My Desktop
Prepare & Submit Proposals
New! Prepare Proposals (Limited proposal types)
Prepare Proposals in FastLane
Proposal Status
Awards & Reporting
Notifications & Requests
Project Reports
Award Functions
Manage Financials
Program Income Reporting
Grantee Cash Management Section Contacts
Administration
Lookup NSF ID

Preview of Award 1331939 - Annual Project Report

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

Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1331939
Project Title:	Southern Sierra Critical Zone Observatory
PD/PI Name:	Roger C Bales, Principal Investigator Martha H Conklin, Co-Principal Investigator Michael L Goulden, Co-Principal Investigator Clifford S Riebe, Co-Principal Investigator Christina Tague, Co-Principal Investigator
Recipient Organization:	University of California - Merced
Project/Grant Period:	10/01/2013 - 11/30/2020
Reporting Period:	10/01/2018 - 09/30/2019
Submitting Official (if other than PD\PI):	Roger C Bales Principal Investigator
Submission Date:	10/04/2019
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Roger C Bales

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.

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.

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.

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.

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.

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 (C), nitrogen (N) and phosphorus (P) 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: *Research Question 1, Spatial Patterns.* We showed that consistent values of regolith attributes can be predicted in multiple ways, including direct measurements, estimates of water stored in the regolith, and remote sensing coupled with terrain

analysis and water balance. This period, through data analysis and synthesis, we identified factors that control regolith thickness and modeled spatial patterns regolith thickness at the basin scale (Figure 1). For spatial scaling of critical-zone attributes and fluxes, we evaluated current forest biomass datasets across the Sierra Nevada, and proposed a strategy to estimate fine-resolution forest biomass and their response to disturbance and management. We then evaluated vegetation water use response to and recovery from forest fire in the Sierra Nevada from long-term satellite data and flux tower measurements. We also investigated how the spatial variability of regolith geochemistry, structure and thickness can impact stream water chemistry, water transit times and drought vulnerability along the SSCZO watersheds.

Research Question 2, Physical, Chemical, and Biological Mechanisms and Interactions. Our work on physical processes and properties focused on hydrologic and meteorological processes, and links to biotic controls. We continued long-term sampling to assess tree growth, growth plasticity (year to year variation), xylem anatomy (variation in cell dimensions of water conducting tissues), cone production, C concentrations, lignin (the primary C-intensive material that confers xylem hydraulic safety) concentration, and likelihood of mortality relative to drought, competition (crowding), and bark beetle pressures. To understand biogeochemical response to fire, we sampled a 44-y fire chronosequence for both baseline soil properties (C, nutrients, pH) as well as many microbial/biogeochemical properties. By incorporating various biochemical measurements with next-generation sequencing of microbial DNA, we elucidated how microbial communities respond to disturbances outside the historic range of system variability. Understanding how soil microbial communities respond to altered climactic conditions is critical in determining responses of key biogeochemical processes. Up to now, this response at depths greater than 30 cm was poorly understood. In order to better understand how physical and chemical processes are coupled in CZ evolution, recent work also involved developing reactive-transport and hydrogeochemical modeling approaches. These efforts aim to link physical properties of the CZ (mineralogy, geomorphology, thickness, …) with hydrologic and chemical behavior of Sierra Nevada rivers.

Research Question 3, Rates of Change. We continued to characterize chemical, mineralogical and physical properties of soils and deep regolith, with the idea of understanding key ecosystem services: C sequestration, water storage, water infiltration, and nutrient cycling. In the current period we completed the lab work needed to estimate C transient time in representative locations. We initiated an analysis of evapotranspiration in the southern Sierra Nevada prior to fire suppression. Since the 1900s, forests in the Sierra Nevada have increased in density, which has had impacts on the amount of water that is returned to the atmosphere through evapotranspiration. Using historical forest survey data from the early 1900s and a relationship between satellite forest greenness and evapotranspiration developed from the SSCZO flux tower network, we are quantifying the change in evapotranspiration over the past century. We also developed a fire-effects model that is being coupled to an ecohydrologic model (RHESSys) and a fire-spread model (WMFire). The coupled model will provide new insight into the interactions between fire regimes, vegetation and hydrology. This model is being calibrated and tested in the Providence Creek watersheds. Process-based modeling of streamwater chemistry and water transit times in SSCZOs watersheds will also allow quantitative estimates on how water quality and availability from headwater catchments will change in the next decades.

Research Question 4, Implications of Change. A significant focus of our data analysis during the last year continued to focus on the impact of the 2012-15 drought on hydrology and forest mortality. We initiated geochemical modeling to predict and

scale both stream geochemical fluxes and regolith attributes. We also initiated a synthesis of biogeochemical data to develop more-complete nutrient balances (Figure 2) for the 8 Providence and Bull catchments at the Kings River Experimental Watersheds (Figure 3), and 4 elevation-transect sites at SSCZO (Figure 4). The primary aims are to: i) do a synthesis to quantify the distribution and bioavailability of C, N and P within the critical zone, ii) evaluate if elevation (climate) differences control the storage and fluxes of C and nutrients, and iii) examine how disturbance and climate change will impact the storage and fluxes of C and nutrients. We have been examining how fuel treatments that were conducted in the co-located Kings River Experimental Watersheds (Figure 3) at the onset of the recent California drought have affected watershed hydrology. The analysis includes a combination of paired-watershed analyses to document hydrologic changes and remote sensing to document treatment changes. We are using both top-down and bottom-up modeling for synthesis of regolith-water-vegetation data related to drought, and development of scaling and prediction methods. Using both bottom-up and top-down methods we developed results on root-zone storage, and on drought vulnerability. Bottom-up, we continue to develop a 1-D bucket model, coupled with RHESSys, to explore the sensitivity of actual evapotranspiration to plant accessible water storage capacity, across the climates of the CZOs, for both baseline and warming scenarios. This simple model was then used to account for the difference in timing and amount of recharge and potential evapotranspiration as limited by plant available water storage capacity to calculate the range of values over which actual evapotranspiration is sensitive to for each site. Using a top-down approach, we calculated spatially resolved annual evapotranspiration across the 14 main river basins draining into California's Central Valley, USA, based on flux-tower measurements and a data-driven model using satellite greenness, gridded precipitation, and other data.

Research Question 5, Tools to Study 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 continued monitoring water content at 50-cm intervals in observation wells over the entire deep regolith thickness at each site using a neutron probe. We have also continued our baseline monitoring of hydrologic and sediment fluxes from the SSCZO catchments, along with developing and refining numerical modeling tools for answering management relevant questions. Recent efforts also involve development of novel coupled geochemical, reactive-transport, and geomorphological approaches.

Specific Objectives:

Research Question 1, Spatial Patterns. Measuring, characterizing, and understanding the spatial patterns of critical-zone properties and processes remain to be central objectives in the SSCZO. Key critical-zone properties and processes of interest include regolith depth and weathering, vegetation density and growth, and water balance and flux. Our ultimate objective is to quantify and understand the spatial patterns of critical-zone properties, especially the amount of water that is available for transpiration. This period we refined studies initiated in prior years and advanced them to publication. We completed scaling of evapotranspiration values from the SSCZO flux towers to the full Sierra Nevada. Concerning stream water quality and water storage, our recent work provides new insights on how the physical/geochemical properties of the regolith, which are acquired through the long-term evolution of CZ, are controlling present water transit times and stream chemistry in the CZ, both in the Sierra Nevada and more generally. New results also allowed us to link the spatial variability of regolith mineralogy and thickness with the differences of hydrogeochemical behaviors observed in the stream water along the 8 Providence and Bull watersheds.

Research Question 2, Physical, Chemical, and Biological Mechanisms and

Interactions. Our sampling of soil chronosequences helped determine the length of recovery of various biogeochemical properties and processes after high-severity fire in the Sierra Nevada. Linking to tree response, current hypotheses regarding physiological resistance to drought in pines posit that trees that grow water-conducting tissues (xylem) with thick cell walls and smaller diameters are more resistant to the increasingly negative water potentials experienced under drought, as thick walls provide mechanical resistance to xylem collapse and eventual hydraulic failure (Figure 5). However, our samples demonstrated that drought-killed trees actually grew “safer” xylem than survivors leading up to the drought (Figure 6). This may be due to the C cost of growing thickened cell walls, and if trees are stressed by both drought and pests, which require C-rich chemical compounds to defend against, then C “starvation” may occur. We found that dead trees had higher C concentrations than living trees, confirming a potential C-starvation mechanism. Hydrochemical modeling of stream chemistry also provides useful insights on how physical and water-rock interactions processes control the mobility of basic cations (Ca2+, Mg2+, Na+ and K+) within the regolith and along the stream networks of SSCZO watersheds. We were also able to capture the chemical variations of stream chemistry along the complete range of hydrological conditions, allowing identification of the key primary mineral dissolution, clay mineral precipitation and geochemical reactions occurring within the regolith.

Research Question 3, Rates of Change. Our work on regolith formation continued to expand our understanding of the processes that shape subsurface critical-zone architecture over million-year timescales. We identified how P stock and speciation changes with climate, reflecting the rates that CZ properties can evolve and change. We completed an initial analysis of historical evapotranspiration rates in the Sierra Nevada, which suggest that historical evapotranspiration was lower than that at present. This suggests that restoration of forests to historical density levels may increase streamflow, with water benefits for urban, agriculture and environmental uses. Next steps are to take this work to publication. The fire-effects model was successfully able to replicate burn severity patterns in the Southern Sierra Nevada for both overstory and understory vegetation across a range of stand ages.

Research Question 4, Implications of Change. Recent wildfires, drought, and recovery have provided the opportunity to better understand how the water cycle and vegetation will respond to hotter, drier conditions. We set up hydrochemical modeling over the 8 Providence and Bull catchments, at and above the rain-snow transition elevation in the southern Sierra (Figure 3). Initial results from the relatively light fuels treatment at the SSCZO showed no discernible change in post-treatment streamflow during the drought. This finding suggests that there are thresholds for levels of fuel treatments and/or post-treatment wetness conditions for generating hydrologic responses.. Initial results from a synthesis of C fluxes and pools at the SSCZO suggest that our mixed conifer site at Providence stored the most C among the four sites. The ecosystem C turnover rate increased with elevation, which was the opposite trend for temperature (Figure 7). Our top-down scaling of evapotranspiration showed that average basin-scale evapotranspiration agreed well with annual precipitation minus runoff, with deviations in the wet and dry years suggesting withdrawal or recharge of subsurface regolith water storage (Figure 8). This scaling provides a foundation for predicting forest vulnerability to drought, using the gridded data. While we previously established that the recent forest die-off was tied to the occurrence of anomalously warm droughts, the underlying mechanisms remained inadequately understood. California’s 2012–2015 drought, with exceptionally low precipitation and warmth, and widespread conifer death, provided an opportunity to explore the chain of events leading to forest die-off. In the current period we established the spatial and temporal patterns of die-off and moisture deficit during

California's drought, based on field and remote sensing observations, and explained them in terms of mechanisms.

