from all projects will be posted within two years, with the possibility of restricting access for a third year if needed by the investigator for the purposes of publishing. During the last year we met these goals. Most core data underwent quality assurance and quality control and were posted within a few months after the end of the water year. We published the first five years of CZO data in a perpetual archive, and have a doi assigned.

As part of our effort to measure outcomes, we tracked citations of our peer-reviewed papers, use of our data, and online reach. We also track the number of scientists interested in coordinating with the SSCZO. As listed above, there are more than 25 collaborators working on active projects or pursuing new projects with the SSCZO team.

The depth and breadth of our reach online is tracked through several metrics, including use of our data from Google Analytics for our main website, tracking activity on Twitter and Facebook, and the use of data from the digital library. As an online resource, the Sierra Nevada-San Joaquin Hydrologic Observatory (SNSJHO) digital library is accessed not only by SSCZO team members but also by the broader population of researchers online. We now have a several dozen registered users for SSCZO data on the digital library; eight of those users registered since our last annual team meeting. Note that many of our data are public, and it is not necessary to register to access those data.

Since we started tracking website activity with Google Analytics in September 2013, we have had more than 62,200 page views, 10,760 unique visitors, and an average site visit time of 4:00. This year's highest month of site activity was in April 2016, when 802 individual sessions occurred on SSCZO website, from 567 individual users; we garnered heightened, national attention in April when articles featuring SSCZO were published in The New York Times, The Desert Sun, and USA Today. The Southern Sierra CZO is maintaining a Facebook page, with 72 likes. Through Twitter, the SSCZO connects with other observatories, researchers, and organizations interested in critical zone science. Since the SSCZO Twitter account was created in 2013, we have gained 290 followers and have posted a total of 549 tweets. In the past year, we have gained 168 new followers and 3,743 profile visits, and generated over 60,000 tweet impressions. Since starting in Dec 2014, SSCZO PI R. Bales has sent 931 tweets and has 730

followers. Several other SSCZO colleagues use twitter and post tweets relevant to SSCZO, including new SSCZO presentations and publications.

We conducted a RHESys training workshop using CZO data for Ph.D. students from multiple universities, which focused on implementing the model to investigate forest management and climate change impacts on watershed hydrology.

We also track the adoption of our technology at other sites. The wireless sensor network developed at the SSCZO has been implemented in the American River Basin project west of Lake Tahoe. Work completed in 2014 included instrumentation at 14 sites in the American River Basin project. In summer 2016 we initiated installation of 3 instrument clusters in the Feather R. basin, in collaboration with Pacific Gas & Electric. We are also working with the California Department of Water Resources to develop broader plans for soil-water, snowpack and energy-balance sensor networks. Further proposals to expand these systems are pending with state and local agencies.

Impacts include better decision making because of our research findings, and improvements to the research process. To achieve broader impacts, we have developed an extensive dissemination network. Our dissemination strategy reaches stakeholders and resource managers as well as researchers. To that end, we have published opinion pieces in local newspapers, produced video and radio segments through collaborations with regional television and radio stations, presented at numerous stakeholder meetings, and hosted visits to our field sites and laboratories. We have communicated with everyone from foresters and other resource managers, to legislative staff and policy makers at the state and Federal level. In aggregate, SSCZO investigators average at least bi-weekly presentations to public audiences.

We have employed evaluation forms to assess multiple events. Among these are the 2015 Annual Meeting, and visiting researchers. Feedback from the 2015 Annual Meeting has directly informed agenda structure and logistics for the 2016 meeting. Response rate from visiting researchers is low. We also have, for the first time, used program evaluation forms in our ongoing high school field research partnership with the Center for Advanced Research and Technology. Survey feedback will be analyzed this summer, with two-fold potential to improve future programming and to evaluate impacts of the research project on participants. Evaluation forms were also administered by Merced County Office of Education to TEAM-E participants; a report of teachers' survey results will be shared with SSCZO in the coming months.

CZO network activities. Cross-CZO work was used to finalize a method using LiDAR data, computer vision, and machine learning to optimally configure multi-node snow observatories. We gathered data from Jemez River and Boulder Creek CZOs to examine the effect of site physiographic variables on the optimal number and distribution of sensor nodes. We use snow on / snow off LiDAR data to determine site-specific correlations with independent physiographic variables. Optimal sensor locations at each CZO were determined using the expected values from a Gaussian Mixture Model applied to the site data.

A CZO National Office-funded proposal by E. Aronson (SSCZO), Rachel Gallery (CJCZO), and S. Hart (SSCZO) supported a CZO Biogeochemistry Workshop in fall 2016 at UC Riverside. Goals will be to agree upon and address a set of cross-CZO questions, with future cross-CZO sampling to test and validate these conceptual models. Participants were recruited through the CZO PI network and through recommended international participants.

SSCZO team members are also participating in other cross-CZO working groups and workshops. R. Bales and M. Conklin participated in the critical-zone services working group meeting hosted by the Luquillo CZO at UC Berkeley in January. Plans were made during this past year for several meetings in fall 2015.

C. Tague and colleagues received a National Socio-Environmental Synthesis Center grant that is supporting a two-year working group on integrating economic and biophysical models to examine pre- and post- ecosystem service impacts of wildfire and fuel treatment using several Western U.S. case-study sites, including the Sierra CZO. Work by B. Kastl and C.Tague involves investigating how science-based model presentation influences the way stakeholders understand the complex watershed dynamics studied by scientists at the CZO. The SESYNC working group involves forest managers from agencies as well as communication expertise through COMPASS (compassonline.org), a group that specializes in science based communication for the public.

CZO program budgets. See attached budget summary.

Additional funding. CZO investigators routinely leverage funding to support students and postdocs, install equipment, engage collaborators and initiate complementary research. All of the students listed above were supported at least in part by non-CZO funds, and most were largely supported by non-CZO funds. Leveraging with the USDA Forest Service is also important, and the SSCZO is in part co-located with Forest Service research programs. UC Merced provided institutional support for four incoming graduate students last year. The U.S. Forest Service provides a budget of several hundred thousand dollars per year for the streamflow, met station and stream geochemical measurements and data, as well as some vegetation surveys used by the CZO team and collaborators. The U.S. Forest Service and UC Merced also jointly supported a research scientist whose main focus was on the SSCZO, and the co-located Kings River Experimental Watersheds program.

Southern Sierra Critical Zone Observatory

Media Coverage

1 July 2015 to 29 June 2016

1. *Plants and Animals Are Dying for a Drink: Four Years of Extreme Drought Taking Big Tolls*. Article by Tyler Hayden, Santa Barbara Independent. July 16, 2015.
<http://www.independent.com/news/2015/jul/16/plants-and-animals-are-dying-drink/>
Interview with C. Tague.
2. *Dying California forests offer a glimpse into climate change*. Article and video by Kim Brunhuber, CBC News. August 12, 2015.
<http://www.cbc.ca/news/technology/dying-california-forests-offer-a-glimpse-into-climate-change-1.3187672>
Interview with C. Tague.
3. *Talk about Forest Restoration*. Radio show by Tom Wiley, Down on the Farm, 88.1FM KFCF. September 4, 2015.
<https://www.facebook.com/KFCF881/posts/10155859324565391>
Interview and discussion with R. Bales.
4. *Watershed Connections: Forest Management and Its Impacts Downstream*. Article by Niki Woodard, Tulare Basin Wildlife Partners. October 14, 2015.
<http://www.tularebasinwildlifepartners.org/ow6-forest-management.html>
Interview with M. Safeeq, C. Hunsaker, R. Bales.
5. *Computer models aren't playing with fire*. Article by Lance Farrell, Science Node. November 9, 2015.
<https://sciencenode.org/feature/computer-models-arent-playing-with-fire.php>
Interview with C. Tague.
6. *The Secret Life of a Raindrop*. Article by Amy Miller. Video by Quest. KQED Science. November 10, 2015.
<http://ww2.kqed.org/quest/2015/11/10/secret-life-of-a-raindrop/>
Article and video feature SSCZO critical zone tree and National Critical Zone Observatory Program. Video also features interview with R. Bales.
7. *UW Researchers Discover Sediment Size Does Matter in High-Elevation Erosion Rates*. Article by University of Wyoming. November 16, 2015.
<http://www.uwyo.edu/uw/news/2015/11/uw-researchers-discover-sediment-size-does-matter-in-high-elevation-erosion-rates.html>

Research summary of Riebe et al., 2015, and interview with C. Riebe and C. Lukens. Article reprinted in Science Daily.

8. *Amid Severe Drought, California Snowpack Hits 5-Year High*. Radio show by Jeremy Hobson, Here and Now, 90.9 FM WBUR. January 27, 2016.
<http://www.wbur.org/hereandnow/2016/01/27/california-snowpack-5-year-high>
Interview with R. Bales.
9. *Let It Snow! The Science of Winter*, National Science Foundation Special Report. January 13, 2016.
http://www.nsf.gov/news/special_reports/snow/
Features previously published article about SSCZO, *A Tree Stands Tall in the Sierra Nevada*. Article by Cheryl Dybas, National Science Foundation. August 7, 2012.
10. *New report explains ancient phenomenon known as “winter”*. Article by Suzanne Jacobs, Grist. January 14, 2016.
<http://grist.org/article/new-report-explains-ancient-phenomenon-known-as-winter/>
Coverage of National Science Foundation Special Report *Let It Snow! The Science of Winter*.
11. *Prospects Dim for Drought Relief as California Snowpack Falls Below Average*. Radio show by Michael Krasny, KQED Forum, KQED Radio. March 3, 2016.
<http://ww2.kqed.org/forum/2016/03/03/prospects-dim-for-drought-relief-as-california-snowpack-falls-below-average/>
Interview and discussion with R. Bales.
12. *Sierra Nevada Snow Won’t End California’s Thirst*. Article by Henry Fountain. Photos by Jim Wilson. The New York Times. April 11, 2016.
<http://www.nytimes.com/2016/04/12/science/california-snow-drought-sierra-nevada-water.html>
Interview with R. Bales, M. Safeeq, and M. Conklin. Photos also include E. Stacy.
13. *Losing snow in a changing climate: What global warming means for our water supplies*. Article by Ian James. Photos and video by Jay Calderon. The Desert Sun. April 13, 2016.
<http://www.desertsun.com/story/news/environment/2016/04/14/climate-change-snowpack-water-supplies/82631192/>
Interview with E. Stacy and M. Thaw. Article reprinted in USA Today.
14. *Under Where? Underground Water and Its Contribution to Streams*, in Natural Inquirer Freshwater, 18(1).
<http://www.naturalinquirer.org/Underground-Water-and-Its-Contribution-to-Streams-a-169.html>
Features article about research methods and findings from Liu et al., 2012; classroom activities based on research; and researcher profiles for F. Liu, C., Hunsaker, and R. Bales.

Dead Trees Adding to California Firefighters' Battle

Published: June 22nd, 2016

By [John Upton](#)

With drought and climate change conspiring to push California's summer wildfire season into premature overdrive, the state's lead wildfire agency has acquired a multimillion dollar arsenal to help it cope with unprecedented numbers of dying trees.

California recently bought \$6 million worth of chippers, mobile sawmills, portable incinerators and other equipment to help its firefighters remove some of the nearly 30 million trees that now stand dead across the state, killed by drought and insects.



A firefighter from Chino Hills keeps watch on a wildfire as it burns near Potrero, Calif.

Credit: REUTERS/Mike Blake

The equipment is being used as parched southern California landscapes explode in the types of summertime flames that wouldn't normally be expected until August. Grasses that fattened up following winter storms in central and northern California are expected to fuel major blazes in the weeks ahead.

"The more time that goes by, the dryer the fuels are going to become," said Tom Rolinski, a U.S. Forest Service meteorologist who [forecasts fire conditions](#) in southern California. "As this summer unfolds and we get into the August and September timeframes, the fuels are going to be that much dryer, and we're probably going to see more intense fires."

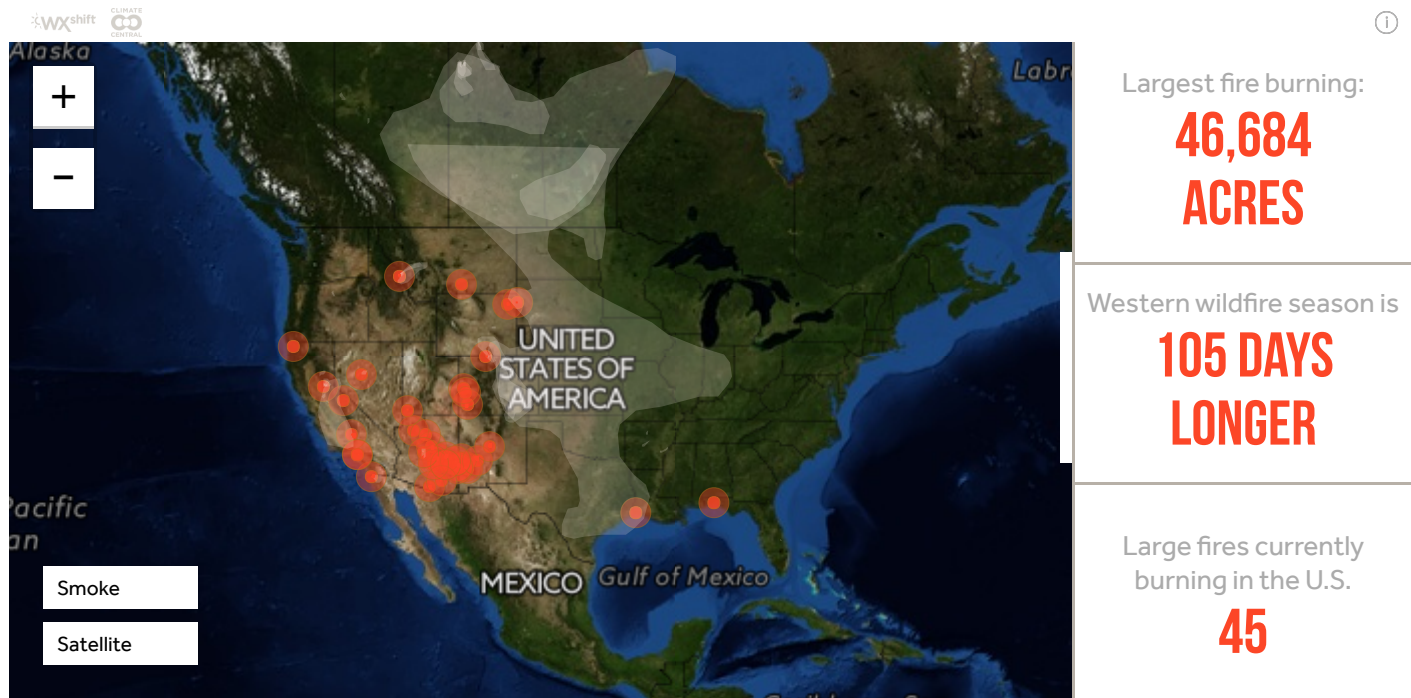
The California Department of Forestry and Fire Protection, normally called CAL FIRE, which is charged with protecting tens of millions of acres of mostly private land, responded to about 250 fires last week — an unusually large number for mid-June.

RELATED [The Weird Weather That Entrenched California's Drought](#)
[Warming Is Increasing Wildfire Risks in California](#)
[Wildfires Tied to Drought, Heat & Topography, Not Beetles](#)

On Tuesday, CAL FIRE was working with other agencies to try to contain [two major blazes](#) in southern California as firefighters in other southwestern states also battled big fires amid [record-breaking heat](#).

The fires are being fueled by droughts exacerbated by warming temperatures, which scientists have [linked to climate change](#) and to the natural [whims of the weather](#).

"Warming causes fuels to be drier than they would otherwise be," said [Park Williams](#), who researches ecology and climate change at Columbia's Lamont-Doherty Earth Observatory. "Whether that corresponds to a large area burned for California this year will depend on human activities and individual weather events."



Even as firefighters in California toil to battle the extraordinary blazes, they're being forced to deal with another extraordinary phenomenon: the widespread [dying of trees](#).

About 30 million trees across the state are estimated to have died, succumbing to attacks by beetles because of the weakening effects of drought.

"It's the drought that sort of sets it off, and then it lets the beetles get out of hand," said [Roger Bales](#), a professor at the University of California, Merced.

Gov. Jerry Brown declared an emergency in the fall because of the unprecedented die-offs, helping to free up funds needed to remove and dispose of some of them. CAL FIRE hired hundreds of seasonal workers early this year to help remove dead trees and clear out other potential fuel for fires.

While ecologists value dead trees as natural assets that provide holes and logs needed by wildlife, firefighters view them as safety hazards that can crash down on roads, power lines and homes and that could potentially fuel bigger blazes.

The "scale of this tree die-off is unprecedented in modern history," Brown's [emergency declaration stated](#), worsening wildfire risks and erosion threats and creating "life safety risks from falling trees."

A group of ecologists formally objected to the emergency declaration, [arguing in a letter](#) to Brown that dead trees are natural and necessary parts of Californian landscapes. They pointed to a [growing body of research](#) downplaying the wildfire hazards posed by trees killed by beetles.

One of those ecologists, [Chad Hanson](#), director of a small California nonprofit, says he agrees that dead trees that pose falling hazards should be removed. But he said trunks should be left on the ground to provide habitat instead of being incinerated or removed. "Once you fell the trees, they're no longer a hazard," he said.

Summertime fires in California cause less property damage than the fires that are fanned by dry Santa Ana winds in the fall and winter, but they sap more firefighting resources, [research published last year](#) showed.

"We were really trying to figure out how fires will change in southern California in the future," said [James Randerson](#), a University of



Dead pines photographed during an aerial survey last year in Los Padres National Forest.

Source: [U.S. Forest Service](#)

California, Irvine earth scientist who contributed to the study. “What we realized early on is that there are two distinct fire types.”

While the effects of climate change on Santa Ana winds fires remain riddled with uncertainty, scientists are generally convinced that the parching effects of global warming will lead to bigger, longer and more damaging summertime blazes in California — if they aren’t already doing so.

That suggests the intense and early summer fire seasons in this and other recent drought-stricken years may have been less an aberration and more a bellwether of something that CAL FIRE officials frequently describe as a “new normal” for firefighters.

With more greenhouse gas pollution piling into the atmosphere daily, continuing to warm the planet toward a 2°F increase from preindustrial times, and with warmer weather exacerbating droughts, mass tree die-offs could become routine features of Western landscapes.

Not only would that eliminate or shrink some forests, driving them northward or uphill toward cooler climates, it could also force increasingly overworked firefighting agencies to juggle the additional routine task of managing dead trees.

CAL FIRE is focusing its tree removal efforts in areas where most trees have died and where the dead trees pose the most immediate dangers.

“We’re focused on high hazard areas with the greatest threat to life safety and critical infrastructure,” CAL FIRE spokeswoman Janet Upton said. “There are literally hundreds of thousands of acres, and growing, affected by the unprecedented scope and magnitude of tree mortality.”

You May Also Like:

[Extreme Oil Prices May Be Costly to the Climate](#)

[Rodent Threat Defeated As Delmarva Battles Rising Seas](#)

[With May Record, Global Temps in ‘New Neighborhood’](#)



Courtesy Jeff Head.

Computer models aren't playing with fire

Six of the last 11 years have seen more than eight million acres (3.2 million hectares) burned in the US. To combat these infernos, the modern firefighter looks to computer models, like those provided by the US National Center for Atmospheric Research (NCAR). There's much these models can tell, and much they can't.

Speed read

- Global warming is increasing the number of wildfires.
- Firefighting in 2015 looks to computer models for help — before, during, and after a wildfire.
- Computer models are a great help, but not infallible.

Posted on 09 NOV,
2015



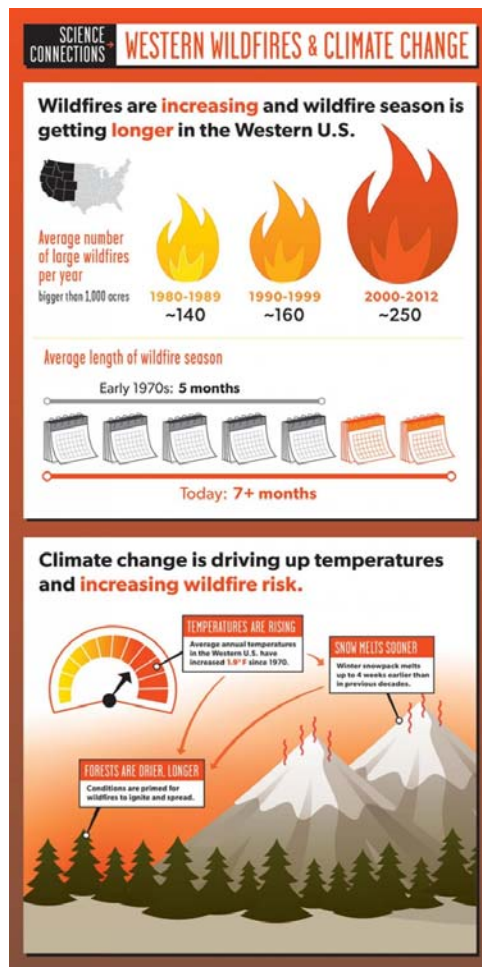
The western United States is on fire. Again.

Frequent wildfires have become the new normal, un

Frequent wildfires have become the new normal, up by 78% since 1970. In six of the last eleven years, fires have consumed more than 8 million acres (3.2 million hectares), with 2015 on pace to set a new record. 65 fires remain unchecked, and the toll is still rising.

The spike in wildfires is attributed to global warming; temperatures in the western US are rising at double the pace of the global average. By 2070, the US National Center for Atmospheric Research (NCAR) predicts the number of days over 95° Fahrenheit (35° Celsius) will quadruple.

Rising temperatures mean earlier snowmelt, leading to drier conditions and hotter temperatures that leave forests vulnerable to even a spark. Nine out of

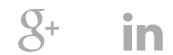


Courtesy Union of Concerned Scientists.

Lance Farrell

US editor

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10 times this spark comes from a human source (lightning and lava flows still account for a small percentage), which firefighters then have to battle for weeks at a time.

Outsmarting the wildfire

Armed with hoses, trucks, and helicopters — and of course lots of water — modern firefighters now also have computer models at their disposal. By predicting where a fire will be and how fast it will get there, models help firefighters allocate resources strategically.

A new type of model offers more precise predictions, such as when a fire will accelerate or produce fire whirls. It can calculate when downdrafts from a cloud might cause a change in fire direction or intensity, or how airflow coming down from a mountain might cause a fire to grow in oddly shaped patterns.

NCAR scientist Janice Coen has developed two such models. Funded by the US [National Science Foundation \(NSF\)](#), NCAR aims to understand the dynamics between the atmosphere and fire.

“Fire modeling is actually a weather modeling problem,” says Coen. “The greatest challenges are the same — trying to model airflow correctly in complex terrain and, in addition, battling the buildup of errors that is an unavoidable part of weather forecasting.”

Weather prediction models consist of fluid dynamics equations based on, among other things, laws of mass conservation, thermodynamics, and motion. Coen's models assume a fire is affected by natural weather conditions, while also recognizing that a fire creates its own weather. As fire blazes across it releases heat into the sky, pulling air from behind and creating winds that literally fan the flames.

Fire modeling is actually a weather modeling problem. You can be pretty confident about the weather forecast you are given for tomorrow, while the forecast for several days from now may be less good.



Tools of the trade. *Firefighters battle fires for weeks on end, and use a variety of tools to douse the flames. To allocate resources wisely, many fire departments now look to computer models which can tell them when and where a fire will spread. Courtesy US Bureau of Land Management and the US Forest Service.*

Wildfire models cannot predict which burning embers lofted ahead of the fire will light the would-be tinder on which they land. And, like any tool that tries to predict weather, fire-spread models are not infallible.

“You can be pretty confident about the weather forecast you are given for tomorrow, while the forecast for several days from now may be less good, and the one for the next week may not have any predictive value,” Coen notes. “My models depict airflow at very fine scales, and these lose value very quickly — they may be useful only for a day or two. To increase their longevity, my current work injects data into the running model.”

Living with fire: forest management before the blaze

While Coen's models of fire behavior help support fire fighting during a fire, [Professor Christina Tague's](#) models look at how fire risk changes over time and space. Tague, of the University of California, Santa Barbara (UCSB), is investigating whether land management can reduce these risks before the fire starts. Tague's work builds on the [Regional hydroecological simulation system \(RHESSys\)](#), an open-source software portal with over 75 algorithms that represent how water, climate, fire, vegetation and soil interact over space and time.

[Her NSF-funded approach links a social science](#)

model to improve understanding of the biophysics of fire and its effects. Tague and her collaborators will integrate models of forest growth, fire risk, and hydrology with models of how pre-fire forest management decisions are made. This combination will help them assess the potential of fuel treatments like thinning a forest, removing fallen trees, leaves, branches, and other understory vegetation that act as ladders that fires climb into the tree canopy.

Tague's wildfire model offers two advancements. First, it adds a sophisticated representation of the water cycle that can investigate the impacts of both fire and fuel treatments on water—how it is used by vegetation and how much ends up in streams. Wildfires can significantly change the water supply by altering vegetation and soil characteristics. They can also impact water quality by increasing soil erosion. Before fires, how much water is available for vegetation can be an important indicator of fire risk. Water and fire are closely linked and Tague's NSF-funded model will capture these interactions.