Research Question 5, Tools to Study the Critical Zone. One of the hallmarks of the SSCZO has been the diversity of tools we are using and developing to investigate the critical zone; these tools range from geochemical tracers to embedded networked sensor arrays to remote sensing. Our development and use of a wireless-sensor network as part of a spatially extensive catchment-scale measurement program focuses on improving methods to optimize placements of sensor clusters, and sensor nodes within the clusters. This work continues to progress on a number of fronts. Primary results from monitoring water and sediment fluxes were: i) characterizing water and sediment yield across the rain-snow elevation gradient of the SSCZO; and ii) investigating the impact of forest fuel treatments (i.e. thinning, prescribed fire) on water and sediment production. Leave-one-out cross validation of our scaling analysis revealed that the statistical model for annual evapotranspiration is sensitive to the number and distribution of measurement sites, implying that additional strategically located flux towers would improve evapotranspiration predictions. Leave-one-out with individual years was less sensitive, implying that longer records are less important. We also develop innovating modeling approaches, involving concentration-discharge analysis, reactive-transport and geomorphological analysis to depict spatio-temporal variability of water chemistry and its relations with CZ evolution. Recent work also expand the ability of the SSCZO to model, interpret and synthesis data with novel geochemical and reactive transport modeling.

Significant Results:

Research Question 1, Spatial Patterns. Our analysis of weathering highlights a feedback in which sediment size reduction due to weathering on hillslopes and transport in channels is both a key response to and control of bedrock channel incision and landscape adjustment to base-level change. Catchment-scale erosion rates from cosmogenic nuclides suggest that the treads in the "stepped topography" of the western slope of the Southern Sierra are relict surfaces that have adjusted to a previous base level. Nevertheless, erosion rates of relict interfluves are similar to canyon incision rates, implying that relief is unchanging in the lower Kings and San Joaquin rivers (Figure 9). The finding of both static knickpoints and static overall interfluve-canyon relief implies that landscape evolution in the southern Sierra Nevada is in a state of arrested development; erosional equilibrium prevails on risers and treads of the region's stepped topography, despite their marked differences in hillslope gradient and despite pronounced Pleistocene canyon cutting along main-stem rivers that drain the range. We hypothesize that lack of coarse sediment supply is the primary cause of arrested development in the landscape. We propose that this paradox can be explained in part by the region's characteristically thick regolith and moderate erosion rates, which together promote long residence times for regolith on hillslopes.

Research Question 2, Physical, Chemical, and Biological Mechanisms and Interactions. We found that more than 40% of the organic matter exported from southern Sierra forested catchments was free particulate organic matter, or organic matter physically protected inside relatively less stable macroaggregates, versus organic matter inside microaggregates or chemically associated with soil minerals. Years with greater precipitation generally yielded more transport of mineral-associated organic matter, with lower C and N concentrations, compared to dry years (Figure 10). Our results suggest that without stabilization through burial or reconfigured organomineral associations, this sediment organic matter is prone to decomposition, which may contribute little to terrestrial C sinks. Along soil chronosequences, we found that most C processes do not recover by 44 years since fire, but N processes returned to levels of the unburned stands by 13 years. At least for C biogeochemical processes, this is an extremely long recovery time for this

ecosystem (twice the natural fire return interval) and others found in the literature. Based on isotopic analyses, we found that vegetation in the Sierra Nevada uses new water, and switches water sources depending on availability. And most Sierra Nevada river water comes from above the respective mean catchment elevation and, most frequently, above 2000 m. We also found that a significant amount of snowmelt in the Sierra Nevada is stored in the subsurface, which provides a longer term buffer to drought than year-to-year snowpack.

Research Question 3, Rates of Change. Regarding deep C, most published inventories of soil organic C typically include stocks in the upper 1-m of soil or less, even though up to 60% of soil organic C can exist below 1-m depth. We analyzed the entire regolith (soil and saprock) at the four sites in SSCZO (Figure 11). Up to 78% of organic C can be stored below 30-cm depth, with up to 29% of total organic C stored in deep saprock found 1.5-m below the soil surface as deep as 10 m. Mean annual air temperature explained more variability in organic C regolith stock than other climatic variables tested. Using radiocarbon analyses we show that organic C in saprock is 5000-20,000 years old. We also found that regolith organic C is a mixture of different organic functional groups that have been persevered at depth, but could be vulnerable to loss. A conservative global scaling of these results revealed deep regolith can store 201 Pg of organic C, considering a regolith thickness of 5 m. Regarding P in soil, our findings demonstrate that organic P proportionally increases with increases in soil weathering probably due to the warmer temperatures but not variations in precipitation. However, the composition of the species within the pool suggests that bioavailability decreases, indicating that P will become increasingly more limited with a warming climate.

Research Question 4, Implications of Change. In modeling spatial patterns of regolith thickness, we found both distance from stream and biotite content had significant positive relationships with regolith thickness. From a prediction of regolith thickness at the watershed scale with a high level of accuracy when considering shallow classes (<1 m) and deep classes (>7 m) (Figure 1), we found that wildfires in 1985-2015 over the Sierra Nevada reduced vegetation water use by 2.2 billion m3 in the first year post fire. Wildfires impacts on vegetation water use peaked in denser forests over the mid-elevation zones. Medium-intensity fire across over-stocked forests can reduce vegetation water similar to that from restoration treatments (Figure 12). Our top-down scaling showed that the majority of runoff in northern Sierra basins was generated below the rain-snow transition, and originated in snow-dominated elevations in the south (Figure 13). Thus, climate warming that increases growing seasons will increase evapotranspiration and reduce runoff across all elevations in the north, and higher elevations in the south. We found that forest die-off during the drought was closely tied to multi-year deep-rooting-zone drying, which would help diagnose and predict mortality. Marked tree death followed a four-year moisture overdraft, with cumulative 2012–2015 evapotranspiration exceeding precipitation by ~1500 mm, and subsurface moisture exhaustion to 5–15-m depth (Figure 14). Observations across the entire Sierra Nevada further linked tree death to deep drying, with die-off and moisture overdraft covarying across latitude and elevation (Figure 15). Unusually dense vegetation and warm temperatures accelerated southern Sierra evapotranspiration in 2012–2015, intensifying overdraft and compounding die-off by 55%. High-elevation catchments with thinner regolith and diluted stream chemistry have lower water storage capacity and shorter water transit times than the mid-elevation catchments, implying that in a warming climate with a decreasing snowpack, high altitude catchments may not be able to store in regolith all the water that is currently stored in snowpack during winters. Our investigations suggest that in a warmer climate, high elevation watersheds may experience a higher number of flash-winter floods followed by longer and drier summer with lower runoff

available for the San Joaquin Valley.

Research Question 5, Tools to Study the Critical Zone. The SSCZO has proven to be a significant community resource for integrated critical-zone studies. In the current year, we compiled 10 years of research data for our first installations, and published 3 sets of data to further encourage use by the larger community. The locations covered are Providence (Figure 16), Wolverton and Tioga. Thorough analysis of data and modeling results indicate that the impact of fuel treatments on water and sediment yield were masked by both the level of biomass removal and extended drought during the post-treatment period. We also found that background sediment yield is predominantly comprised of suspended sediment and primarily controlled by snow. This study contributes to the growing body of knowledge demonstrating when and where changing forest fuel treatments and snow condition may affect streamflow and sediment yield. Extending analysis of sampling design, we found that a quasi-Bayesian application an eco-hydrologic modeling is a useful approach to guide field sampling to efficiently obtain data that contributes to more mechanistic understanding of the eco-hydrology of snow-dominated watersheds.

Key outcomes or Other achievements:

Outcomes cut across the five research questions and were introduced in detail above. 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 climate change and management actions along the climate -ecosystem gradient covered by the SSCZO.

1. We found significant lithologic controls on regolith evolution (physical weathering) where biotite abundance was positively correlated with regolith thickness. The heat energy load at a given depth was positively correlated with clay and Fed (rain-dominated site) indicating that subsurface and near-surface temperatures are needed to understand controls on biogeochemical weathering. Using surface temperatures or mean annual precipitation may not directly reflect weathering conditions of saprock several meters below the surface. Among other factors, deep regolith regulates climatic effects on weathering through its capacity to store water and heat energy. Tian et al., 2019.
2. Over a six-year period involving both wet and dry years, soil texture consistently had high importance for predicting spatial soil-water storage. Other landscape attributes exhibited seasonal trends: the importance of northness peaked during the wet-up period, and the importance of elevation and topographic wetness index peaked during the recession and dry periods. Oroza et al., 2018.
3. The effects of an aeolian dust input on soil P transformations are functions of the relative magnitude and chemical composition of the dust input and the soil weathering intensity. For a given source of dust, when the net dust flux is greater than the weathering rate, dust accumulates and thus alters the pattern of P transformations during pedogenesis; otherwise, the dust influence on soil P transformations is negligible. Gu et al., 2019.
4. Soil greenhouse-gas fluxes can be surprisingly resistant to hydrological changes associated with earlier snowmelt, likely because of persistent moisture and microbial activities in deeper mineral soils. As a result, a drier California in in a warmer climate may result in seasonally snow-covered soils in the Sierra Nevada emitting more greenhouse gases. Blankenship et al., 2018.
5. Much of the southern Sierra Nevada is in a state of arrested development: the landscape is not fully adjusted to—and moreover is not responding to— changes in base-level lowering in the canyons. This can be explained by a paucity of coarse sediment supply, which fails to provide sufficient tools for bedrock channel incision at knickpoints. The lack of coarse sediment in channels is driven by intense weathering of the local granitic bedrock, which reduces the size of

sediment supplied from hillslopes to the channels. Callahan et al., 2019.