In addition, her model provides insights into how management decisions affect fire risk. “There are many factors that determine when and where fuel treatments are done. For example, when there has recently been a fire, the risks of fire are fresh in the public mind, and this can lead to pressure for





Living with fire. *Wildfires have increased by 78% since 1970. Cost can be measured in terms of property, lives lost, displacement, and destruction of habitat. Christina Tague recently won an NSF-grant to see if practices like forest thinning and removing ground materials helps or hinders the fight against wildfires. Courtesy Jeff Head.*

responses from public institutions. We don't really know if this is an efficient use of the often limited funding available for fuel treatments," Tague says.

As high-performance computing (HPC) advances, so too does the ability to predict the weather and how to fight fire and strategically manage landscapes where fires will continue to occur. HPC enables researchers to include larger amounts of atmospheric and land surface data, at increasingly finer resolutions, and to explore the implications of many different scenarios. HPC also bestows an ability to integrate disparate models and multiple algorithms to offer comprehensive and more predictive firefighting and fire risk management tools.

We may always have to live with wildfires – but with the better modeling that comes from HPC, we may

reduce the risks to things we care about.

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Let us know!

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Dying California forests offer a glimpse into climate change

Experts say effects could be worse in Canada

By Kim Brunhuber, [CBC News](#) Posted: Aug 12, 2015 3:20 PM ET Last Updated: Aug 17, 2015 8:47 AM ET

Forestry researcher Nick Ampersee chops into the pine with his axe and removes a slice of bark. The inside looks as though it has been slathered with white-out.

"Mycelia," he says. "That's a fungus. It usually weakens the tree and then something like a bark beetle will finish the tree off."

Another researcher cuts into a different tree with her knife and shows me what looks like a couple of over-boiled grains of rice.

"We are dealing with some weevil activity here at the base," she says. The tree doesn't have long to live.

- [Photos: Drought-ravaged California seen from above](#)
- [California's drought offers Canada lessons in crisis prevention](#)

Every year over the last decade and a half, the U.S. Geological Survey has descended on Yosemite and Sequoia National Parks in California to give 17,000 trees a physical. But in a growing number of cases, what's starting off as a check-up is turning into an autopsy.

The cause of death is usually insects or fungus, but researchers suspect it's almost always because of one culprit: lack of water.

Normally, only about two per cent of the trees in their study areas die. But this year, that number has grown to 13 per cent.

"That's a really severe uptick," says U.S. Geological Survey ecologist Nate Stephenson. "We've never seen anything like it before."

Stephenson bends the branch of an incense cedar. Most branches are covered with dry, dead orange needles. The rest are bare.

"I used to call them 'the immortals,' because they just never seemed to die," he says. "In the fourth year of drought, they've started dying by the bucket-loads. So they're no longer the immortals."

Warming temperatures to blame

Stephenson has surveyed some of the oldest, richest forests in the U.S. and British Columbia. Compared to just a few decades ago, he found that the trees' death rate has doubled from one to two percent. It may not sound like a lot, he says, but he says imagine if you were talking about your hometown.

"If you looked back and saw that death rates had doubled, you'd really wonder what was going on," Stephenson says. "The one thing that really stood out is warming temperatures. We think that's what's driving the increase in tree death rates."

For the past four years, California has been going through a record-setting drought. In January, the state's governor, Jerry Brown, declared a state of emergency.

In June, Naomi Tague of UC Santa Barbara published a study in the journal *New Phytologist* on die-off in California forests that found that 12 million trees died due to drought this year alone. Tague, who is Canadian, says the hot, dry weather has been great for the insects and bad for the trees.

While the situation in California is dire now, in the future, Canadian forests may be at greater risk, even if the drought is less severe.

"The trees [in California] are used to drought, and so you have to get this severe drought before you start to see this die-back," Tague says.

"But you can imagine that a spruce forest in the boreal part of Canada, it's not used to seeing drought. So it hasn't developed the same types of defensive mechanisms to insects."

Canada's boreal forest, which stretches across the north of the country, is one of the world's largest intact forests. According to Tague, it may be particularly vulnerable as you move further north.

"The increase in temperature is greater at greater latitudes," Tague says. "A cold drought is not the same as a warm drought."

Their research has found that no tree seems to be immune, including the toughest, most drought-resistant trees in this forest: giant sequoias.

Some of the trees in Sequoia National Park were a thousand years old when Julius Caesar crossed the Rubicon. Last year, Stephenson spent a few days crawling around the forest floor examining sequoia seedlings, convinced they'd be affected by the heat and the drought.

"They all looked really happy," he says. "I sat back, scratched my head and looked up, and there was a huge adult giant sequoia that had a lot of foliage die-back in it. That really got us interested, and we figured the drought was probably the cause of that. And that created a cascade of studies."

They found that a significant number of older trees that had shrugged off the Dust Bowl in the 1930s were losing as much as half of their leaves.

"Ten per cent of the trees had 25 to 50 per cent die-back," says Koren Nydick of the U.S. National Park Service. "This is the first time that this kind of foliage die-back has been observed since this has been a national park."

Aiming for answers

To determine the exact extent of the problem, a small group of scientists is going to extreme -- and dangerous -- lengths.

Diagnosing dead trees (footage courtesy of UC Berkeley researchers Wendy Lloyd Baxter and Anthony Ambrose)

Anthony Ambrose, a tree biologist currently working in the Department of Integrative Biology at UC

Berkeley, aims his crossbow at the uppermost branches of a huge sequoia, fires... and misses.

"That was the perfect shot," Ambrose says ruefully. "It just dropped short."

Ambrose has to shoot an arrow with a line attached over a branch so far away you need a spotter to track it. That's the easy part. Next, he has to hoist himself by hand more than 80 metres up into the canopy to collect samples and take measurements.

"This tree here is in an area that has been exhibiting signs of severe crown die-back, so we wanted to characterize the trees in this part of the grove to see how stressed they are, and compare them with trees in areas that aren't affected by the drought," Ambrose says.

If there's a positive from this tree-killing drought, it's this: for Ambrose and his team, it's literally a dry run. A chance to improve their models in order to better predict what will happen in North America when this hotter, drier climate is the norm.

"This tree here is maybe a thousand, maybe two thousand years old," Ambrose says, looking at the next giant sequoia he's about to climb.

"It's dealt with severe conditions, extreme droughts, fires in the past. They're really resilient trees, but every species, every organism, has a limit, and in the future, there may be a point where drought impact becomes so severe that they shed all their foliage, they stop growing. Maybe at some point, they get susceptible to insects or disease, and start to die back."

Corrections

- A previous version of this story wrongly attributed quotes about the health of giant sequoia trees to a United States Geological Survey biologist named Adrian Das. The person who actually said these quotes is Anthony Ambrose, a tree biologist currently working in the Department of Integrative Biology at UC Berkeley. The error has been corrected in the text.

Aug 13, 2015 11:15 AM ET

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SCIENCE

Sierra Nevada Snow Won't End California's Thirst

By HENRY FOUNTAIN APRIL 11, 2016

YOSEMITE NATIONAL PARK, Calif. — Thanks in part to El Niño, snowpack in the Sierra Nevada is greater than it has been in years. With the winter snowfall season winding down, California officials said that the pack peaked two weeks ago at 87 percent of the long-term average.

That's far better than last year, when it was just 5 percent of normal and Gov. Jerry Brown announced restrictions on water use after four years of severe drought. But the drought is still far from over, especially in Southern California, where El Niño did not bring many major storms.

Despite the better news this year, there are plenty of worrying signs about the Sierra snowpack, which provides about 30 percent of the water Californians use after it melts and flows into rivers and reservoirs, according to the state Department of Water Resources.

Many of those concerns stem from the effects of climate change and the structure of Sierra forests, which can influence how the snowpack accumulates and melts. Because the snow, in effect, serves as a reservoir that is released over time, any changes can affect how much water is available for people, industry and agriculture, and when.

“We'll be getting more rain and less snow here,” said Roger C. Bales, a professor

at the University of California, Merced, and a principal investigator with the Southern Sierra Critical Zone Observatory, which studies snowpack and other water-related issues. “That means less snowpack storage and faster runoff.”

Dr. Bales was standing on a snowy slope in Yosemite last Thursday, at about 7,000 feet elevation, just off a 19th-century wagon road that is used by hikers and snowshoers. Nearby, amid car-size granite boulders and close to a soaring Ponderosa pine, were instruments that he and his fellow researchers use to obtain detailed information about the snowpack in several spots throughout the southern Sierra.

The effects of warmer temperatures can already be seen here, Dr. Bales said.

“Historically, this has been the reliable snow zone, where it accumulates till late March or early April and then melts,” he said. But now the snowpack here is more like that at lower elevations, “where it will accumulate, melt, accumulate, melt,” he said.

Proof was close at hand, as well. Until the last quarter-mile of a two-mile hike here from 6,300 feet, snowshoes were not needed. What snow remained was in small patches.

Similar effects of climate change have been seen throughout the Sierra, including at the Central Sierra Snow Laboratory, which is operated by the University of California at Berkeley near the Donner Pass, about 120 miles to the north. Researchers there still make some measurements the way they have since the lab started in the 1940s, by inserting special metal tubes into the snow.

“We are seeing an ever-increasing percentage of annual and winter precipitation in liquid rather than solid form,” said Randall Osterhuber, who spends winters at the lab. The altitude above which snow accumulates is becoming higher as temperatures warm. “That change in elevation means a lot less terrain is covered in snow.”

Climate change is also expected to increase precipitation in some areas, because warmer air can hold more moisture. But it is not yet clear if that will be the case in the Sierra Nevada.

Snowpack is measured in “snow water equivalent,” or how much water would result if the snow were melted. When snow first falls in the Sierra, it is usually dry and powdery, with about 10 to 12 percent moisture by volume, but as it accumulates and compresses, the moisture content rises to about 40 percent. So 30 inches of snow on March 30 would be equivalent to about 12 inches of water.

The data from Dr. Bales’s instruments will not be downloaded until later in the spring, but just up the slope, other instruments set up by the Department of Water Resources send data continuously to state offices in Sacramento. Last Thursday, they recorded a water equivalent of 18.36 inches. With warm spring temperatures, the snowpack here was past its peak, with the water equivalent declining by more than three inches in less than two weeks.

The Department of Water Resources instruments are set up in a relatively open part of the forest. The observatory’s instruments, by contrast, are near the Ponderosa pine, and there are three of them: one next to the trunk, one a little farther away where water drips from the tips of the branches, and one in the open, about 20 feet away. Other sensors, which are buried, detect how much water is in the ground.

The goal is to gather a complete picture of the snowpack, which is far from a uniform blanket of white. A tree, for example can affect snow cover in several ways, Dr. Bales said. Some snow is caught by the branches and turns directly to vapor. Other flakes melt and the water drips to the ground. The tree trunk itself absorbs sunlight and re-emits it as heat, melting the snow around it. Boulders do the same thing. Even the tiniest pieces of forest litter — needles or bits of pine cones — can heat up in the sunlight and cause melting.

“We’re strategically sampling the landscape,” Dr. Bales said. “We pretty much know what topographic features affect snowpack.” That will give water managers a truer understanding of how much water the snowpack will generate.

Trees also affect the amount of water stored in the mountains simply by growing, sucking up water from the ground. Some of it is used in photosynthesis, but much of it is lost through evaporation and transpiration through the leaves and stems. Dr. Bales and his colleagues study this, too, with instruments atop towers that

measure the flow of water vapor from the tree canopy.

The scientists learned that a lot of water was lost through the trees — more than was even thought to be there in some cases. “That told us the precipitation estimates that people had for higher elevations were just plain wrong,” Dr. Bales said.

Warmer temperatures also mean that trees grow faster, and don’t necessarily shut down for the winter. Thus they use more of the melting snow, and over a longer period. That leaves less water to flow into streams and down to reservoirs.

Less snow, earlier melting and faster growth mean that more trees are running out of water in the summer. Mohammad Safeeq, a colleague of Dr. Bales at the university, said that, in general, water was flowing off the mountains two weeks earlier than in the past. “Two weeks in a three-month summer window is significant,” he said.

Water-stressed trees are more susceptible to pests and disease, so one result of the changes is more tree deaths. This is readily apparent at Yosemite in the drive from the valley floor, where the green hillsides are dotted — in some cases in large numbers — with the brown of dead pines and firs.

Contributing to the problem is the fact that there are many more trees here than there used to be. A century ago, Dr. Safeeq said, Yosemite had perhaps 20 trees an acre; now the number is closer to 100. That means more of the melting snowpack never gets off the mountain to the valley below, he said. The greater number of trees is due in part to years of forest agency policies under which small natural fires were quickly extinguished to protect homes and other property in the mountains.

But smaller, less intense fires are nature’s way of thinning the forest, culling trees that are less fire-resistant, said Martha H. Conklin, a Merced professor and another principal investigator with the observatory. Paradoxically, because fire suppression leaves so much timber on the mountains, it can lead to much bigger and hotter fires, like the Rim Fire that burned 250,000 acres in and around Yosemite and destroyed more than 100 structures in 2013.

Fire suppression is a controversial subject in California. But thinning the forest

by letting small fires run their course would increase snowpack because more of the snow would reach the ground, and less of the water would be taken up by the trees. That could be, in effect, like adding an entire new reservoir of water in the mountains, rather than building a new billion-dollar reservoir down in the valley.

If small fires were allowed to burn, Dr. Conklin said, “you’d have a forest of a very different structure.” Even the types of trees would eventually change, she said, as species that are better able to resist fire replaced others. “I don’t know if we can ever go back to a forest that has a natural fire regime,” Dr. Conklin said. “It’s very difficult to let a fire burn if you have houses dispersed in the forest.”

But with climate change affecting how much water is available from the mountains, she added, “we have to think about how we’re going to manage these forests.”

Correction: April 14, 2016

An article on Tuesday about the effects of climate change on California’s mountain snowpack paraphrased incorrectly from comments by Mohammad Safeeq, a researcher at the University of California, Merced, about the density of trees in the Sierra Nevada now compared with a century ago. Sierra forests now average about 100 trees an acre, not 250, he said; and a century ago they had about 20 trees an acre, not 80.

A version of this article appears in print on April 12, 2016, on page D1 of the New York edition with the headline: Uncertainty in the Sierra.

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Losing snow in a changing climate

What global warming means for our water supplies

Story by Ian James and photographs by Jay Calderon, The Desert Sun | April 14, 2016

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Among firs and cedars high in the Sierra Nevada, scientists are using an array of instruments to monitor the health of the forest, measure the snowpack and track the water that melts and seeps into the soil.

As they collect data, they're taking snapshots of a landscape in the midst of major changes.

When Erin Stacy checked the instruments last month at one of the research stations she manages in the Sierra National Forest, her boots crunched through snow that blanketed meadows and lay in patches among the trees. But the snow was melting early near the end of a record-warm winter. And in the future, there's likely to be much less snow, if any, on the ground here.

Already, as the winters have grown warmer, the snow has been melting earlier after storms pass. It's just the beginning of a shift that is projected to dramatically shrink the snowpack in the mountains as global warming intensifies.



"We're going to get a smaller snowpack. It's going to melt out earlier and it might melt out more times during the winter, and that has some pretty big implications for people downstream – all of our water users downstream," Stacy said, standing beside a sensor that measures snow depth. "The snowpack acts as a reservoir for us, and if we don't have that reservoir, then we need to find some way to store more water or to use less water."

Across the continental United States, measurements from sensors since the 1950s show that the average snowpack has been decreasing in most areas as temperatures have risen. Precipitation that used to fall as snow is increasingly falling as rain. Snowlines in the mountains have begun creeping upward. And scientists

have estimated that for each 1 degree Fahrenheit of warming in mountain regions, the snowpack could retreat upslope by a distance of roughly 300 feet in elevation.

The impacts are expected to vary by location. But across the mountains of the West, the snowpack is already melting about a week earlier on average as compared to the mid-20th century.



The decreases in snow and the earlier runoff pose especially critical challenges for western states, where many areas rely heavily on snowmelt for water supplies and where the demands of growing populations, agriculture and industries are already draining rivers and depleting aquifers.

As the planet heats up, the changing climate is projected not only to shrink the snow and melt the glaciers, but also to unleash more extreme weather ranging from floods to longer-lasting and more intense droughts. The severe drought that has ravaged California for more than four years has coincided with record heat, and it appears to offer a preview of what the hotter droughts of the future will look like.

“It’s pretty dire. I think we need to start moving pretty quickly, whether that’s water conservation or even just more conversations about it,” said Stacy, a scientist with the Sierra Nevada Research Institute at the University of California, Merced. “We’re going to have to figure out how to deal with water downstream differently.”

Just how radically water supplies are altered will depend in part on whether the world takes significant steps to slow emissions of carbon dioxide and other planet-warming pollutants. But even if the world successfully limits warming to the goal of 2 degrees Celsius set last year in Paris – a target that appears increasingly difficult to achieve – snowpack-dependent regions from the Pacific Northwest to the Colorado River basin could still be hit hard.



Play Video



As the planet warms, the average snowpack is shrinking in the mountains. That poses challenges for water supplies downstream.

Jay Calderon/The Desert Sun

In order to face that threat, there have been growing calls by academics, conservation advocates and policymakers to rethink how water is used and managed, and to adopt a lineup of strategies to prepare and

adapt.

The list of ideas is long: capturing more stormwater during floods; using more surface water to recharge depleted aquifers; treating and reusing more wastewater; cleaning up contaminated groundwater; improving efficiency on farms and in cities; and adopting policies that encourage conservation, among other things.

No single strategy is likely to be enough on its own. Many government officials in charge of water management in places from California to Washington, D.C., have lined up behind what they've called an "all-of-the-above" approach. They say that making water systems more resilient is achievable with intelligent planning, and that steps are underway to adapt.

Questions about how global warming will affect water supplies have become an active focus of scientific research. Many scientists agree that the scale of the water challenges, especially in the West, is monumental, and that each area will need to develop its own local solutions to stretch water supplies further.

In a 2014 study, researchers at the University of Idaho examined likely shifts in the rain-snow transition zone across the western United States. They projected declines in the areas where snow falls in the wintertime of between 24 percent and 53 percent by mid-century.

The changes in the timing of runoff are projected to be drastic. And as temperatures rise, more of the snow and rain that falls will evaporate instead of running off. Scientists expect those changes to shrink the average flows of streams and rivers.

At the research site in the Sierra Nevada, located more than 6,000 feet up in the mountains northeast of Fresno, Stacy was at work along with doctoral student Melissa Thaw, who was collecting water samples from the soil beneath a large incense cedar.

Her research involves using isotope "signatures" in the water to track how it moves through the soil and where trees and shrubs are taking up water. Thaw is interested in learning more about how climate change will affect the water and the ecology of the forest, and she is focusing on the transition zone between rainfall and snow.

As the climate warms, it will push this transition zone higher into the mountains, moving the snowline upslope. Thaw said that points to a need to anticipate the effects on water supplies, while also taking steps to slow global warming.

"The mountains are the world's water towers, so when the water can be held up in the Sierra Nevada later in the year, we have a longer amount of time where we have runoff coming down into the reservoirs," she said, standing among boulders and snow-covered manzanita bushes.

"I think being aware that these water resources are changing pretty fast and that they're limited is important," she said. As for the scale of the threats posed by climate change, she said: "It's super important, and I don't think people are doing enough."

Where the runoff goes

The snow that melts in this rugged stretch of the Sierra collects in Providence Creek and flows into Big Creek, snaking down through forests of brown, dry ponderosa pines that have been killed by infestations of bark beetles during the drought. The creek eventually reaches the Kings River, which flows into Pine Flat Reservoir.

Much of the water flows through canals to the farms of the Central Valley, which produce a large share of the nation's fruits, vegetables and nuts.

During the drought, the levels of Pine Flat Reservoir have fallen far below average levels. But in times of flooding, the Kings River can also unleash huge pulses of water.

Farmer Don Cameron has been preparing for those times. He is the general manager of Terranova Ranch, and in 2010 his farm received a \$75,000 grant from the U.S. Department of Agriculture's Natural Resources Conservation Service to help pay for an experimental project that involved flooding 1,100 acres of farmland in order to replenish the aquifer.

When the floodwaters poured in during 2011, the inflows helped boost groundwater levels, which have been declining for decades in this area and across the Central Valley.

Cameron said the project worked well, and now the farm has obtained a larger \$5 million grant from the California Department of Water Resources to spread larger quantities of floodwater on its fields in the future. The farm is contributing \$2 million in matching funds for the project.

"For the long-term viability of the area, we need to do this," said Cameron, who manages more than 7,000 acres of farmland growing two dozen crops ranging from tomatoes and carrots to onions, wine grapes and kale.

The grant from the state will be used to pay for upgrades to canals, pipelines and other infrastructure. The state will also buy an easement to be able to permanently use a portion of the ranch's lands to deliver floodwaters to fields. The project will involve spreading water over 6,000 acres on Terranova Ranch and neighboring farms to replenish the aquifer. In subsequent phases, the plan calls for spreading water over a total of 16,000 acres.

Cameron sees it as an important strategy to prepare for the effects of warming. The farm, which relies on groundwater, has also converted many of its fields from flood irrigation to drip irrigation.

"When I look long-term at climate change, I look at a probably less reliable water supply as a grower," Cameron said, standing above a dry canal. "I think growers are going to be the ones that are going to see the real net effect before anyone else."

He ticked off examples of the changes that are already occurring: The seasons have begun to shift, changing the times of plantings. Last year, the pistachio crop was a disaster due to the warm winter.

"I think we're going to see growers having to adapt to change crops possibly and to be more cognizant of the water that they use. They're going to have to capture floodwater when it comes by," Cameron said. "We need to be proactive. We need to put in systems. We need to use the systems that we already have in place to be able to use this water when it is here and save it for times when we don't have it available."

The city of Fresno is taking a similar approach in trying to boost its underground water supply. When surface

water from reservoirs is available, some is diverted through canals to a series of spreading ponds at a 203-acre city facility called Leaky Acres, where the water seeps down into the soil to the aquifer.

The water shimmers in pools encircled by a freeway and busy avenues, attracting birds that float on the surface.

“We put the water into the ponds and let nature take its course,” said Ken Heard, chief of water operations for the city’s public utilities department.

Lately, about 15 million gallons a day have been flowing into the ponds. It’s still not enough, though. The average groundwater levels around Fresno have fallen more than 100 feet in the last 80 years, and the levels are still declining, Heard said. As the water table continues to recede, pumping costs for the city’s wells gradually increase.

With climate change, Heard said, that supply of groundwater is going to become even more precious.

“From Fresno’s perspective, one of the biggest impacts of limited or no snowpack is it’s going to limit our ability to offset our groundwater pumping with treated surface water,” he said. Fresno recently began building a plant that will treat surface water from reservoirs to relieve pressure on the aquifer.

“Now with the prospect of prolonged or more frequent droughts, we may not be able to do that as much, which means we’ll have to continue using the wells,” Heard said. “And as long as we keep using the wells faster than the water is being replenished – whether artificially or naturally – that’s going to be a losing battle.”

He said that makes conservation all the more important. People in Fresno have reduced water use by about 25 percent in response to the state’s emergency drought regulations, building on previous reductions.

“I think these levels that we’re seeing that we’re calling reductions are going to need to just become our normal,” Heard said. “It’s definitely going to take a change in thinking for pretty much the whole state.”

Other water managers express confidence that the Kings River basin is relatively well prepared. Steve Haugen, the watermaster of the Kings River Water Association, said the area has already grown accustomed to highly variable natural swings in runoff. The amounts of water in the Kings River in a record wet year can be on the order of 10 times larger than a dry year, he said.

“At least in this area, most of the basin I think is well set and prepared,” Haugen said. “Unless we get into these 20- or 30-year droughts, there are some challenges there, and that’ll have to be responded to as we see those develop.”

Across California, the state government has received reports of more than 3,000 households out of water since the summer of 2014, many of them with dry wells – and most of them in small communities around Central Valley farms that have been pumping groundwater heavily during the drought.

As for the future, Haugen said the mountains above the Kings River are so high and steep that even a rise of 1,000 feet in the snowline – which scientists say is likely with 2 degrees Celsius of warming – should have a “fairly minimal impact” on the total amount of water.

But in other areas of California, such as the watersheds that feed the Feather River and the American River, he said the same rise in snowlines would change snow to rain over large areas. And that would unleash much bigger impacts.

Dwindling snow

Using data from snow sensors across the country, scientists have tracked significant declines in the average snowpack throughout much of the continental United States as the climate has begun to heat up.

Some stations at the highest elevations, including parts of the southern Sierra Nevada and the southern Rocky Mountains, have been the exception and have seen increases in snowfall with that initial warming. But that's because at those heights a little extra warmth can make the atmosphere more conducive to generating snow – and scientists expect that will last for only a limited time.

Once the atmosphere warms up enough, then snow is projected to decrease at those high-elevation sites, too, said Sarah Kapnick, a research physical scientist at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey.

The snow is melting earlier at all of the monitoring stations in the western U.S., Kapnick said, "and that's why you don't have as high of a peak within the season."

She and colleague Alex Hall of the University of California, Los Angeles, estimated in a 2012 [study](#) that across the West, snow has been melting on average one day earlier per decade since 1950 – about a week earlier than it used to melt. In Northern California and the Northern Rockies, they found the melt has moved up even more – by about two weeks over that same period.

Stream gauges have also shown earlier spring runoff from snowmelt than in the past.

Trends in western snowpack

Projected changes in snowfall

Projected changes in average annual snowfall due to global warming

The map illustrates projected snowfall changes as a result of human-caused global warming, based on a scenario in which carbon dioxide is doubled from 1990 levels. This information was calculated by researchers at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory. The scientists used a global climate model named CM2.5 to calculate snowfall in a constant climate (with 1990 carbon dioxide levels held constant) and compared that against a climate with carbon dioxide doubled.