6. We developed an approach to estimate snow water equivalent (SWE) through interpolation of spatially representative point measurements using a k-nearest neighbors (k-NN) algorithm and historical spatial SWE data. It accurately reproduced measured SWE, using different data sources for training and evaluation. Bias was reduced by using a Gaussian-process regression model to spatially distribute residuals. Using as few as 10 historical scenes of Lidar-derived SWE as training data to estimate spatial SWE, both RMSEs and MAEs were reduced from around 20–25 cm to 10–15 cm comparing to using SWE reconstructions as training data. Zheng et al., 2018.
7. Trees may exhibit what we call ‘fight or flight’ behaviors under stress. ‘Fight’ behaviors involve greater resource allocation toward survival (e.g., growth, drought-resistant xylem and pest defense). ‘Flight’ consists of higher relative allocation of resources to reproduction, potentially increasing both offspring production and mortality risk for the adult. We hypothesize that flight behaviors increase as drought stress escalates the likelihood of mortality in a given location. Lauder et al., 2019.
8. Measurements at 25 flux tower sites in the semiarid western United States show that more than 52% of annual evapotranspiration in Mediterranean climates is supported by seasonal drawdown of subsurface plant-accessible water storage, versus 29% in monsoon influenced climates. Vegetation responded to multiyear dry periods by lowering evapotranspiration and/or significant year-over-year depletion of plant accessible water storage. Sites maintained wet-year evapotranspiration rates for 8–33 months before attenuation, with a corresponding net drawdown of as much as 334 mm. Rungee et al., 2019.
9. Forest die-off during the 2012-15 drought was closely tied to multi-year deep-rooting-zone drying, and this relationship provides a framework with which to diagnose and predict future tree mortality. We found this at both local, intensively monitored SSCZO sites, and across the broader Sierra Nevada. Climate change is expected to further amplify evapotranspiration and moisture overdraft during drought, potentially increasing Sierra tree death during drought by ~15–20% °C-1. Goulden and Bales, 2019.
10. Vegetation structure and subsurface properties may be as important as climate in explaining hydrologic response to climate warming in small Sierra Nevada watersheds, limiting space-for-time analyses as predictors of future watershed response to warming. Owing to different subsurface properties, evapotranspiration depends on subsurface storage and thus differs along elevation transects, with the result that streamflow response does as well. Son and Tague, 2019.

It is also helpful to look beyond that past year to the full grant period. Since the start of the current NSF award in 2013, the SSCZO has met the science objectives in our proposal and opened up new areas of inquiry for Critical Zone science and the CZO network. First, we have developed methods for measuring, characterizing, and understanding the spatial patterns of critical-zone properties across the landscape, as well as associated critical-zone processes. Second, we have determined how climate and landscape properties interact to modulate physical, chemical, and biological interactions in the critical zone. Third, we have determined rates of change for regolith properties, highlighting the interplay between lithology, vegetation, and subsurface critical-zone structure, and the influence on shorter-term critical-zone processes. Fourth, our team has used the 2011-15 drought and coincident wildfires as "natural experiments" to better understand how the critical zone will respond to climate-driven perturbations, and how management actions can modulate those responses. Fifth, we continue to develop measurement and modeling tools to better study the critical zone.

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

Students and postdoctoral researchers associated with the SSCZO receive fundamental training and professional development to increase scholars' scientific knowledge, research skills, and science communication experience with research and non-research audiences. Professional-development opportunities have also been made available to SSCZO staff. Personnel at all levels have also provided training and development opportunities to external audiences.

Several M.S., Ph.D., and postdoctoral scholars are preparing themselves for independent measurement and data-analysis work in hydrology, biogeochemistry, geophysics, ecohydrologic modeling, and other disciplines. Many of these students identify with genders, ethnicities, and/or socioeconomic backgrounds that are traditionally underrepresented in STEM fields.

The SSCZO and national network of CZOs creates a multi-institutional team environment that is manifested through shared resources and collaborative work (e.g. shared LiDAR, sensor data, field campaigns for soil pits, analytical tools, programming, modelling). For instance, UC Merced student K. Moreland and UC Davis student Z. Tian also closely collaborated on carbon research in the deep critical zone. UC Merced student M. Barnes continues to collaborate with U. Wyoming student R. Callahan on critical-zone subsurface properties research. In addition, the wireless-sensor network installed at SSCZO remains an uncommon approach to gathering remote field data, one of the largest wireless networks for its purpose. Through the work on the sensor network, training and experience continues for undergraduate and graduate students, and staff.

Graduate students also receive competitive external fellowships for travel and research. For example, Moreland was awarded the UC Merced Bobcat Fellowship, UC Lab Fees Research Program Graduate Fellowship, and IUSS Wilford Gardner Travel Fellowship in the last year. External fellowships often grant students opportunities to collaborate with other researchers in settings beyond their home institution, such as National Laboratories. UC Merced graduate students Barnes, Moreland, and N. Dove conducted research analyses at Pacific Northwest, Lawrence Livermore, and Lawrence Berkeley National Laboratories in the last year through competitive fellowships. M. Thaw also continues as a Lawrence Scholar at Lawrence Livermore National Laboratory.

SSCZO students and staff also attended professional development workshops in the last year, including the CUAHSI Watershed Science Master Class (Thaw) and a data visualization and graphic design workshop (Dove, E. Stacy, M. Gilmore).

Current and recent graduate students, postdoctoral researchers, and early-career staff were first authors of 23 peer-reviewed journal publications that featured results or used data from SSCZO, with current statuses ranging from submitted to published. In addition, these personnel and an undergraduate 28 posters and talks at scientific meetings this year. Conferences include annual meetings hosted by internationally-known groups such as American Geophysical Union, European Geosciences Union, Soil Science Society of America, and Ecological Society of America; as well as smaller conferences such as the Sequoia-Kings Canyon Science Symposium, Yosemite Hydroclimate Conference, and our SSCZO Annual Meeting. In addition, graduate students, postdoctoral scholars and staff presented lectures about their work at university and department colloquia and research symposia.

Our team also provided research mentorship and site tours to scholars and early-career researchers, many of whom are not directly affiliated with the project. C. Tague advised a UC Santa Barbara Bren School master’s thesis group project that wrapped up in Spring 2019 titled “Cumulative Impacts Assessment for Timber Harvest: How Best to Incorporate Wildfire Risk and Hazard.” An undergraduate visiting UC Merced from U. Ausburg, Germany (M. Mainka) for one month was provided research mentorship by Barnes and a field site tour by Gilmore. Stacy hosted a tour of SJER and Soaproot Saddle field sites for 7 UC Merced postdoctoral scholars. We also provided information for a self-guided tour of Providence to graduate student I. Horner from Irstea Centre de Lyon-Villeurbanne.

Training and professional development in science communication to non-research audiences continues to be strong as well. Students and staff regularly work with faculty members to brief visitors to campuses. Project personnel including early-career researchers share research findings, methods, and implications with diverse audience groups such as watershed, forest, and agricultural stakeholder groups; local educators; kindergarten to undergraduate students; and the general public. Graduate students, postdocs, and staff also provide instructional assistance in courses, in addition to traditional teaching assistant roles. Several researchers also regularly share activities and findings related to SSCZO on personal Twitter accounts. See Dissemination and Products sections below for details.

At the undergraduate level, students from UC Merced and partner universities have worked as field and lab technicians. For example, the SSCZO continues to hire a full-time undergraduate field assistant to work each summer (N. Ojeda 2018 & 2019). S. Hart's research lab employed multiple undergraduates this year to assist with SSCZO projects, the majority of whom identify as a gender, race/ethnicity, or socioeconomic demographic traditionally underrepresented in STEM fields. Undergraduate M. Castro continued to assist with SSCZO outreach and education efforts.

Several graduate and undergraduate courses related to critical-zone science are taught by SSCZO faculty-level researchers at multiple institutions. Graduate students conducting critical-zone research also serve as teaching assistants for undergraduate courses at several campuses. These courses regularly include both scientific knowledge and research techniques (field, lab, and computer-based) from SSCZO and the CZO network; they serve both CZO and non-CZO students Some examples of graduate and undergraduate courses include Environmental Chemistry (M. Conklin), Soils in Land Use and the Environment (A. O'Geen), Fundamentals of Soil Science (A. Berhe), and Critical Zone Science (Berhe).

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

As described in our Management Plan, the SSCZO is a resource for the critical-zone research community; our team has actively engaged other scientists in using this resource. Public education and outreach are equally important. SSCZO team members share CZO findings with several audiences. We summarize these efforts from the last year below. Details for individual papers, presentations, datasets, media, and other output are available in Products.

Scientific community. Dissemination to the science community includes publishing datasets and findings; alerting colleagues of our publications and presentations through our websites, email, and social media; attending scientific meetings and workshops; and participating in CZO network activities. In the past year, three peer-reviewed long-term datasets from our field areas were published. More than 30 SSCZO-related, peer-reviewed scientific journal articles were published, and our team gave over 40 SSCZO-related presentations at national and international scientific conferences. We also participated in several smaller regional scientific meetings and specialty conferences. Faculty, staff, and graduate students also presented more than 40 guest lectures at universities and other science-focused venues. For example, R. Bales and M. Conklin gave talks at several universities in China about critical-zone research from SSCZO and the NSF CZO network.

Our team also contributed to NSF CZO network activities in our outreach to the scientific community, including volunteering at the US NSF CZO Network booth at AGU Fall Meeting and co-authoring cross-CZO publications.

In addition, our datasets, results, and infrastructure are being used in other research projects as well, as seen in ~20 externally-funded book chapters, journal articles, and conference presentations published in the last year.

Regional stakeholders. Communication of scientific findings with stakeholders and the public includes talks and discussion panels around the state, briefings to decision makers and resource management workgroups, and interviews for news articles and videos. Our work is informing the debate around water and ecosystem service benefits of forest management, with emphasis on climate change, carbon stabilization and sequestration, and runoff from the Sierra which provides about 60% of California's water supply. There is widespread interest in bringing new resources and tools to watershed and forest management, and in improving the knowledge base for predicting the effects of different management approaches.

Our team engages with several Sierra Nevada stakeholder groups attempting to develop and implement regional solutions to the state's 21st-century water and forest management challenges, including multi-agency groups planning and financing forest restoration activities. Bales shares information with Blue Forest Conservation and presented to the California Air Resources Board. O'Geen shares findings with the UC Cooperative Extension Forest Workgroup; members of this workgroup are extension academics who extend knowledge and conduct applied research relevant to federal, state and private stakeholders in California's forested landscapes. Stacy continues activities with the Dinkey Landscape Restoration Project. R. Bart and S. Khan (nee M. Safeeq) regularly attend meetings with the Southern Sierra IRWM and Tulare Basin Watershed Partnership, whose members include hydrology stakeholders in the southern Sierra region. Findings from the SSCZO were incorporated into the 2018 update to the Southern Sierra Integrated Regional Water Management Plan. A group of Master's students at UC Santa Barbara's Bren School developed a strategy for incorporating wildfire into forest management plans, which was advised by Tague and incorporated findings from SSCZO-supported research; the group publicly presented their findings in Santa Barbara and published their final report this spring. Data and findings from our work are also being incorporated in models and stakeholder-focused products through

a newly-created Innovation Center for Advancing Ecosystem Climate Solutions, funded by the CA Strategic Growth Council and directed by M. Goulden; Bales, Conklin, Hart, and O'Geen are also involved in the Innovation Center. Multiple researchers also presented at the Yosemite Hydroclimate Meeting, Sequoia-Kings Canyon Science Symposium, and California United Water Conference; attendees included researchers and managers associated with public agencies and private firms involved in resource management.