SOURCE: Sarah B. Kapnick and Thomas L. Delworth, NOAA Geophysical Fluid Dynamics Laboratory

MAP: Robert Hopwood, The Desert Sun

Those shifts are just the beginning of the more pronounced changes that scientists expect. Kapnick has estimated in her [research](#) that if the quantity of carbon dioxide in the atmosphere is doubled from 1990 levels, the average amounts of snowfall are likely to decline by 50 percent or more in coastal regions of the lower 48

states, and by amounts ranging from 10 percent to 40 percent on inland mountains.

As the amounts of snowfall gradually decrease with warming, Kapnick said, “it takes us closer to drought conditions on an average basis.”

In fact, the drought in Oregon and parts of Northern California during 2014 and 2015 had a lot to do with the very warm winter, said Philip Mote, a climate scientist at Oregon State University.

“Here we had pretty close to average precipitation in the previous winter, but only about 10 percent of average snow in much of Oregon and the northern counties of California,” Mote said. “So that was an illustration of what happens if it’s just a lot warmer.”

Scientists concluded in one study last year that global warming has exacerbated the drought in California by drawing moisture from the soil and plants into the air.

California, Oregon and Washington rely to a large extent on spring snowmelt to sustain water supplies through the summers, and that natural reservoir is shrinking.

“So if you imagine a big reservoir like Shasta in Northern California or Lake Mead or Lake Powell, and every year we’re sort of cutting another foot off the top of the dam, reducing the amount of water that we can store,” Mote said. “That’s sort of effectively what’s happening, because as we raise the snowline, we’re reducing the area over which snow can accumulate.”

One team of scientists recently studied how declines in snowpack will likely affect the water supplies of different regions around the world based on the projections of climate models. And what they found was striking. Of 421 drainage basins in the Northern Hemisphere, they identified 97 regions as being “snow-sensitive” and dependent on snowmelt to help meet water demands. Those regions are home to about 2 billion people.

The scientists’ results, laid out on a map, show that much of the western U.S. – from California to the Colorado River basin to the Rio Grande – is shaded in red and maroon. That indicates those regions are particularly vulnerable and face high risks of having less water available during spring and summer months due to decreases in snowpack.

“What we’re really quantifying in that study is, what’s the potential of the climate of tomorrow to supply the water needs of today?” said Justin Mankin, a climate scientist at Columbia University’s Lamont-Doherty Earth Observatory who co-authored the [study](#).

NOTE: Analysis does not take into account pumping of groundwater or transfers of water between river basins.

SOURCE: Justin S. Mankin, et al., Environmental Research Letters

MAP: Robert Hopwood, The Desert Sun

Declining snowpack puts water supplies at risk

This map shows scientists’ calculations of how declines in snowpack are likely to affect the water supplies of different regions of the United States. Using climate models, researchers found that much of the western United States is especially vulnerable and faces high risks of having less water available during spring and summer

months.

In regions that pop up as red across the western U.S., Mankin said, “according to our measure, the climate of tomorrow will not be in a position to supply the water demands of today.”

Mankin, who is also affiliated with the NASA Goddard Institute for Space Studies, said the findings point to a need for a “management response.” He said how policymakers should respond differs for each river basin. “But in general, what a measure like this is telling us is that our historical reliance on snow is untenable in a future climate.”

The challenges for the Southwest appear especially daunting. Over the past few decades, the region has grown drier. Using climate models, scientists have projected that increasing emissions of greenhouse gases make for higher chances of a decades-long “[megadrought](#)” by the end of the century.

Even without such an extreme event, many scientific studies forecast significant declines in the flow of the Colorado River, which together with its tributaries provides water for nearly 40 million people and more than 5 million acres of farmland.

Researchers have [estimated](#) that warmer temperatures and the resulting declines in runoff could reduce the river’s flow by between 5 percent and 35 percent by the middle of the century. That will add to the enormous pressures on a river that is already heavily over-allocated and rarely reaches the Sea of Cortez anymore.

Federal officials who manage dams for the U.S. Bureau of Reclamation have recently calculated that the chances of Lake Mead reaching shortage levels in 2018 have risen to 59 percent.

If a shortage is declared, that would trigger cutbacks in the amounts of water delivered to Arizona and Nevada. Those sorts of impacts could grow more severe if continued decreases in the flow of the river collide with the existing framework of water allocations, which was drawn up during wetter times over the past century. Even California, which under the law of the river would be the last in line to have its water deliveries reduced, could face growing pressures to accept cutbacks.

With warming, demands for water also will tend to increase in the Southwest as the same amount of irrigated acreage will grow thirstier, and as more water will evaporate off the landscape.

“The Colorado system is really vulnerable to climate warming,” said Dan Cayan, a climate researcher with the Scripps Institution of Oceanography and the U.S. Geological Survey. He pointed to recent research indicating that for every 1 degree Celsius of warming, the Colorado River could lose somewhere between 5 percent and 10 percent of its flow.

While the pressures grow on the river’s limited supply, potential remedies are constrained by the legal framework laid out under the 1922 Colorado River Compact and subsequent water agreements.

Some researchers have compared the river to a pie that’s being cut up to share: The problem now, they say, is that the pie is still being divided in the same way as it has been for a long time, even though we’re finding the pie is actually much smaller than we once thought it was.

“The management of the river is going to have to dramatically change,” said Gary Wockner of the environmental group Save the Colorado.

“There’s going to have to be more conservation. There’s going to have to be more water transferred from farms to cities. And it is increasingly unlikely that there’s going to be enough water,” Wockner said. “So something has to change.”

Adapting to water changes

Aside from the scandal over lead-contaminated water in Flint, Michigan, water issues haven’t come up during the U.S. presidential race. Candidates have barely discussed climate change, much less the impact of warming on water supplies.

But some people argue the United States is long overdue to move toward a comprehensive national water policy, especially with the effects of climate change looming.

“We’re in a water transition from what I would say is a 20th century way of managing water to what I think will be a much more sustainable way of managing water, and it’s a transition,” said Peter Gleick, president of the Pacific Institute, a think tank that focuses on water issues. “Inevitably, our water system will be much more sustainable. Ultimately the question is how quickly and with how little pain we can get there.”

He and others say adapting will require a host of strategies, from preparing for more severe droughts to adopting new “rule curves,” or sets of guidelines for managing water levels in reservoirs, based on patterns of runoff that are shifting away from historical norms. Adapting will also require investments in infrastructure, better water data and science-based policymaking to address vulnerabilities.

While all of those steps may sound relatively simple, efforts to make the nation’s water systems more sustainably face a host of barriers. Just fixing old, leaky infrastructure could save vast quantities of water, but doing that would require substantial investments by local and state governments. Budgets for new infrastructure projects are limited in many areas, and private investments in new water-saving technologies have also remained small when compared with the rapid growth in investments in renewable energy.

Many areas could recycle and reuse much more treated wastewater if there were enough investment by public agencies. Other barriers include a lack of sufficient monitoring and measurement of groundwater use; antiquated and rigid water rights systems; and in some places, pricing systems that don’t go far enough in encouraging conservation. With management responsibilities fragmented among many local and state entities, some agencies appear to be taking forward-looking steps while others are constrained by bureaucratic inertia, pursuing the same old approaches even as the climate changes.

Questions about preparedness for climate change need to be answered at the local level, area by area, said Mote, the climate scientist at Oregon State.

“I think there’s no better test than a drought like we’ve just had,” Mote said. “Whatever can be done now to figure out a better way to manage that situation will probably stand us in good stead for the next time it

happens.”

With the snow holding less water, that seasonal water-storing capacity will need to be replaced elsewhere. But that doesn't necessarily have to involve building more dams.

“There are multiple ways to get storage,” said Roger Bales, a professor and director of the Sierra Nevada Research Institute at UC Merced. “Before we ask the public to pay for an expensive dam, we'd better make sure that's the best option, that we need to exhaust local options such as groundwater storage and recharge.”

Researchers have also found that investments in thinning overgrown forests could help. By removing vegetation and carrying out prescribed burns, those sorts of projects can make forests healthier and reduce the risks of wildfires, while also increasing runoff from the mountains – which could give a boost to water supplies downstream.

“We need to prioritize where investments in forest restoration will actually make a difference, both for fire and water,” Bales said.

Preparing for a hotter climate will involve not only counting on less snowmelt, scientists say, but also getting ready for changes in the timing and intensity of storms, and more extreme downpours. Among other things, warming can raise the odds of events in which rain falls on top of snow. By rapidly melting the snowpack, that can trigger floods.

“What we have to think about is, how are we going to manage the infrastructure that is not adapted to the new regime which we'll be operating under?” said Noah Molotch, director of the Center for Water Earth Science and Technology at the University of Colorado, Boulder. “That really is the challenge, I think, for society.”

Many managers of local water districts as well as state and federal officials have been emphasizing a need to use water more efficiently and stretch local supplies further.

“If you just do what we do now over the next 30 years, we will definitely face challenges,” said David Groves, co-director of the RAND Water and Climate Resilience Center. “The region is not prepared for growth in certain areas, as well as superimposing climate warming.”

He and other experts see enormous potential for California and other states to recycle more wastewater, “bank” water in aquifers, and capture more stormwater instead of letting it run off city streets into the sea.

When California's Natural Resources Agency recently issued a report outlining the state's efforts to prepare for climate change, it focused on objectives such as preparing for floods, managing groundwater, diversifying local water supplies and improving efficiency, among other things.

The Obama administration has also launched several initiatives aimed at encouraging more investments in water infrastructure, improving water data and boosting technologies that can help shrink the country's water footprint. When the White House held its first-ever national water summit in March, much of the discussion focused on efforts to help address the threats posed by climate change.

Coinciding with the event, the Interior Department released a report detailing projections of climate change

impacts on the regional water supplies of 17 western states. In the report, the department said average temperatures will likely rise by 5-7 degrees Fahrenheit by the end of the century, bringing reductions in stream flows of between 7 percent and 27 percent from April through July in several river basins, including the San Joaquin River, the Rio Grande and the Colorado River.

Deputy Interior Secretary Mike Connor said recently that some of the White House's key goals include encouraging more wastewater recycling and promoting investments in water treatment and desalination technologies.

"There's great potential across the West to increase what we're doing in the area of water reuse," Connor said. "There's very significant opportunities for targeted desalination facilities, brackish groundwater desalination. We're already seeing that in some areas. That can add to the water supply from previously unusable supplies. That can help relieve the stress on existing potable water supplies."

Some California water districts have begun investing heavily in plans to prepare for longer and more intense droughts, as well as for the wetter times.

The Santa Ana Watershed Project Authority, for instance, is backing a \$100 million project that involves developing four large groundwater basins to store imported water from Northern California when it is available. Celeste Cantú, the authority's general manager, said the strategy is to "capture the flashy wet years."

Several agencies are pooling their resources and participating jointly in the project.

"You have four basins that are going to be managed for the greater good of the watershed," Cantú said. She called it a big step toward becoming more climate-resilient.

A number of California agencies are taking significant steps to become less dependent on imported water supplies, said Frances Spivy-Weber, vice chair of the State Water Resources Control Board. She pointed out some water districts are projecting they will need less water in two decades than they do now, and she said that's cause for optimism. Growing numbers of water districts have also switched to tiered pricing systems that reward those who conserve and penalize those who don't.

"Climate adaptation definitely is achievable with conservation and portfolio of water supplies," Spivy-Weber said. "We're going to be able to ride out the droughts – even if they last for 10 years or 20 years."

The drought in California, now in its fifth year, has been a harbinger of the hotter droughts expected under climate change.

Last year was the planet's [warmest year](#) since records began in 1880, surpassing a record set the previous year.

This past winter also brought record-breaking warmth, partly influenced by El Niño. In the continental U.S., the average temperature in the three months from December through February was 4.6 degrees Fahrenheit warmer than the 20th century average.

Stacy and other scientists who are doing research in the Sierra Nevada have been seeing the effects of the

abnormal heat all around them, even as this winter brought a larger snowpack that peaked at 88 percent of average in late March.

Stacy works at five research sites as field manager for a project called the Southern Sierra Critical Zone Observatory. Over the past couple of years, she and other researchers have watched mid-elevation forests of ponderosa pines turn brown and die.

Warm winters have enabled bark beetles to flourish in the drought-stressed forests, and the insects have left the mountains covered with [millions of dead trees](#).

At the beginning of last summer, Thaw began studying one lower elevation site and marked trees to take samples over the following months.

"I came back later in the summer and they were dead," Thaw said, "so I had to change my research plan."

At research sites where several years ago Stacy trekked in using snowshoes or skis, she's now often able to park nearby and walk on exposed ground.

"Sometimes it makes our work a little bit easier up here, but it's really noticeable when we're out here doing research that the snow isn't there," Stacy said.

She slipped on a safety harness and climbed up a 160-foot tower to replace air filters on instruments that monitor water vapor and carbon dioxide in the air. She explained that the measurements enable her team to "observe the forest breathing" as the trees conduct photosynthesis.

Then she went to check a snow sensor. As she walked across a white meadow, she skirted holes in the snow where sheets of water were flowing beneath and shimmering in the sun. The water streamed off onto patches of bare ground.

"It's been melting pretty quickly over the past couple of weeks," she said, "because it's been so warm."

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More information:

SOUTHERN SIERRA CRITICAL ZONE OBSERVATORY

2016 WORK PLAN – CZO investigators and their research groups

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1. Core Observatory measurements, data management and integration

Investigators:	Roger Bales (UC Merced) Martha Conklin (UC Merced)
Students & research staff:	Erin Stacy, Field Manager (UC Merced) Xiande Meng, Data Manager (UC Merced) Michelle Gilmore, Outreach and Project Manager (UC Merced)

Scope. The Southern Sierra Critical Zone Observatory (SSCZO) is centered on an elevation transect of measurements of water, soil and nutrient fluxes on the west slope of the southern Sierra Nevada. The elevation transect serves as a backbone for related projects including the eddy co-variance flux towers, deep soil/regolith investigations, and remote sensing endeavors. Catchment-scale measurements of water, soil, and energy balances in selected SSCZO catchments, and management of data and information for the SSCZO core measurements provide a framework for multiple other projects. Metadata, spatial data, and project integration are driven by staff for the benefit of the entire project.

Field installations & support. Core measurements made by the SSCZO team span an elevation grade from the oak woodland foothills (400 m) to the subalpine coniferous forest (2700 m). The four sites

comprising the transect are anchored by eddy covariance flux towers and soil pits with sensors for temperature and moisture; installations include soil moisture and temperature in deep soil pits (up to 250 cm), subsurface groundwater monitoring, and arrays of instrument clusters for quantifying the water balance. Several instrument clusters are installed at mid-elevation sites to measure snow depth, air temperature, soil moisture, incoming radiation (open canopy), and multi-depth soil temperature and soil matric potential. One site is installed around the Wolverton basin in Sequoia National Park (2100-2730 m). At the Providence Creek site (1695-2015 m) in the Sierra National Forest, core SSCZO measurements (including instrument clusters) complement those done by the USDA Forest Service Kings River Experimental Watershed (KREW) team. Existing instrument cluster networks are installed at the Providence site (1) in the P301 watershed (1970-2020 m); (2) at the lower end of the snow accumulation area near the [KREW-operated] Lower Met (1740 m); and (3) at a location receiving a mix of rain and snow near the [KREW-operated] Upper Met (1980 m). Across the Providence meadow and stream sections, measurements will continue for water level, temperature, and electrical conductivity in wells and piezometers. Core measurement collection benefits other SSCZO projects including extended geophysical work, vegetation-atmosphere links, ongoing water and vegetation sampling, and deep subsurface soil sampling, among others (detailed in projects below); SSCZO staff will support these efforts as part of the core measurements.

Data management. SSCZO data are available in the SSCZO digital library:

Main folder: https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW

Sequoia site: <https://eng.ucmerced.edu/snsjho/files/MHWG/Field/SEKI>

Schedule, including field work. Ongoing, continuous

Researcher stays at Glen Meadow or Dinkey Mill? Request for CZO summer lodging

2. Southwest U.S. Drought Characterization

Investigator: Roger Bales (UC Merced)

Collaborator: Michael Goulden

Students & research staff: Joe Rungee, graduate student (UC Merced)

Scope. Current methods for assessing and predicting drought rely on empirically derived potential evapotranspiration. These methods view the landscape as homogeneous, resulting in a less accurate assessment of the impacts of drought on hydrology. Based on the extreme inter-basin heterogeneity of mountainous areas, and recent results from eddy covariance flux towers in California, drought should be assessed at a minimum spatial resolution of basin scale. Evapotranspiration estimated through eddy covariance can be used as a proxy for site characteristics that control runoff, including precipitation timing and magnitude, soil drainage, and vegetation. Thus, eddy covariance flux tower data can be used to better characterize the hydrologic response to drought in the forested mountain West of the United States. In addition, the model will be structured to accommodate a moving baseline – the changing global climate. This approach could greatly increase drought assessment and forecasting capabilities, providing decision-support tools that would allow water-resource managers and decision makers to more efficiently and effectively respond.

To build this drought assessment model, point data will be combined with remote sensing data and modeled parameters. Eddy covariance data from a suite of sites (from California to the Rockies) will be compiled and extrapolated using a remotely sensed vegetation index, along with the PRISM (Parameter-elevation Regression on Independent Slopes Model) precipitation. From there, each site will be assessed for its relative response to drought as a function of water storage deficit.

Field installations & support. The current phase of the project involves compiling eddy covariance flux

tower data located throughout the mountain West. Meteorological and eddy covariance flux data as needed from existing SSCZO sites. Further data from LiDAR or spatial files may be also needed.

Data management. *SSCZO model metadata and output will be uploaded to the digital library:*

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Models/Mountain_west_dryperiod_assessment_Rungee

Schedule, including field work. Finishing second year; data and modeling-focused. Field work not required.

Possible permit amendment needs: None

3. Deep soil and regolith characterizations across an elevational transect

Investigator:	Toby O'Geen (UC Merced)
	Steve Hart (UC Merced)
Students & research staff:	Asmeret Asefaw Berhe (UC Merced)
	Cliff Riebe (Uni. Wyoming)
	Pete Hartsough, research (UC Davis)
	Katelin Alldritt, graduate student (UC Davis)
	Morgan Barnes, graduate student (UC Merced)
	Nick Dove, graduate student (UC Merced)
	Ryan Ferrell, graduate student (UC Davis)
	Kimber Moreland, graduate student (UC Merced)
	Tian (Tina) Zhiyuan, graduate student (UC Davis)

Scope. Previous SSCZO work showed that bedrock weathering and regolith are much deeper than previously hypothesized. This project explores multiple aspects of deep soil and regolith profiles at four sites across the 400 m to 2700 m SSCZO elevation transect. The interdisciplinary nature of the project will inform aspects of soil formation, water storage, soil composition, and other soil-vegetation interactions on multiple fronts. Researchers from several groups have collaborated on these deep pits. Deep drilling with a Geoprobe rig has been completed at three sites of the elevation transect; the set up has reached depths of 11 m at one of the sites. In 2015, another round of Geoprobe sampling was coordinated with large-scale 3D passive seismic measurements to connect deep soil and regolith biochemical characteristics with the larger geophysical landscape. A second component to this work involved multiple large pits at each site to characterize soils, assess physical, chemical and biological components across the profiles, and install electrical sensors. A mini-excavator was used to expose pits at San Joaquin Experimental Range and Soaproot Saddle; due to access constraints, pits were hand-dug at the highest elevation site (Short Hair). At all four of the transect sites, deep pits were instrumented in 2015 for measurement of soil moisture and temperature (depths of 120-250 cm).

Most of the field work for these projects has been completed. The excavation of large pits at Providence still remains. Further auguring and tree-coring at the Soaproot and Providence sites, mostly completed as of Spring 2016, expand the spatial scope of these projects. Samples from these pits are undergoing multiple lab analyses. Those subprojects are detailed in part here:

- Morgan Barnes
 - Use the SSCZO climosequence and an additional climosequence located in the White Mountains to relate soil phosphorus pools to changes in temperature and precipitation along the (Mediterranean and arid) climatic gradients.
 - Hedley P fractionations
- Nick Dove

- The aim of this project is to study how microbial community composition, functional gene abundance, and extracellular enzymatic activity vary with depth along the Southern Sierra Climosequence at SSCZO and relate these factors to different nutrient concentrations (nitrogen, phosphorus, and carbon). Climosequences present an opportunity to study how soils may respond to climate change, where soils under colder climates will shift towards those under warmer ones in the future.
- Ryan Ferrell
 - Characterization of the spatial variation of soil/regolith depth and permeability in the Soaproot watershed in order to: 1) Create a model of regolith thickness using terrain attributes; and 2) Link regolith thickness to drought stress/tree mortality and or productivity
- Kimber Moreland
 - Predicting how critical zone subsoil (below the A-Horizon) is shaped by climate and topography. Specifically, investigating topsoil-subsoil interface to understand how climatic (precipitation and temperature) and topography (slope, aspect) change regulates subsoil organic carbon storage/stock, composition, stability (resistance to mineralization), and stabilization mechanisms. Primary goal is to improve our ability to predict subsoil carbon cycling response to environmental change in the critical zone. Sampling completed at CJCZO, and four sites planned at SSCZO. Lab techniques include solid state ^{13}C Nuclear Magnetic Resonance, stable and radioactive isotopes of carbon (^{13}C and ^{14}C), and Fourier Transformed Infrared Spectroscopy. Critical zone and Central Valley STEM outreach is also a priority. Cross-CZO work will contribute to a model for deep C with climate (MAP/MAT) on granitic parent material.
- Zhiyuan Tian
 - Documenting how characteristics of soil and weathered bedrock change across the Sierran elevation gradient with a primary focus on key ecosystem services such as carbon sequestration, water storage, and nutrient cycling. Across the elevation gradient, the project is drawing comparisons between soil and weathered bedrock with respect to carbon stock, pore space and water holding capacity, mineral transformations, and nutrient availability.
Summit and back slope positions were sampled in triplicate at three different locations along the gradient (oak savannah, pine oak forest and mixed coniferous forest). Depths ranged from 1.5 m to 10 m. Physical properties measured included particle size distribution, bulk density, water retention curves and porosity. Parameters affecting fertility were analyzed as well - pH, soil organic carbon, available P, exchangeable cations and potassium fixation capacity. Mineralogical transformations are assessed through the characterization of pedogenic iron, clay mineralogy and primary mineral composition of soil and weathered bedrock.

Field installations & support. CZO staff will support the deep pit instrumentation through data downloads, archiving and analysis.

Data management. CZO soil sensor data from the deep pits are uploaded under each tower folder, e.g.: https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Soaproot_Saddle_Flux_Tower/Deep_pit

Pit sample data will be uploaded, in appropriate folders, to the Studies folder, or to:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Studies/Soil_deep_profile_pits

Schedule, including field work.

[Completed] Drilling with the Geoprobe occurred in 2013 (San Joaquin Experimental Range - SJER, Soaproot, Providence) and 2015 (Providence, Duff). Pits and deep instrumentation have been completed at three of the four transect sites (SJER, Nov. 2014; Short Hair, Sept. 2015; Soaproot, Nov. 2015). Deep instruments were installed at one pit at Providence, summer 2015.

[Forthcoming] Deep augur or drilling is being planned to assess microbial communities at depths greater than 2 m (Hart lab). The Geoprobe is a potential option to reach that depth (as lead on previous Geoprobe work, UC Davis group requests notification and involvement).

Further large pits at Providence are approved and currently planned for June 2016, pending fire conditions.

Barnes plans plant matter collection at SSCZO and White Mountains, Fall 2016.

Possible permit amendment needs. Soaproot pits approved through SNF (pits open November 2015 – March 2016). Providence pits approved through SNF, KREW; there is no limited operating period, though may need to hand dig in place of an excavator if confronting fire danger; SNF prescribed burn at Providence should not interfere

Researcher stays at Glen Meadow or Dinkey Mill? Potentially, or campgrounds especially for campaign work on pits

4. Distinguishing soil nutrient hot spots and hot moments in a spatial context

Investigators:	Steve Hart (UC Merced) Asmeret Asefaw Berhe (UC Merced)
Collaborator:	Dale Johnson
Students & research staff:	Morgan Barnes, graduate student (UC Merced)

Scope. Provide plot-scale measurements of water and material balances in selected SSCZO catchments, and management of data and information for the SSCZO. Carry out integrated modeling of the water balance using the rich data sets in selected catchments. Share results with stakeholders in California.

Patches of elevated nutrient fluxes in the soil exists as persistent locations (hot spots) and for distinct periods of time (hot moments). Research on the high elevation watersheds of the Southern Sierra has identified nutrient hot spots and moments, but has been inconclusive on the mechanism causing this heterogeneity in nutrient flux. Previous research attributes hot spot formation on the western side of the Sierra to preferential flow paths, although a direct association has not been found. This study will, for the first time, investigate the spatial relationship between preferential flow paths with hot spots and hot moments using additional data collected from the nutrient pit sites studied by Johnson (2011; 2014) and Woodward (2012; 2014).

Preferential flow paths in the unsaturated soil will be isolated through the application of a widely used, non-toxic dye applied to previously studied nutrient grid locations. After application, directed excavation will be used to characterize flow paths. The information obtained from the dye study will be used as input parameters for a HYDRUS 2D simulation to model water flow and standard solute transport. The overall objective is to simulate the observed hot spots and hot moments in regards to location, quantity and dimensions of the preferential flow paths from a representative soil on the west side of the southern Sierra Nevada.