We have collaborated to bring CZO technology to other parts of the Sierra Nevada through other funding as well. Our team continues working with water leaders to develop prototypes for a new water information system for California building on advances in wireless sensor networks developed at the SSCZO, plus parallel advances in cyberinfrastructure and in measurements by satellite and aircraft.

K-16 Education. The SSCZO also frequently engages with K-16 students and teachers using CZO research topics, data, and findings. Our presentations and partnership activities align with several aspects of K-12 Next Generation Science Standards and Common Core State Standards. This year we reached over 900 K-8 students through multiple presentations at the Society of American Foresters' Fall Conservation Week and Spring Conservation Day (Gilmore). Conklin participated in a science and engineering workshop for school-age girls hosted by American Association of University Women. Moreland led a soils-focused activity for BIOTA-Q at Yosemite High School. Four Center for Advanced Research and Technology juniors and seniors publicly presented research evaluating snow depth and density variation at P301; their measurements are used as validations for the site's snow depth sensors. We collaborated with Merced County Office of Education to provide math and science content related to Sierra snowpack for 25 Merced County K-12 teachers in June 2019, supported through a California Mathematics and Science Partnership grant (Conklin, Gilmore). Gilmore presented about dust as a phenomenon topic for teachers at a Next Generation Science Standards workshop for ~20 Atwater elementary teachers. Conklin continues to serve on the advisory board for NatureBridge Yosemite. At the undergraduate level, we hosted students from Berhe's Critical Zone Science course at the Providence site and assisted in teaching field measurement methods for R. Rice's Snow Hydrology course. Graduate students and staff also gave guest lectures in these courses (Barnes, Stacy, Thaw).

Public. Public outreach for the SSCZO is communicated in diverse formats for local to international audiences. Tague worked with Santa Barbara visual artist Ethan Turpin and students from the Media Arts and Technology program at UCSB to design and implement a 3-D interactive visualization of forest, snow, water fluxes and fire for the P301 watershed of SCZO. The interactive visualization allowed users to "see" how this landscape has changed throughout a 30 year period and then explore how forests, snow and streamflow would change under warming scenarios. Videos highlighting SSCZO-related work and personnel, particularly related to water resources, continue to be created and disseminated. Multiple short films were created using footage from Jim Thebeaut's film Beyond the Brink, including one for the Aquarium of the Pacific in Long Beach. Recent publications and attention on California drought, forest mortality, and fire have also resulted in numerous media covering research findings, including Smithsonian Magazine, Grist, Phys.org, Science Daily, and News Deeply. In addition, we demonstrated snow depth sensors and gave away comics A Tale of Two Dust Specks and What is the Southern Sierra Critical Zone Observatory? at the Merced River Fair. We continue to publicly disseminate news, videos, articles, and other content through our website and social media.

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

Going forward into the next year, our scientific focus will be on research questions that require interdisciplinary collaborations and syntheses, and that build network understanding and predictive capability for the critical zone. This will continue to require both individual but coordinated investigations and broader synthesis. During the coming year will focus on continuing the ongoing core observations (for example, the flux towers and associated water and soil moisture observations), and limited targeted measurements needed for students to complete dissertation research that is in progress. We will continue our emphasis on communicating our results to the broader community (publications); taking stock of what we've learned and building intellectual bridges; and planning for the future. The following text is drawn from our recent supplement request and details the four areas we will target for continuing integration.

Synthesis - Spatial and temporal patterns of biogeochemistry. In semi-arid montane ecosystems water- and nutrient-limited terrestrial ecosystems, soil (or regolith) depth is a major determinant of net primary productivity (NPP). Based on water-balance calculations across SSCZO focal measurement sites, we estimate that deep rooting increases NPP by as much as five-fold relative to what could be supported in shallow-rooted (i.e., < 1 m) ecosystems. Predicting nutrient distribution and bioavailability within the CZ following disturbance and in a changing climate depends on an integrated

understanding of biogeochemistry, ecology, ecosystem physiology, geophysics, and hydrology. We will focus on two q*uestions*. First, what controls the vertical and horizontal distribution of C and nutrient pools, and how are they influenced by climate and disturbance (i.e., biomass removal). Second, how do lateral fluxes of nutrients through erosion or vertically through the soil solution compare with other ecosystem transfers? It is proposed to use data from four SSCZO focal measurement sites as well as our collaborative site (Kings River Experimental Watersheds), to project and estimate nutrient pool sizes and fluxes, above- and below-ground. We will make limited but strategic new measurements (e.g., radiocarbon estimates of C turnover within the regolith and organic P in soil solution and stream water). Combined with existing data, this will help infer what proportions of these nutrients are stored in long-term, below-ground pools. We will use existing C and water fluxes from eddy covariance to help constrain our smaller-scale measurements of ecosystem pools, and help estimate how above-ground disturbances (e.g., fire, drought mortality) influence C and nutrient cycling.

Capstone analysis - Vegetation dynamics – natural and climate driven. Building on our research linking vegetation, regolith properties, and water balances, we have developed approaches for scaling these attributes across the landscape. We are extending that work to assess the effects of disturbance, and thus provide templates for assessing forest resilience and the effects of restoration. We will address two main issues. The SSCZO is addressing outstanding questions related to the effects of natural and management disturbance on vegetation and ecosystem function, including legacy effects and rates of recovery. The goal is to understand how: i) disturbance and management affect forest processes, particularly water and C balances, and ii) how quickly forests recover from disturbances, e.g. wildfire, fuel reduction and drought mortality. Our research will involve both remote-sensing analyses and on modeling. We will bring the two lines noted above together, with an emphasis on comparing and reconciling Landsat analyses and RHESSys modeling. We will use the historical Landsat record, to quantify the effects of past fire or forest thinning on forest ET. We analyzed Landsat time series to quantify the effects of drought across the full Sierra Nevada; this paper showed the SSCZO's ability to analyze Landsat at larger spatial scales, though the analysis did not look at the effects of past management or disturbance. The SSCZO is poised to combine these lines of work to understand the effects of past management and disturbance at larger spatial scales, through a capstone analysis that targets this issue in the next year.

Capstone analysis - Reactive-transport modeling. The next step for our conceptual modeling of regolith formation is to apply a well-developed reactive-transport model to predict both chemical composition of water draining to streams, and regolith formation. We will address two questions. First, what is the origin of the temporal and spatial variability of water chemistry discharging from the SSCZO catchments? Second, what are the links and feedbacks between the long-term evolution of the CZ (mineralogy, geomorphology, structure and thickness) and the short-term hydrogeochemical functioning of the watersheds (water chemistry, water storage, seasonal variability). It is proposed to use long-term data of stream chemistry to understand the origin of the temporal variability, through a reactive-transport geochemical model that links fluid flow with weathering. This process-based approach will link weathering products in stream waters to regolith weathering processes and chemical/physical CZ properties. The modeling will help understand the observed spatial variability of surface waters, plus the time evolution of surface waters along a unique altitudinal gradient of 8 watersheds in the SSCZO. We will take advantage of this innovating work to constrain water transit times and water storage capacity, and to bring new quantitative estimates on the future water resources provided by these headwater catchments of the Sierra Nevada.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
SSCZO_AnnualReport2018-19_Figures.pdf	Figures for 2018-2019 annual report to NSF	Roger Bales	09/16/2019
ADDITIONAL REPORTING 2018-19 BINDER.pdf	Additional required reporting: metrics, CZO network activities, program budgets, and additional funding.	Roger Bales	10/04/2019

Products

Books

Book Chapters

SANTOS, F., ABNEY, R., BARNES, M., JIN, L., MORELAND, K., BOGIE, N., SULMAN, B., GHEZZEHEI, T. A., BERHE, A.A. (2018). The role of soil physical properties for determining biogeochemical responses to soil warming. *Ecosystem Consequences of Soil Warming: Microbes, Vegetation, Fauna and Soil Biogeochemistry 1st Ed.*. Jacqueline Mohan. Academic Press. . Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = Yes

WANG W., CHEN P., LEE EJ., MU D. (2019). Full-3D Seismic Tomography for Structure of the Critical Zone. *Earthquake and Disaster Risk: Decade Retrospective of the Wenchuan Earthquake* Y.G. Li. Higher Education Press & Springer Nature Singapore. Singapore. . Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1007/978-981-13-8015-0_8.

Inventions

Journals or Juried Conference Papers

ACIEGO, S., CLAKOWSKI, M., DOVE, N., HART, S.C., ARVIN, L., RIEBE, C., MALTZ, M., ARONSON, E., BARNES, M., BOTTHOFF, J., KOORNNEEF, J., JOHNSON, K. (). Competing droughts affect dust delivery to Sierra Nevada. *Aeolian Research*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

BALES, R., STACY, E., SAFEEQ, M., MENG, X., MEADOWS, M., OROZA, C., CONKLIN, M., GLASER, S., and WAGENBRENNER, J. (2018). Spatially distributed water-balance and meteorological data from the rain-snow transition, southern Sierra Nevada, California. *Earth System Science Data*. 10 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/essd-10-1795-2018

BALES, R.C., STACY, E.M., MENG, X., CONKLIN, M.H., KIRCHNER, P.B., and ZHENG, Z. (2018). Spatially distributed water-balance and meteorological data from the Wolverton catchment, Sequoia National Park, California. *Earth System Science Data*. 10 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/essd-10-2115-2018

BARNARD, D.M., J.F. KNOWLE, H.R. BARNARD, M.L. GOULDEN, J. HU, M.E. LITVAK, N.P. MOLOTCH (2018). Reevaluating growing season length controls on net ecosystem production in evergreen conifer forests. *Nature: Scientific Reports*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/s41598-018-36065-0

BART R.R., KENNEDY M.C., TAGUE C.L., MCKENZIE D. (). Integrating fire effects on vegetation carbon cycling in an ecohydrology model. *Ecological Modelling*. . Status = SUBMITTED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes

BLANKINSHIP, J.C., E.P. MCCORKLE, M.W. MEADOWS, S.C. HART (2018). Quantifying the legacy of snowmelt timing on soil greenhouse gas emissions in a seasonally dry montane forest. *Global Change Biology*. 24 (12), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1111/gcb.14471

BOGAN, S.A., A.S. ANTONARAKIS, P.R. MOORCROFT (2019). Imaging spectrometry-derived estimates of regional ecosystem composition for the Sierra Nevada, California. *Remote Sensing of Environment*. 228 . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1016/j.rse.2019.03.031

BOGENA, H.R., T. WHITE, O. BOUR, K.H. JENSEN (2019). Toward Better Understanding of Terrestrial Processes through Long-Term Hydrological Observatories. *Vadose Zone Journal*. . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.2136/vzj2018.10.0194