Field installations & support. Nutrient Grid 2 (in P301) currently has resin capsules that will need to be removed post-snowmelt. Multiple extra hands needed for the dye application and excavation campaign. Approval from C. Hunsaker and KREW team on file.

Need: Shovels, camera, extra camera battery, tripod; Water tank, mixing apparatus or other protocol

Data management. Dye study data and model output will be uploaded to the digital library:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Studies/Hot_Spot_3_D_soil_grids_Woodward_Barnes

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Models/HYDRUS_Hot_Spots_Barnes

Schedule, including field work.

Post-snowmelt (pre-rainfall) – Remove capsules at Grid 2

Post-snowmelt (pre-rainfall) – Dye tracer study at Grid 2

Modeling – Fall 2016 and Spring 2017 focus

Possible permit amendment needs. Checking on Brilliant Blue dye or alternative.

Researcher stays at Glen Meadow or Dinkey Mill? Potentially, especially for campaign work on infiltration study

5. Linking surface and groundwater with vegetation water use

Investigator: Martha Conklin (UC Merced)

Collaborator: Ate Visser (LLNL)

Students & research staff: Melissa Thaw, graduate student (UC Merced)
Ryan Lucas, graduate student (UC Merced, graduating 2016)
Erin Stacy, field manager (UC Merced)

Scope. Surface-groundwater interactions are investigated through multiple avenues in the Conklin research group. Parts of the surface-groundwater investigations have been reduced this year as graduate student Ryan Lucas finishes his doctoral work. Ground water elevation and depth specific pressure head continued to be monitored in the 24 wells and piezometers in the P301 meadow (Sierra National Forest) and the 31 wells and piezometers in Long Meadow (Sequoia National Park). Ground water elevations were analyzed for inter-annual and seasonal trends as well as daily evapotranspiration (ET) signals. This project is incorporating data from water samples and slug tests into a larger modeling assessment of these surface-groundwater linkages. A snow-depth sensor was added to the meteorological station deployed in P301 Meadow. The eddy covariance flux tower was deployed in Long Meadow from March 2015 until February 2016. These instruments may be added to an existing tower to measure lower canopy fluxes or redeployed at a new site, pending discussions and permitting.

A second project addresses seasonal sources of water that vegetation accesses during a severe drought. It is hypothesized that vegetation adapts to using different water sources during summer severe drought conditions compared to during the return of winter precipitation. These multiple sources, including sub-surface soil layers, weathered bedrock depths, and precipitation, will be isolated using tritium and stable oxygen and hydrogen isotopes. Winter precipitation tracking includes high temporal resolution sampling of new snow deposition and melt throughout the winter. Passive capillary samplers will capture variability in water stable isotope signature through the winter season deposition-melt-freeze cycles and the influence of forest structure on stable isotope signatures in snowmelt. Multiple species of trees and shrubs will be followed through the year to separate different adaptations or responses.

The goal of another project, in collaboration with Lawrence Livermore National Laboratory, is to track water through the Critical Zone by integrating multi-isotope fingerprints into a coupled hydrology and land surface model (PARFLOW+CLM) at the SSCZO. This project will focus on three catchments of varying sizes with distinct geographical characteristics in the Sierra National Forest: P301 (1 km²), Providence Creek (4 km²) and Big Creek (50 km²). The combination of unique isotopic tracers, high performance computing and highly instrumented catchments will address a critical research question: *Which catchment parameters indicate stream flow vulnerability to drought?*

To answer this question, the three specific objectives are:

- 1) Assess the source and residence time of water lost by evaporation and plant transpiration using high frequency in-situ measurements of water isotopologues using the LLNL developed mini tunable diode laser in conjunction with existing flux towers.
- 2) Constrain the effective storage capacity of selected catchments by deriving the age distribution of water leaving the catchment as stream flow, using a combination of stable (^2H and ^{18}O) and cosmogenic isotopes (^3H , ^{22}Na , ^{35}S).
- 3) Integrate the knowledge derived from isotopic fingerprinting into the ParFlow+CLM model, using isotopic measurements as calibration targets, to investigate drought vulnerability indicators.

Field installations & support. Installations include passive capillary samplers for snow and soil water (2015 Dec. installation), use of the existing P301 meadow wells and piezometers, and access to creek sampling locations. Staff will help with sampling help as needed for water, snow, and precipitation samples. Data downloads of P301 and Sequoia National Park well and piezometer measurements will continue biannually for now. Additional work on spatial mapping would be useful.

Data management. Vegetation and water sample data posted under:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Studies/Tracking_Water_LDRD

Schedule, including field work

Ongoing monthly+ samples from streams, plus vegetation, soil, and tree core samples.

Reinstall miniflux station at Sequoia Long Meadow

Possible permit amendment needs. Installations around tower footprints; KREW approval on file. Request for stream Levellogger sensors submitted March 2015 – no approval yet.

Researcher stays at Glen Meadow or Dinkey Mill? No, primarily camping

6. Connections between above-ground and below-ground critical zone processes at tree-slope scale

Investigator:	Pete Hartsough, researcher (UC Davis)
Collaborator:	Mohammad Safeeq, researcher (UC Merced)

Scope. The investigation of the coupling of above-ground with below-ground critical zone processes continues using both data analysis and hydrodynamic modeling techniques. This project will further integrate data streams from the instrumented Critical Zone Trees with relevant models for hypothesis testing of coupled lower atmosphere boundary conditions (ET) and tree canopy measurements (canopy water potential, tree stem sap flow) with relevant subsurface hydrological processes (depth to bedrock, deep vadose zone, lateral flow). Existing measurement and modelling efforts are supplemented with stable isotope fractionation techniques to help assess the contribution of deep vadose zone water to total tree transpiration. In this context we set out to answer two fundamental questions.

- How much water can be stored in the weathered material in the subsurface? How important is that water to the summer ET budget?
- Where are the roots of these trees and how do they access moisture? What are the mechanisms and timing of water extraction to feed transpiration demands?

Field installations & support. Installations include the instruments and dataloggers at CZT-1 and 2, as well as the central datalogger on the P301 tower, as well as neutron probe measurements made regularly at depth at Providence, Soaproot, and SJER (neutron probe transect access wells installed at the Geoprobe coring locations).

These questions are being approached through five activities:

1. Ongoing monitoring at CZT-1 and 2
2. Deep Vadose Zone instrumentation and modeling
3. Subsurface investigations with the Geoprobe (also see Project 3)
4. Modeling the Soil-Tree-Atmosphere Continuum at CZT-1

Data Management. Data is posted to several folders on the digital library.

Critical Zone Tree data:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Critical_Zone_Tree

Neutron probe data:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Studies/Neutron_Pro_Pr_Transect

Model output will be added to the digital library:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Models/CZTree_models

Schedule, including field work. Regular monthly neutron probe readings occurred from 10/14/2014 to 4/12/2016; from this point forward measurements will be taken as convenient, less than monthly, to add to the record. Critical zone tree instruments will be maintained at current levels.

Possible permit amendment needs. Permitting current (see ideas under consideration, section 14).

Researcher stays at Glen Meadow or Dinkey Mill? Primarily camping.

7. Spatial variation of soil moisture and snow across the landscape

Investigators: Steve Glaser (UC Berkeley)
Roger Bales (UC Merced)

Students & research staff: Carlos Oroza, graduate student (UC Berkeley)
Zeshi Zheng, graduate student (UC Berkeley)
Erin Stacy, field manager (UC Merced)

Scope. Snow depth sensors distributed across the landscape have improved real-time information for water resource management. However soil water storage capacity and patterns of soil moisture usage across the landscape are still little understood. This project uses soil moisture data from existing installations at Providence (the P301 subcatchment, Upper and Lower Met) to analyze soil moisture storage and vegetation water use. Development and analysis of algorithms for optimal siting of sensor locations for snow depth is continuing.

Additional instrumentation will be deployed to extend the representation of soil moisture fluxes across gradients of climate and vegetation. Scientific goals of the expansion include: (1) quantifying the spatial distribution of total belowground soil storage capacity, (2) identifying the driving mechanism of storage carryover between zones with ephemeral and seasonal snowpack, (3) quantifying the role of biotic and abiotic controls on soil moisture stability and persistence at the catchment scale, (4) constraining hydrologic model uncertainty, and (5) quantifying differences in soil moisture usage across large gradients of biomass.

Field installations & support. Sensor nodes the P301 Wireless Sensor Network are prepared for the potential re-ignition of the Providence prescribed burn around May 2016. Nodes are ready to be renetworked; steps to achieve this will include testing the 4G network connection, a long-range ethernet connection, and finally installing the base station and repeaters. Ongoing work with the existing sensors will include a reevaluation of the battery system, and a cost comparison for replacement. New installations will be added (planned in 2016) to complement existing sites.

Data management. SSCZO sensor network data posted:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/P301_Water_Balance_Transect/Snow_Soil_and_Radiation

Schedule, including field work.

[Completed]

1. Soil moisture collaboration with JPL project: expand sensors on the ground in P301
 - a. Also links with core instrumentation/data
 - b. New pits with GS3, potentially others
 - c. Ground truth – synoptic survey at times

[Forthcoming]

1. Consider move to Li-ion batteries and new charge controllers
2. Test wireless network repeater (begun 2015)
3. If the wireless network connection is reliable, test long-range ethernet
4. Install 30 repeaters and test network (repeaters already fabricated)

Possible permit amendment needs. New installations outside of current tower footprints would need approval from Sierra National Forest and KREW.

Researcher stays at Glen Meadow or Dinkey Mill? Potentially, especially for work on the wireless sensor network repeaters or new installations.

8. Balance of land-vegetation-atmosphere water use interactions in a drought

Investigator: Mike Goulden (UC Irvine)

Collaborators: Roger Bales

Mohammed Safeeq

Students & research staff: Cyril McCormick, department researcher, as needed (UC Irvine)
Erin Stacy, Field Manager (UC Merced)

Scope. The California drought has caused millions of trees to die from a combination of pests and water stress. It is anticipated that such vegetation shifts combined with climate change will cause ecosystem scale shifts from forest to chaparral, even as some areas recover from the drought. The large-scale installation of eddy-covariance flux towers across a 2300 m elevational transect form the backbone of the SSCZO research sites. These flux tower sites provide both anchor points at four distinct elevations as well as data at a grove-landscape scale on the land-vegetation-atmosphere connections. The baseline years after installation and prior to the drought have provided insight into the drought and possible drought-recovery, as vegetation reacts to pest-infestation and limited precipitation.

Current focus for this project is on data analysis and preparing manuscripts for publication. Any requests for instrument installation on towers are welcomed for discussion.

Field installations & support. Field time will probably be occasional visits to maintain equipment, likely 7-10 days total. Potential installation of a tower above tree line would increase needed field time and support. Staff time for data download, filter changes, and other equipment maintenance will be requested as needed. Gas analyzer at Short Hair replaced March 2016. Trouble shooting the P301 panning camera/LiDAR installation will continue until working. Workload for this set-up may require a visit from Irvine.

Data management. Flux tower data are posted to four separate folders under each site name:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW

Schedule, including field work.

[Completed] Spring, 2016:

1. Install the panning camera and LiDAR system at P301
 - a. Completed February 24, troubleshooting ongoing

- b. LiDAR system pulled down for maintenance on April 27
 - 2. IRGA replaced at Short Hair (March 1)
- [Forthcoming] 2016:
- 3. Panning LiDAR needs to be reinstalled on the P301 tower
 - 4. High elevation @ White Mountain Research Station; 12,400'; or near South Lake/Bishop; Exploratory trip with Melissa – would need a graduate student champion
 - 5. Maintenance visits (Ongoing)
- Possible permit amendment needs.** No, if installations are on existing structures; YES if we move to a new site.
- Researcher stays at Glen Meadow or Dinkey Mill?** Potentially for accessing sites (or local campground)

9. Immediate effects of prescribed burning on mycorrhizal communities

Investigator: Steve Hart (UC Merced)
Collaborator: Carolyn Hunsaker (Forest Service, Pacific Southwest Research Station)
Students & research staff: Nick Dove, graduate student (UC Merced)

Scope. The short-term responses of mycorrhizal communities to prescribed burning are poorly delimited. While others have studied the long-term (> 1 year) and intermediate (6 – 12 months) effects of prescribed burning on mycorrhizal communities, this project will sample mycorrhizal communities immediately prior to burning (< 2 weeks) and immediately after (whenever is safe to do so). Fifteen sample locations will be stratified randomly within each watershed. At each location we will sample the organic horizon (10 cm diameter), and we will sample soil to a depth of 10 cm. Soil DNA will be extracted and PCR amplified using fungal-specific primers and sequenced on the Illumina platform. Sequence taxonomy will be assigned using the UNITE database. Communities will be analyzed using permutational multivariate analysis of variance (PerMANOVA) and visualized using non-metric multidimensional scaling plots.