BREWER, T.E., E.L. ARONSON, K. AROGYASWAMY, S.A. BILLINGS, J.K. BOTTHOFF, A.N. CAMPBELL, N.C. DOVE, D. FAIRBANKS, R.E. GALLERY, S.C. HART, J. KAYE, G. KING, G. LOGAN, K.A. LOHSE, M.R. MALTZ, E. MAYORGA, C. O'NEILL, S.M. OWENS, A. PACKMAN, J. PETT-RIDGE, A.F. PLANTE, D.D. RICHTER, W.L. SILVER, W.H. YANG, N. FIERER (2019). (Pre-Print) Ecological and genomic attributes of novel bacterial taxa that thrive in subsurface soil horizons. *BioRxviv*. . Status = OTHER; Acknowledgment of Federal Support = No ; Peer Reviewed = No ; DOI: 10.1101/647651

CALLAHAN, R.P., K.L. FERRIER, J. DIXON, A. DOSSETTO, W.J. HAHM, B.S. JESSUP, S.N. MILLER, C.T. HUNSAKER, D.W. JOHNSON, L.S. SKLAR, C.S. RIEBE (2019). Arrested development: Erosional equilibrium in the southern Sierra Nevada, California, maintained by feedbacks between channel incision and hillslope sediment production. *GSA Bulletin*. 131 (7-8), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1130/B35006.1

DAVIS, F.W., N.W. SYNES, G.A. FRICKER, I.M. MCCOLLOUGH, J.M. SERRA-DIAZ, J. FRANKLIN, A.L. FLINT (2019). LiDAR-derived topography and forest structure predict fine-scale variation in daily surface temperatures in oak savanna and conifer forest landscapes. *Agricultural and Forest Meteorology*. 269 . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1016/j.agrformet.2019.02.015

DOVE, N.C., H.D. SAFFORD, G.N. BOHLMAN, B.L ESTES, S.C. HART (). High-severity wildfire leads to multi-decadal impacts on soil biogeochemistry in mixed-conifer forests. *Ecological Applications*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

FRICKER, G.A., N.W. SYNES, J.M. SERRA-DIAZ, M.P. NORTH, F.W. DAVIS, J. FRANKLIN (2019). More than climate? Predictors of tree canopy height vary with scale in complex terrain, Sierra Nevada, CA. *Forest Ecology and Management*. 434 . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1016/j.foreco.2018.12.006

GOODWELL, A.E., P. KUMAR, A.W. FELLOWS, G.N. FLERCHINGER (2018). Dynamic process connectivity explains ecohydrologic responses to rainfall pulses and drought. *Proceedings of the National Academy of Sciences*. 115 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1073/pnas.1800236115

GOULDEN, M.L. & R.C. BALES (2019). California forest die-off linked to multi-year deep soil drying in 2012–2015 drought. *Nature Geoscience*. 12 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/s41561-019-0388-5

GU, C., S.C. HART, B.L. TURNER, Y. HU, Y. MENG, M. ZHU (2019). Aeolian dust deposition and the perturbation of phosphorus transformations during long-term ecosystem development in a cool, semi-arid environment. *Geochimica et Cosmochimica Acta*. 246 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.gca.2018.12.017

HEEREN, A., T. PATHAK, T. MATLOCK and M. CONKLIN (). Public Perceptions of California's Exceptional Drought. *Journal of the American Water Resources Association*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes

HOLBROOK, W.S., V. MARCON, A.R. BACON, S.L. BRANTLEY, B.J. CARR, B.A. FLINCHUM, D.D. RICHTER, C.S. RIEBE (2019). Links between physical and chemical weathering inferred from a 65-m-deep borehole through Earth's critical zone. *Nature: Scientific Reports*. 9 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1038/s41598-019-40819-9

JEPSEN, S.M., T.C. HARMON, S. SADRO, B. REID, S. CHANDRA (2019). Water residence time (age) and flow path exert synchronous effects on annual characteristics of dissolved organic carbon in terrestrial runoff. *Science of the Total Environment*. 656 . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1016/j.scitotenv.2018.11.392

KLOS, P.Z., R.G. LUCAS and M.H. CONKLIN (). How critical zone architecture moderates the influences of snowpack loss on streamflow generation in a headwater meadow-forest system. *Water Resources Research*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

LAUDER, J.D. E. V. MORAN, S. C. HART (2019). Fight or Flight? Tradeoffs Between Drought Defense and Reproduction in Conifers. *Tree Physiology*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1093/treephys/tpz031

MA, Q., RUNGEE, J., BALES R., GOULDEN M., et al. (). (In preparation) Forest-fire Controls on Vegetation Water Use in the Sierra Nevada of California. *Journal of Hydrology*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

MA, Q., RUNGEE, J., BALES, R., GOULDEN, M., et al. (). (In Preparation) Evaluating the Recovery of Vegetation Water Uses from Wildfire Disturbances over the Past Three Decades. .. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

MASSOUD, E.C. (2019). Emulation of environmental models using polynomial chaos expansion. *Environmental Modelling & Software*. 111 . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1016/j.envsoft.2018.10.008

ORELAND, K., BERHE, AA., O'GEEN, A., MCFARLANE, K., HART, S. (). Carbon in the Critical Zone: Regolith thickness governs carbon pools and dynamics. *Nature Geoscience*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

OROZA, C. A., R. C. BALES, E. M. STACY, Z. ZHENG, and S. D. GLASER (2018). Long-Term Variability of Soil Moisture in the Southern Sierra: Measurement and Prediction. *Vadose Zone Journal*. 17 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/vzj2017.10.0178

O'GEEN, A.T., M. SAFEEQ, J. WAGENBRENNER, E. STACY, P. HARTSOUGH, S. DEVINE, Z. TAIN, R. FERRELL, M. GOULDEN R.C., M.L. GOULDEN, J.W. HOPMANS and R. BALES (2018). Southern Sierra Critical Zone Observatory and Kings River Experimental Watersheds: A synthesis of measurements, new insights, and future directions. *Vadose Zone Journal*. 17 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/vzj2018.04.008

PURDY, A.J., FISHER, J.B., GOULDEN, M.L., COLLIANDER, A., HALVERSON, G., TU, K., FAMIGLIETTI, J.S. (2018). SMAP soil moisture improves global evapotranspiration. *Remote Sensing of Environment*. 219 . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1016/j.rse.2018.09.023

RICHARDSON, J.B., A.A. AGUIRRE, H.L. BUSS, A.T. O'GEEN, X. GU, D.M. REMPE and D. DE B. RICHTER (2018). Mercury sourcing and sequestration in weathering profiles at six Critical Zone Observatories across North America. *Global Biogeochemical Cycles*. 32 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1029/2018GB005974

RICHTER, D. D., BILLINGS, S. A., GROFFMAN, P. M., KELLY, E. F., LOHSE, K. A., MCDOWELL, W. H., WHITE, T. S., ANDERSON, S., BALDOCCHI, D. D., BANWART, S., BRANTLEY, S., BRAUN, J. J., BRECHEISEN, Z. S., COOK, C. W., HARTNETT, H. E., HOBBIE, S. E., GAILLARDET, J., JOBBAGY, E., JUNGKUNST, H. F., KAZANSKI, C. E., KRISHNASWAMY, J., MARKEWITZ, D., O'NEILL, K., RIEBE, C. S., SCHROEDER, P., SIEBE, C., SILVER, W. L., THOMPSON, A., VERHOEF, A., and ZHANG, G. (2018). Ideas and perspectives: Strengthening the biogeosciences in environmental research networks. *Biogeosciences*. 15 . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.5194/bg-15-4815-2018

ROCHE, J.W., R. RICE, X. MENG, D.R. CAYAN, M.D. DETTINGER, D. ALDEN, S.C. PATEL, M.A. MASON, M.H. CONKLIN, R.C. BALES (2019). Climate, snow, and soil moisture data set for the Tuolumne and Merced river watersheds, California, USA. *Earth System Science Data*. 11 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.5194/essd-11-101-2019

RUNGEE, J., MA,, Q., BALES, R., GOULDEN, M. (). Closing the mountain water balance: challenges and uncertainties in the eastern California headwater river basins. *Water Resources Research*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

RUNGEE, J., R. BALES, M. GOULDEN (2019). Evapotranspiration response to multi-year dry periods in the semi-arid western United States.. *Hydrological Processes*. 33 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = No ; DOI: 10.1002/hyp.13322

SAKSA, P.C., R. C. BALES, C. L. TAGUE, J. J. BATTLES, B. W. TOBIN, M. H. CONKLIN (). Forest fuels treatment and wildfire effects on Sierra Nevada mixed-conifer runoff. *Ecohydrology*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

SON, K., C. TAGUE (2019). Hydrologic responses to climate warming for a snow-dominated watershed and a transient snow watershed in the California Sierra. *Ecohydrology*. 12 (1), . Status = PUBLISHED; Acknowledgment of Federal

Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/eco.2053

SON, K., TAGUE, C. (2019). A top-down soil moisture and sap flux sampling design of a rain-snow transition mountain watershed. *Hydrological Processes*. 33 (11), . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1002/hyp.13421

STACY, E. M., ASEFAW BERHE, A., HUNSAKER, C. T., JOHNSON, D. W., MEDING, S. M., & HART, S. C. (2018). Stabilization mechanisms and decomposition potential of eroded soil organic matter pools in temperate forests of the Sierra Nevada, California. *Journal of Geophysical Research: Biogeosciences*. 124 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1029/2018JG004566

TAGUE, C.L., M. MORITZ (2019). Plant Accessible Water Storage Capacity and Tree-Scale Root Interactions Determine How Forest Density Reductions Alter Forest Water Use and Productivity. *Frontiers in Forests and Global Change*. . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.3389/ffgc.2019.00036

TAGUE, C.L., MORITZ, M., HANAN, E. (2019). The changing water cycle: The eco-hydrologic impacts of forest density reduction in Mediterranean (seasonally dry) regions. *WIREs Water*. . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1002/wat2.1350

TIAN, Z., P.C. HARTSOUGH and A.T. O'GEEN (2019). Lithologic, Climatic and Depth Controls on Critical Zone Transformations. *Soil Science Society of America Journal*. 83 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.2136/sssaj2018.03.0120

VISSER, A., M. THAW, A. DEINHART, R. BIBBY, M. SAFEEQ, M. CONKLIN, B. ESSER, Y. VAN DER VELDE (2019). Cosmogenic Isotopes Unravel the Hydrochronology and Water Storage Dynamics of the Southern Sierra Critical Zone. *Water Resources Research*. 255 (2), . Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes ; DOI: 10.1029/2018WR023665

WLOSTOWSKI, A., et al. (). Signatures of Hydrologic Function and Coevolution Across the Critical Zone Observatory Network. Water Resources Research. *Water Resources Research*. . Status = SUBMITTED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes

ZHENG, Z., N.P. MOLOTCH, C.A. OROZA, M.H. CONKLIN, R.C. BALES (2018). Spatial snow water equivalent estimation for mountainous areas using wireless-sensor networks and remote-sensing products. *Remote Sensing of Environment*. 215 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1016/j.rse.2018.05.029