Field installations & support.

No permanent or temporary field installations are needed for this project. Additional field help may be requested as needed during the year. Vegetation surveys at Bull Creek or Providence Creek sites may be conducted; project would also benefit from any fuel surveys at either site (check with KREW). Potential help needed for sampling around Providence prescribed burn.

Data management. *Microbial and soil data are posted to:*
https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Studies/Microbial_communities

Schedule, including field work.

- 1. Pre- and post-burn sampling completed at Bull Creek site.
- 2. Pre- and post-burn sampling work at Providence Creek is pending according to the prescribed burn schedule.

Possible permit amendment needs.: Research permits current with KREW for Bull and Providence work; small augur/surface soil digs

Researcher stays at Glen Meadow or Dinkey Mill? During sampling work, including during collaborations with KREW project pre- and post-burn work.

10. Local bedrock contributions to dust, soil, and vegetation nutrient flows

Investigator: Cliff Riebe (Uni. Wyoming)

Collaborator: Sarah Aciego (Uni. Michigan, Uni. Wyoming)
Students & research staff: Lindsay Arvin, graduate student (Uni. Wyoming)

Scope. Previous work at the SSCZO identified a potential control of bedrock phosphorus (P) concentration on the spatial distribution of ecosystems (Hahm et al., 2014). Such bottom-up controls on critical zone processes are essential for understanding how ecosystems may or may not survive during environmental changes. Additionally, a study of aeolian dust deposition along an elevation transect near the SSCZO indicates that aeolian P inputs are a significant fraction of total P inputs to soils of the Sierra Nevada (Aciego et al., in prep; also see 0). This project will further assess the hypothesis of bedrock-driven P limitation while also accounting for the aeolian dust P input. Samples collected from the SSCZO will inform the relative fractions of dust and bedrock that contribute to P in soils and vegetation atop plutons with variable bedrock P content. New samples of bedrock, soils (surface and profiles), and pine needles from a number of bedrock plutons and elevations will be compared with dust previously collected along the SSCZO flux towers transect. The bedrock collected for each study site will create a site-specific mixing model for the soil and vegetation based on the specific Nd and Sr signatures of the bedrock. Using these samples, the project will establish two end member (bedrock and dust) values for $^{143}\text{Nd}/^{144}\text{Nd}$ isotopic ratios and the relative mixing of these two end members into soil and vegetation.. Surface soils will be sampled primarily for these mixing calculations, although soil profiles will also be used to evaluate vertical mixing of the dust and bedrock sources. Altogether, the project will clarify the relative importance of bedrock P concentration and aeolian P inputs on nutrient cycling in the critical zone for the Southern Sierra.

Field installations & support. No permanent installations needed for this work. Personnel support during collection times in late July or August may be helpful.

Sample collection details:

- Bedrock: Samples will be taken from outcrops using rock drill with 10 cm diameter. Depth of rock core will also be about 10 cm.
- Surface soils: Minimal amount of soil (<500 ml) taken from the top 0-20 cm using a small spade.
- Pine needles: About 5 branches are sampled for each tree to homogenize the sample. Pine needles are pulled from the outer ~6 inches of the branch, cut using an extendable tree pruner.
- Soil profiles: Samples taken using a hand-auger of 7.6 or 10 cm diameter and collected to the depth of refusal.

Data Management. Geochemical data are posted to:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Studies/Bedrock_and_Soil_Geochemistry

Schedule, including field work.

Field work will be completed in late July or early August—exact schedule TBD. The samples to be collected at different sites are as follows:

SJER: 3 bedrock samples, ~15 surface soils, ~10 pine needle samples (Gray Pine)

Soaproot: 3 bedrock samples, ~15 surface soils, ~10 pine needle samples (Ponderosa Pine)

Providence: 3 bedrock samples, ~15 surface soils, ~10 pine needle samples (Ponderosa Pine, Sugar Pine)

Short Hair: 3 bedrock samples, ~15 surface soils, ~10 pine needle samples (Lodgepole Pine, Western White Pine)

Possible permit amendment needs.. Request submitted regarding bedrock cores, and vegetation/soil samples outside of the SSCZO sites.

Researcher stays at Glen Meadow or Dinkey Mill? Possibly – student visits in late summer around Team Meeting

11. Bedrock-regolith connections at mid-elevations in the Southern Sierra

Investigator: Cliff Riebe (Uni. Wyoming)
Collaborators: Ken Dueker (Uni. Wyoming)
 Steve Holbrook (Uni. Wyoming)
Students & research staff: Nick Taylor, graduate student (Uni. Wyoming)
 Russell Callahan, graduate student (Uni. Wyoming)

Scope. Previous work in the Southern Sierras have measured regolith thickness and structure using geophysical measurements including seismic refraction and electrical resistivity tomography (ERT) (i.e. Holbrook et al., 2014). This study will build on this previous work to understand the functional controls that drive regolith thickness and structure across different topographic positions in the Southern Sierras. Multiple models of regolith thickness have been developed to understand how factors such as topographic stress, bedrock drainage, frost cracking, and water-rock interactions influence the thickness of regolith (i.e. St. Clair et al., 2015; Rempe and Dietrich, 2014; Anderson et al. 2013; Brantley and Lebedeva, 2013). This work will pair borehole observations with surface seismic refraction and ERT measurements from varying topographic positions to test these different models of regolith formation and elucidate the processes controlling regolith thickness and structure in the Southern Sierras.

Field installations & support. Major support needed is in building relationship with Southern California Edison and potentially Pacific Gas & Electric. No permanent field installations needed. Short campaigns for passive seismic readings occurred August 2015. Additional assistance in summer 2016 from SSCZO staff will be requested as needed.

Data Management. Geochemical soil and bedrock data:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Studies/Bedrock_and_Soil_Geochemistry

Geophysical data:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Studies/Geophysical_Surveys

Schedule, including field work. Further geophysical data collection is planned in summer 2016 at the three sites where 3D seismic surveys happened in 2015 (Bald Mountain, near Dinkey Dome, and the D102 Duff Creek watershed near Providence).

Possible permit amendment needs. Previous seismic surveys were on a temporary use permit; waiting on response from Annette about existing vs. needs updating for summer use.

Researcher stays at Glen Meadow or Dinkey Mill? Possibly – student visits in late summer around Team Meeting

12. Predicting catchment hydrologic responses to changes in climate and land-use land cover.

Investigator: C. Naomi Tague (UC Santa Barbara)
Collaborator: Max Moritz (UC Berkeley)
Students & research staff: Chris Heckman, graduate student (UC Santa Barbara)
 Ryan Bart, postdoctoral researcher (UC Santa Barbara)
 Kyongho Son, graduate student (graduated 2015)

Scope. One of the challenges of a broad, interdisciplinary research project is the need to provide useful conclusions the research community and public stakeholders. Coupled models of hydrologic and ecosystem biogeochemical cycling processes are key tools for generalizing results from the SSCZO field-based analyses to other watersheds and future climate and land use scenarios. The primary focus of this

research group has been the use of models, including RHESSys (Regional Hydro-Ecosystem Simulation System), to assess how land use and land cover change alter the hydrologic cycle. Submitted papers include:

Title: Effect of tree-to-shrub type conversion in lower montane forests of the Sierra Nevada on Streamflow. *Authors:* Bart, Tague and Moritz. *In review:* PLOS-One

Title: How plant accessible water storage interacts with changing snowpacks in Mediterranean Environments. *Authors:* Tague, Heckman and Flint, *In review:* PNAS

Title: Effects of model spatial resolution on ecohydrologic predictions and their sensitivity to inter-annual climate variability in California's Sierra Nevada watersheds, *Authors:* Son, Tague and Hunsaker, *In review:* Water

For the coming year modeling work will focus on three areas:

Impact of soil water storage and redistribution on hydrology. Soil water storage is a primary control on the partitioning of precipitation into evaporation and runoff. Understanding the effect of plant available soil water storage (PAWSC) on actual evapotranspiration (AET) will allow us to better predict changes in vegetation under a warming climate. First, the project evaluated how precipitation regimes across the Sierra and a range of PAWSC (see above submitted paper) would impact both the magnitude and direction of AET under climate warming. Second, the same analysis, across all Critical Zone Observatories, looked at how different climates around the United States and a range of PAWSC will impact AET under climate warming. Finally, the project plans to use a spatially interpolated map of the Sierra CZO, which is a research goal of geophysical measurements at the CZO to look at how PAWSC will affect lateral redistribution of water and AET, at a basin-wide scale.

Interactions between forest thinning and forest rooting characteristics on hydrology. In this examination of the role of subsurface storage, the project considers overall PAWSC and whether hydrologic impacts of thinning treatments are likely to vary across the landscape due differences in subsurface water storage. It will also evaluate the spatial neighborhood defining how individual trees compete for available water (i.e., local versus diffuse competition), which determines whether water made available through the removal of transpiring biomass can be used by nearby remaining trees. The analysis assesses treatment impacts for a range of biomass mass removal scenarios and across variation in climate drivers of water availability and demand.

Fire and fire effects. The research group is currently using data from the SSCZO to aid in the development and testing of a fire effects model that is being used to couple a fire-spread model to an ecohydrologic model. These coupled models are being used to investigate the effects of changes in forest management practices on forest health/ productivity and streamflow generation. Another research question will examine how changes in forest productivity feedback to affect fire return intervals and forest management practices. For this latter component, the firespread/ecohydrologic model will be coupled with a model of how fuels treatment decisions are made. (*funded collaboratively by a NSF-HAZARDS grant*)

Field installations & support. Possible staff aid requested as needed. Collaborate with P. Klos regarding outreach developments.

Data Management. RHESSys model output:

https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Models/RHESSys

Schedule, including field work. May need to update for Moritz work.

Possible permit amendment needs. Permitting should be current.

Researcher stays at Glen Meadow or Dinkey Mill? Possibly need camping/lodging for Moritz researchers

13. Dust and related microbial inputs to the Southern Sierra ecosystems

Investigators: Emma Aronson, collaborator (UC Riverside)
 Steve Hart (UC Merced)
 Cliff Riebe (Uni. Wyoming)
 Sarah Aciego (Uni. Michigan)

Students & research staff: Chelsea Carey, postdoctoral researcher (UC Riverside)
 Molly Blakowski, graduate student (Uni. Michigan)

Scope. Mounting evidence shows that California is currently experiencing the most severe drought since 1580, and it is likely that extreme droughts will become more common as the climate changes. During this drought, elevated dust transport may bring nutrients and microorganisms, with unknown, but potentially transformational, impacts on the ecosystems where dust is deposited. In this project, we are measuring the mass, provenance (using isotopic chemistry), chemical makeup, and microbial composition of dust transported to the Sierra Nevada mountain range. Dust is being collected at four sites along an elevational gradient in SSCZO, ranging from 400 m to 2700 m elevation. At each site, dust has been collected monthly in Summer 2014 from passive dust collectors and from filters (1 μ m pore size) on the eddy covariance tower active gas samplers. To complement dust collection, soil samples (10 cm depth) have been collected within the footprint of the towers. Collection of soil samples to a depth of 1 m is scheduled for 2016.

Mass and provenance of dust samples will be determined using radiogenic strontium (Sr) and neodymium (Nd) isotopic tracers. Nutrients and microbial composition of dust and soil samples will also be analyzed. This approach will allow us to identify the effects of mega-droughts on i) dust-related contributions to the geobiology and biogeochemistry of soils and ecosystems, ii) the role of local versus distant dust sources of microorganisms, including bacteria, archaea and fungi, and of nutrients to the Sierra Nevada, and iii) the role of elevation in determining the ecological effects of mega-drought-induced dust transport. As permitted by weather, the data collected during this year of extreme drought will be compared to data collected in wetter years.

Field installations & support. Dust collectors were dismantled October 2015, but the mounting poles remain at each site for redeployment of the collectors. Soil samples to 1 m depth are planned for peak greenness at each of the sites – staff help with permitting and sampling as needed.

Data Management. Data will be posted to the digital library under https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW/Studies/Dust_Collection_Program

Schedule, including field work. Soil sampling at peak greenness underway for each of the elevation transect sites. SJER (400 m) sampling conducted early April.

Possible permit amendment needs.. SJER soil sampling request submitted and approved; soil sampling at Soaproot and Providence will be coordinated through SSCZO staff.

Researcher stays at Glen Meadow or Dinkey Mill? Stays at SJER Guesthouse requested as needed

14. Research ideas under consideration

Reestablish dendrometer/litter plots @ four tower sites (Hart, Goulden, others)

- a. Part of 2016 team meeting?
- b. Fix/add/reinstall bands and remeasure tree growth, mortality status
- c. Reinstall litter traps

Organic matter/fine root turnover project – 2017 (Hart)

Potential interception experiment, pending additional funds and above-ground sensor installation, or tree removal manipulation experiment. (Hartsough, Safeeq, Bales)