ZHENG, Z.; MA, Q.; QIAN, K.; BALES, R.C. (2018). Canopy Effects on Snow Accumulation: Observations from Lidar, Canonical-View Photos, and Continuous Ground Measurements from Sensor Networks. *Remote Sensing*. 10 . Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.3390/rs10111769

Licenses

Other Conference Presentations / Papers

WALKER, B., S.R. HALL, C.M. SCHMIDT, J.R. PAUL (2018). *132-11: AN ENVIRONMENTAL FIELD AND CAREER PREPARATION PROGRAM FOR STUDENTS AT 2-YEAR AND 4-YEAR INSTITUTIONS: A REPORT ON STUDENT ATTITUDINAL CHANGES, SKILL ACQUISITION, AND LESSONS LEARNED FROM A MULTI-INSTITUTIONAL COLLABORATION*. Geological Society of America Abstracts with Programs. Vol. 50, No. 6. Indianapolis, IN. Status = OTHER; Acknowledgement of Federal Support = No

HART, S.C., AARONS, S., ACIEGO, S., ARONSON, E.L., ARVIN, L.J., BARNES, M.E., BLAKOWSKI, M., CAREY, C.J., CHRISTENSEN, J.N., COBLE., A.A., DOVE, N.C., GU, C., MALTZ, M.R., NWOSU, G., O'DAY, P., RIEBE, C., & ZHU, M. (2018). *Ashes to ashes, dust to dust: the significance of aeolian particulate inputs to temperate ecosystems*. Ecological Society of America Annual Meeting. New Orleans, LA. Status = OTHER; Acknowledgement of Federal Support = Yes

CONKLIN, M.H.; RUNGEE, J.P.; BALES, R.C. (2018). *B11B-2132: For a mountain forest, subsurface water storage determines drought survival*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

MA, Q.; BALES, R.C.; RUNGEE, J.P; GOULDEN, M. (2018). *B24B-06: Vegetation water use responses to forest fires in the Sierra Nevada, California using remote sensing*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

ZHENG, Z.; MA, Q.; JIN, S.; SU, Y.; GUO, Q.; BALES, R. (2018). *C11B-04: Canopy and terrain interactions on spatial distributions of snowpack in the Sierra Nevada*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

CONKLIN, M (2019). *Current vs historical situation, potential runoff changes, water impacts, and opportunities for storage*. California United Water Conference. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

MORELAND, K., TIAN, Z., BERHE, AA., O'GEEN, A. (2019). *D14C partitioning along the SSCZO climosequence*. European Geoscience Union Annual Meeting. Vienna, Austria. Status = OTHER; Acknowledgement of Federal Support = Yes

MORELAND, K., TIAN, Z., BERHE, AA., O'GEEN, A. (2019). *Deep Soil Carbon in the Critical Zone: Climatic influences on the amount and chemical composition of carbon in weathered bedrock*. Soil Science Society of America Annual Meeting. San Diego, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

MORELAND, K., et al. (2018). *Deep subsoil carbon dynamics*. Southern Sierra Critical Zone Observatory 2018 Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

RUNGEE, J., et al. (2018). *Distributed evapotranspiration and drought in river basins draining into the Central Valley*. Southern Sierra Critical Zone Observatory 2018 Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

BART RR, SAFEEQ M, WAGENBRENNER J. (2018). *Do forest fuel treatments enhance streamflow during drought? Case study from the Kings River Experimental Watersheds*. Yosemite Hydroclimate Conference. Yosemite National Park, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

MALTZ, M., et al. (2018). *Dust associated with microbial communities in an elevation gradient*. Southern Sierra Critical Zone Observatory 2018 Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

LOHEIDE, S.P.; CIRUZZI, D.M.; LOWRY, C.; TAGUE, C.; MICHAEL, H.M.; HYNDMAN, D.W.; TYLER, S.; THOMPSON, M.; TRAN, E. (2018). *ED51E-0706: CUAHSI Virtual University: An inter-institutional framework for graduate education applied to the hydrologic sciences*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = No

GILMORE, M.E.; STACY, E.M.; MEADOWS, M.; SULLIVAN, L.; CONKLIN, M.H. (2018). *ED53B-07: Bringing high school students into the world of field-based environmental research: eight years of partnership in the San Joaquin Valley and Sierra Nevada*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

CALLAHAN, R.P.; RIEBE, C.S.; HOLBROOK, W.S.; GOULDEN, M. (2018). *EP11D-2084: Climatic and lithologic controls on critical zone structure and ecosystem productivity in the Sierra Nevada, California, evaluated using geophysical and geochemical measurements*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

KLOS, P.Z., TAGUE, N. (2018). *EP11D-2087: The Unseen Canopy: Sensing Lateral Root Overlaps to advance Predictive Modeling of Ecohydrologic Function*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

DOVE, N., ET AL. (2018). *Ecologically-novel, high-severity wildfire leads to multi-decadal recovery of soil biogeochemistry in the Sierra Nevada*. Southern Sierra Critical Zone Observatory 2018 Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

BALES, R. (2019). *Evaluating and partitioning the multi-sectoral benefits of forest restoration; including wildfire risk, erosion, air quality, forest health & resilience, and carbon storage*. California United Water Conference. Auburn, CA.

Status = OTHER; Acknowledgement of Federal Support = Yes

BALES, R. (2018). *Forest disturbance, water management, and opportunities for landscape restoration*. Yosemite Hydroclimate Conference. Yosemite National Park, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

RUNGEE, J.P. II; MA, Q.; BALES, R.C.; GOULDEN, M. (2018). *H11W-1788: Scaling Evapotranspiration Measurements to Assess Forest Water Availability and Close the Mountain Water Balance*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

BERHE, A.A. (2018). *H12D-08: Linking biogeochemical and geomorphic processes to further our understanding of organic matter dynamics in the critical zone (Invited)*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

BART, R.R.; SAFEEQ, M.; WAGENBRENNER, J.; BALES, R.C. (2018). *H12H-05: How do forest fuel treatments affect watershed hydrology during extreme drought? Insight from the southern Sierra Nevada*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

VISSER, A.; THAW, M.; BIBBY, R.K.; DEINHART, A.; CONKLIN, M.H.; VAN DER VELDE, Y. (2019). *H13N-1959: Hydrochronology and storage selection of a headwater catchment and major rivers in the Sierra Nevada, California*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

TAGUE, C. (2018). *H21B-04 (Invited): Animating 'green stuff' in hydrologic models: where we are and what is next*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

VON BLANCKENBERG, F.; SCHUESSLER, J.A.; UHLIG, D (2018). *H22H-07: Forest Nutrient Supply and Uptake Depth Depends on Erosion Rate as Disclosed by Metal Isotopes*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = No

SOHRABI, M.; SAFEEQ, M.; CONKLIN, M.; KNIFFIN, M. (2018). *H23N-2146: Constraining annual water balance estimates with spatial calibration of evapotranspiration*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

SAFEEQ, M.; HUNSAKER, C.T.; WAGENBRENNER, J. (2018). *H31G-1966: Hydrogeomorphic controls on sediment characteristics in the southern Sierra Nevada*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

THAW, M.; VISSER, A.; CONKLIN, M.H. (2018). *H53H-1686: Extrapolating Catchment Scale Processes from Stable Isotopes Across a Mountain Range*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

LAUDER, J. D., E. V. MORAN (2018). *How Conifers Cope with Drought: Differences in Growth and Wood Anatomy of Sierra Nevada Pines*. Ecological Society of America Annual Meeting. New Orleans, LA. Status = OTHER; Acknowledgement of Federal Support = Yes

BART RR, SAFEEQ M, WAGENBRENNER J. (2018). *How do fuel treatments affect watershed hydrology during drought? Insight from the Kings River Experimental Watersheds*. Sequoia and Kings Canyon Science Symposium. Three Rivers, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

BART RR, SAFEEQ M, WAGENBRENNER J (2018). *How do fuel treatments affect watershed hydrology during drought? Insights from the Kings River Experimental Watersheds*. Southern Sierra Critical Zone Observatory 2018 Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

STACY, ERIN M., BALES, R., MENG, X., and CONKLIN, M. (2018). *Measuring spatial variability in snow depth in the Wolverton Catchment*. Sequoia-Kings Canyon Science Symposium. Three Rivers, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

GILMORE, M.E.; CONKLIN, M.H. (2018). *PA22C-11: Words carry power: the importance of bringing the term and concept of Earth's critical zone more directly into the public eye and into K-16 education*. American Geophysical Union Fall Meeting. Washington, DC. Status = OTHER; Acknowledgement of Federal Support = Yes

NWOSU, U., B. LASH, M. BARNES, S. HART, A.A. BERHE, P. O'DAY (2018). *Phosphorus speciation in atmospherically deposited air particulates from high and low elevation sites of California and Colorado*. Abstracts of papers of the American Chemical Society 255. Boston, MA. Status = OTHER; Acknowledgement of Federal Support = Yes

CASTRO, M., and M. GILMORE (2018). *SSCZO interactive online field site map*. Southern Sierra Critical Zone Observatory 2018 Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

BALES, R. (2018). *Sierra Nevada forests depend on water stored in weathered bedrock during droughts*. Sequoia and Kings Canyon Science Symposium. Three Rivers, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

THAW, M., et al. (2018). *Sierra Nevada isotope hydrology, tracking water at different scales (Oral)*. Yosemite Hydroclimate Conference. Yosemite National Park, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

BART RR, SAFEEQ M, WAGENBRENNER J, HUNSAKER C (2018). *Sierra Nevada streamflow response to forest fuels treatments during the California drought*. 6th Interagency Conference on Research in the Watersheds. Shepherdstown, WV. Status = OTHER; Acknowledgement of Federal Support = Yes

BARNES, M, A.A. BERHE, P. O'DAY, & S.C. HART (2019). *Soil phosphorus stock and speciation in a changing climate*. Soil Science Society of America International Soils Meeting. San Diego, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

BARNES, ME, HART, SC, & BERHE, AA. (2018). *Southern Sierra Critical Zone Observatory Annual Meeting*. Southern Sierra Critical Zone Observatory Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

LAUDER, J. D., E. V. MORAN (2019). *The Role of Carbon Depletion in Conifer Physiological Resistance to Drought*. North American Forest Ecology Workshop 2019. Flagstaff, AZ. Status = OTHER; Acknowledgement of Federal Support = Yes

VISSER, A., et al. (2018). *Tracing water from headwaters to groundwater*. Southern Sierra Critical Zone Observatory 2018 Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

THAW, M., et al. (2018). *Tracking Sierra Nevada runoff, storage, and evapotranspiration with stable and radioactive isotopes*. Southern Sierra Critical Zone Observatory 2018 Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

LAUDER, J. D., E. V. MORAN (2018). *Tradeoffs between physiological drought defense, pest defense, and reproductive output in Sierra Nevada conifers*. Southern Sierra Critical Zone Observatory 2018 Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

O'GEEN, A.T., FERRELL, R., WILSON, S., GOULDEN, M., BALES, R (2018). *Where is deep regolith located in the Southern Sierra Critical Zone Observatory?*. Southern Sierra Critical Zone Observatory 2018 Annual Meeting. Berkeley, CA. Status = OTHER; Acknowledgement of Federal Support = Yes

Other Products

Audio or Video Products.

California's Watershed: Beyond the Brink (video). By The Chronicles Group and UCTV Sustainable California. July 13, 2018. https://www.uctv.tv/sustainable-cal/search-details.aspx?showID=33729

Audio or Video Products.

The Watershed (video). By The Chronicles Group. June 24, 2019. https://www.youtube.com/watch?v=cOion3C3jHI&feature=youtu.be

Audio or Video Products.

Beyond the Brink: A Matter of National Security (abridged) (video). By The Chronicles Group. April 19, 2019. https://www.youtube.com/watch?v=KvtFKnsphmM&feature=youtu.be

Audio or Video Products.

Beyond the Brink: Nexus (video). By The Chronicles Group. October 22, 2018. https://drive.google.com/file/d/18H_qERX5Ef-qQbUjzdnXwxFSjKbzRDqn/view

Audio or Video Products.

Our California Watershed (video). By The Chronicles Group and UCTV Sustainable California. April 18, 2019. https://www.uctv.tv/sustainable-cal/search-details.aspx?showID=34781

Audio or Video Products.

The Watershed (video). By The Chronicles Group and The Aquarium of the Pacific. https://vimeo.com/328859698

Educational aids or Curricula.

Turpin, Ethan. Burn Cycle: Multimedia for Fire Training, Research, and Public Safety. https://burncycleproject.com/

Tague Team Lab collaborative research & education products with Burn Cycle: https://burncycleproject.com/research

Artwork.

Turpin, Ethan. Burn Cycle: Living with Fire (Installation Art Exhibition). April 11-20, 2019. Santa Barbara Community Arts Workshop, Santa Barbara, CA.

Exhibit advertisement example: https://www.thesquirefoundation.org/news/2019/4/8/ethan-turpins-burn-cycle-living-with-fire-exhibit

Lecture/Presentation (Non-Conference).

ACKERER, J. Crossing geochemical and modeling approaches to understand the critical zone, Berkeley National Laboratory. Berkeley, CA. May 8, 2019.

Lecture/Presentation (Non-Conference).

BALES, R. Forests depend on water stored in weathered bedrock during droughts. International Institute for Earth System Science, Nanjing University. Nanjing, China. August 24, 2018.

Lecture/Presentation (Non-Conference).

BALES, R. Lessons on Drought Resilience and water security: California’s Sierra Nevada. Soils Institute, CAS Nanjing. Nanjing, China. August 23, 2018.

Lecture/Presentation (Non-Conference).

BALES, R. Lessons on drought resilience and water security: California’s Sierra Nevada. Tibetan Plateau Research Institute, CAS Beijing. Beijing, China. August 2018.

Lecture/Presentation (Non-Conference).

BALES, R. Making up for lost snow: lessons from a warming Sierra Nevada. Lanzhou University. Lanzhou, China. August 2018.

Lecture/Presentation (Non-Conference).

BALES, R. Sierra Nevada forests depend on water stored in weathered bedrock during droughts. Institute of the Earth

Environment, CAS Xi'an. Xi'an, China. August 2018.

Lecture/Presentation (Non-Conference).

BERHE, A.A., STACY, E., GILMORE, M. Field methods of Critical Zone research. Field Trip for UC Merced undergraduate Critical ZOne Science course. Shaver Lake, CA. October 4, 2018.

Lecture/Presentation (Non-Conference).

CONKLIN, M. American Association of University Women Science Camp, Merced CA. February 9, 2019.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Discussion Panel: Facing the Reality in the Headwaters: The Path Forward. Water Education Foundation 2018 Water Summit. Sacramento, CA. September 20, 2018.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Discussion Panel: Water Industry Trends: How the Forest Resilience Bond Can Protect California's Critical Water Resources. Association of California Water Agency 2019 Spring Conference & Exhibition. Monterey, CA. May 8, 2019.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Real-time precipitation and snowpack from blended wireless-sensor and remotely sensed data. Lanzhou University. Lanzhou, China. August 2018.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Real-time precipitation and snowpack from blended wireless-sensor and remotely-sensed data. International Institute for Earth System Science, Nanjing University. Nanjing, China. August 24, 2018.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Role of CZ structure in moderating influences of snowpack loss on headwater meadows. Soils Institute, CAS Nanjing. Nanjing, China. August 23, 2018.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Role of CZ structure in moderating influences of snowpack loss on headwater meadows. Soils Institute, CAS Nanjing. Nanjing, China. August 23, 2018.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Role of CZ structure in moderating influences of snowpack loss on headwater meadows. Tibetan Plateau Research Institute, CAS Beijing. Beijing, China. August 2018.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Role of CZ structure in moderating influences on snowpack loss on headwater meadows. Institute of the Earth Environment, CAS Xi'an. Xi'an, China. August 2018.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Whole-basin water management: headwater to groundwater. Northwest Institute of Eco-Environment and Resources, CAS Lanzhou. Lanzhou, China. August 2018.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Real-time precipitation and snowpack from blended wireless-sensor and remotely-sensed data. College of

Urban and Environmental Sciences, Northwest University. Xi'an, China. August 2018.

Lecture/Presentation (Non-Conference).

CONKLIN, M. Real-time precipitation and snowpack from blended wireless-sensor and remotely-sensed data. College of Urban and Environmental Sciences, Northwest University. Xi'an, China. August 2018.

Lecture/Presentation (Non-Conference).

DOVE, N.C., TAS, N., HART, S.C. Soil microbial ecology of the Western US: Predications for a warm and fiery future (Invited). California Native Plant Society Meeting. Sonora, CA. October 10, 2018

Lecture/Presentation (Non-Conference).

DOVE, N.C., TAS, N., HART, S.C. Soil microbial ecology of the Western US: Predications for a warm and fiery future (Invited). California Native Plant Society Meeting. Sonora, CA. October 10, 2018

Lecture/Presentation (Non-Conference).

DOVE, N.C., TAS, N., HART, S.C. Soil microbial ecology of the Western US: Predications for a warm and fiery future (Invited). Enviro Lunch, UC Merced. Merced CA. March 7, 2019

Lecture/Presentation (Non-Conference).

DOVE, N.C., TAS, N., HART, S.C. Soil microbial ecology of the Western US: Predications for a warm and fiery future (Invited). Enviro Lunch, UC Merced. Merced CA. March 7, 2019

Lecture/Presentation (Non-Conference).

DOVE, N.C., TAS, N., HART, S.C. Soil microbial ecology of the Western US: Predications for a warm and fiery future (Invited). Oak Ridge National Laboratory. Knoxville, TN. March 26, 2018

Lecture/Presentation (Non-Conference).

GILMORE, M. Measuring California's largest water tower. Alpaugh and Allensworth Climate and Water Project-based Learning Program. Merced, CA. June 14, 2019.

Lecture/Presentation (Non-Conference).

GILMORE, M. Sierra Nevada Soils. Society of American Foresters Conservation Day. Tollhouse CA. May 15, 2019.

Lecture/Presentation (Non-Conference).

GILMORE, M. Sierra Nevada Soils. Society of American Foresters Conservation Week. Sequoia Lake CA. September 24-28, 2018.

Lecture/Presentation (Non-Conference).

GILMORE, M. Soil and nutrients learning station. Livingston School District ASSETS STEM Fair. Livingston CA. April 3, 2019.

Lecture/Presentation (Non-Conference).

GILMORE, M., M. CONKLIN. Science, Math, and Importance of Sierra Nevada Snowpack. CA Math and Science Partnership Workshop hosted by Merced County Office of Education. Fish Camp, CA. June 11, 2019.

Lecture/Presentation (Non-Conference).

GILMORE, M., OJEDA, N., BOLCH, E. Research Topics & Methods of the Sierra Nevada Research Institute & Southern Sierra Critical Zone Observatory. Merced River Fair. Livingston, CA. June 1, 2019.

Lecture/Presentation (Non-Conference).

GILMORE, M., and R. AYERS. Dust as phenomenon: Where does it come from, what is it made of, and what are its impacts on ecosystems and society? Merced County Office of Education Summer Science Institute for Teachers. Atwater, CA. August 2, 2018.

Lecture/Presentation (Non-Conference).

JAURIQUE, D., KUO, J., PERRYMENT, B., TORRES, J. (Mentored by M. Gilmore & E. Stacy) Snowpack Analysis in the Southern Sierra Nevada. Center for Advanced Research and Technology Environmental Science and Technology Lab Spring Action Project Showcase. Clovis CA. May 14, 2019.

Lecture/Presentation (Non-Conference).

MA, Q. Measuring and Monitoring Forest Ecosystem from Remote Sensing Observations (Invited). Department of Forestry, Mississippi State University. Starkville, Mississippi. April 15, 2019

Lecture/Presentation (Non-Conference).

MA, Q., Assessing Fire Impacts on Sierra Nevada California using Remote Sensing (Invited). Lawrence Berkeley National Lab. Berkeley CA. April 1, 2019

Lecture/Presentation (Non-Conference).

MA, Q., Disturbance and recovery, fire impacts on vegetation (Invited). Sierra Nevada Research Institute Research Symposium, UC Merced. Merced CA. March 4, 2019.

Lecture/Presentation (Non-Conference).

MORELAND, K., TIAN, Z., BERHE, AA., O'GEEN, A. ORAL. Deep Soil Carbon in the Critical Zone: Climatic influences on the amount and chemical composition of carbon in weathered bedrock. Environmental Lunch Seminar, UC Merced. Merced CA. 2018.

Lecture/Presentation (Non-Conference).

MORELAND, K., TIAN, Z., BERHE, AA., O'GEEN, A. Oral. Deep Soil Carbon in the Critical Zone: Climatic influences on the amount and chemical composition of carbon in weathered bedrock. CAMS Seminar, Lawrence Livermore National Laboratory. Livermore CA. 2019.

Lecture/Presentation (Non-Conference).

RICE, R., THAW, M., WOMBLE, P., GILMORE, M. Field methods of snow hydrology. Field trip for UC Merced undergraduate Snow Hydrology course. South Lake Tahoe & Carson Pass, CA. March 1-3, 2019.

Lecture/Presentation (Non-Conference).

STACY, E.M. (Invited) Landcover and climate control selective erosional distribution of different soil organic matter pools. Earth and Environmental Sciences departmental seminar, California State University, Fresno. Fresno CA. March 28, 2019.

Lecture/Presentation (Non-Conference).

STACY, E.M. Basic Tools and Analysis, Critical Zone Concepts. Guest lecture for UC Merced Critical Zone Science course. Merced CA. September 10, 2018.

Lecture/Presentation (Non-Conference).

TAGUE, C., Forest structure, productivity and water use: what we are learning from models. Hydrology Colloquium, Interdepartmental Graduate Program in Hydrologic Sciences (GPHS), University of Nevada, Reno. Reno NV. October 2018.

Lecture/Presentation (Non-Conference).

THAW, M. Isotope hydrology in mountain systems, guest lecture, UC Merced undergraduate course, field methods in snow hydrology. Merced CA. March 2019.

Lecture/Presentation (Non-Conference).

THAW, M., et al., Extrapolating Catchment Scale Processes from Stable Isotopes Across a Mountain Range. Lawrence Livermore National Laboratory Post-doc Poster Symposium. Livermore CA. 2019.

Lecture/Presentation (Non-Conference).

BALES, R. Discussion Panel: New Innovative Approaches to Increase the Pace and Scale of Natural and Working Lands Management, Restoration, and Conservation to Meet California's Climate Goals. California Air Resources Board Public Meeting: Natural and Working Lands and Carbon Neutrality. Sacramento, CA. May 17, 2019.

Lecture/Presentation (Non-Conference).

BALES, R. Making up for lost snow: lessons from a warming Sierra Nevada. College of Urban and Environmental Sciences, Northwest University. Xi'an, China. August 2018.

Lecture/Presentation (Non-Conference).

BALES, R. Sierra Nevada forests depend on water stored in weathered bedrock during drought. Northwest Institute of Eco-Environment and Resources, CAS Lanzhou. Lanzhou, China. August 2018.

Lecture/Presentation (Non-Conference).

BARNES, M. Guest lecture for UC Merced Critical Zone Science course. Merced CA. Fall 2018.

Lecture/Presentation (Non-Conference).

BART RR. Feedbacks between vegetation change and hydrology in the Sierra Nevada. EnviroLunch Seminar, University of California, Merced. Merced, CA. October 2018.

News media incorporating SSCZO-related activities & findings.

15 million trees died in California drought, and worse is to come. By Nathanael Johnson. Grist. July 3, 2019. https://grist.org/article/150-million-trees-died-in-californias-drought-and-the-worst-is-to-come/

News media incorporating SSCZO-related activities & findings.

Burn Cycle @ Santa Barbara Community Arts Workshop: Ethan Turpin Mixes Multimedia and Wildfire in Educational Exhibit. By Matt Kettmann. Santa Barbara Independent. April 16, 2019. https://www.independent.com/2019/04/16/burn-cycle-santa-barbara-community-arts-workshop/

News media incorporating SSCZO-related activities & findings.

Burn Cycle @ Santa Barbara Community Arts Workshop: Ethan Turpin Mixes Multimedia and Wildfire in Educational Exhibit. By Matt Kettmann. Santa Barbara Independent. April 16, 2019. https://www.independent.com/2019/04/16/burn-cycle-santa-barbara-community-arts-workshop/

News media incorporating SSCZO-related activities & findings.

California's Drought Killed Almost 150 Million Trees. By Jason Daley. Smithsonian Magazine. July 10, 2019. https://www.smithsonianmag.com/smart-news/why-californias-drought-killed-almost-150-million-trees-180972591/

News media incorporating SSCZO-related activities & findings.

Climate change is ruining your trips to the mountains. By Jacob Margolis. LAist. July 1, 2019. https://laist.com/2019/07

/01/california_forests_dead_trees_climate_change.php

News media incorporating SSCZO-related activities & findings.

For a Warming World, A New Strategy for Protecting Watersheds. By Jaques Leslie. Yale Environment 360. February 19, 2019. https://e360.yale.edu/features/why-restoring-watersheds-is-a-new-priority-in-a-warming-world

News media incorporating SSCZO-related activities & findings.

New Project to Build Climate Resilience through Improved Land Management. By Lorena Anderson. UC Merced Newsroom. February 7, 2019. https://news.ucmerced.edu/news/2019/new-project-build-climate-resilience-through-improved-land-management

News media incorporating SSCZO-related activities & findings.

Three Environmental Systems Graduate Students Receive Department of Energy Fellowships. By Paula Isham. UC Merced Graduate Division. March 15, 2019. https://graduatedivision.ucmerced.edu/news/2019/three-environmental-systems-graduate-students-receive-department-energy-fellowships

News media incorporating SSCZO-related activities & findings.

Wildfire exhibit puts visitors in a room of screens and fire: Climate change studied along with fire history. By John Palminteri. KEYT, NPG of California. April 13, 2019. https://www.keyt.com/news/fire/wildfire-exhibit-puts-visitors-in-a-room-of-screens-and-fire/1068730444

News media incorporating SSCZO-related activities & findings.

Art And Science Mix For Exhibition Which Gives People Experience Of Facing A Wildfire. By Lance Orozco. KCLU. April 12, 2019. https://www.kclu.org/post/art-and-science-mix-exhibition-which-gives-people-experience-facing-wildfire#stream/0

News media incorporating SSCZO-related activities & findings.

Burn Cycle Exhibit Offers Artistic Lessons in Wildfire Science and Safety. Noozhawk. By Melissa Van De Werfhorst. April 5, 2019. https://www.noozhawk.com/article/burn_cycle_exhibit_offers_artistic_lessons_in_wildfire_science_and_safety

News media incorporating SSCZO-related activities & findings.

Burn Cycle exhibit brings public into a fire through video (video). By John Palminteri. KEYT, NPG of California. April 13, 2019. https://www.keyt.com/news/fire/burn-cycle-exhibit-brings-public-into-a-fire-through-video/1068735879

News media incorporating SSCZO-related activities & findings.

Can our forests survive the next drought? By Lorena Anderson. University of California. January 9, 2019. https://www.universityofcalifornia.edu/news/can-our-forests-survive-next-drought

News media incorporating SSCZO-related activities & findings.

Expert Views: Managing Wildfires to Protect Water Resources. By Lindsay Abrams. Water Deeply, News Deeply. August 28, 2018. https://www.newsdeeply.com/water/community/2018/08/28/expert-views-managing-wildfires-to-protect-water-resources

News media incorporating SSCZO-related activities & findings.

Improved land management project co-led by UCI gets $4.6 million in state funding: Data science will help identify best practices to preserve California's forests, wildlands. By Brian Bell. UC Irvine News. February 6, 2019. https://news.uci.edu/2019/02/06/improved-land-management-project-co-led-by-uci-gets-4-6-million-in-state-funding/

News media incorporating SSCZO-related activities & findings.

In drought and heavy rains, ecosystems function like information communication networks: Connectivity explains ecosystem responses to extreme events. By National Science Foundation. Science Daily. September 12, 2018. https://www.sciencedaily.com/releases/2018/09/180912111836.htm

News media incorporating SSCZO-related activities & findings.

Innovative Partnership Aims to Restore Sierra Nevada Forest Health. UC Merced Newsroom. December 13, 2018. https://news.ucmerced.edu/news/2018/innovative-partnership-aims-restore-sierra-nevada-forest-health

News media incorporating SSCZO-related activities & findings.

Lab scientists use radioactive tracers to determine the ages of streamflow. By Lawrence Livermore National Laboratory. Phys.org. April 9, 2019. https://phys.org/news/2019-04-lab-scientists-radioactive-tracers-ages.html

News media incorporating SSCZO-related activities & findings.

Longer growing seasons complicate outlook for coniferous forests. By Trent Knoss. CU Boulder Today. December 19, 2018. https://www.colorado.edu/today/2018/12/19/longer-growing-seasons-complicate-outlook-coniferous-forests

News media incorporating SSCZO-related activities & findings.

Researchers Assess Western Forests' Ability to Survive Next Drought. By Lorena Anderson. UC Merced Newsroom. December 13, 2018. https://news.ucmerced.edu/news/2018/researchers-assess-western-forests%E2%80%99-ability-survive-next-drought

News media incorporating SSCZO-related activities & findings.

Understanding How Fire Alters the Water Use of Sierra Nevada Forests. NASA Landsat Science. December 11, 2018. https://landsat.gsfc.nasa.gov/monitoring-water-use-change-of-sierra-nevada-forests-after-fires/

News media incorporating SSCZO-related activities & findings.

Why California should turn down Trump's offer to raise Shasta Dam. By Jaques Leslie. Los Angeles Times. February 21, 2019. https://www.latimes.com/opinion/op-ed/la-oe-leslie-watershed-restoration-20190221-story.html

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Roche, James. *Evaluating water balance components in the Sierra Nevada: Snowpack sensitivity to climate warming and forest evapotranspiration reduction potential*. (2017). University of California, Merced. Acknowledgement of Federal Support = Yes

Zheng, Zeshi. *Multi-spatial-scale observational studies of the Sierra Nevada snowpack using wireless-sensor networks and multi-platform remote-sensing data*. (2018). University of California, Berkeley. Acknowledgement of Federal Support = Yes

Ma, Qin. *Quantifying Forest Structure Parameters and Their Changes from LiDAR Data and Satellite Imagery in the Sierra Nevada*. (2018). University of California, Merced. Acknowledgement of Federal Support = Yes

Tian, Zhiyuan. *Soil and Weathered Bedrock Evolution along an Elevation Gradient in the Southern Sierra Nevada, California*. (2018). University of California, Davis. Acknowledgement of Federal Support = Yes

Dove, Nicholas. *Soil microbial ecology of the Sierra Nevada: Predictions for a warm and fiery future*. (2019). University of California, Merced. Acknowledgement of Federal Support = Yes

Rungee, Joseph. *o Estimating plant-accessible water storage through evaluating evapotranspiration in the semi-arid western United States using eddy-covariance, remote sensing, and spatially distributed data*. (2018). University of California, Merced. Acknowledgement of Federal Support = Yes

Websites

SSCZO Digital Library
http://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW

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
http://www.facebook.com/SSCZO

The Southern Sierra Critical Zone Observatory maintains a Facebook page. This page currently has 112 followers. Our Facebook activity reaches current and former researchers, other graduate and undergraduate students from associated universities, friends and family of SSCZO colleagues, and a few stakeholders and members of the public.

SSCZO Twitter
http://www.twitter.com/SSCZO

The Southern Sierra Critical Zone Observatory was the first CZO in the National CZO Program with an active Twitter account starting in February 2013. 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, news items, and blog posts related to the local observatory, the CZO network, and the general scope of critical zone research. A majority of our ~700 current followers (~100 followers gained in the last year) are members of the research community, including many individual researchers and research programs unaffiliated with the National CZO Program. Other followers include stakeholders, students, university departments, scientific journals, professional organizations, and interested publics.

Southern Sierra Critical Zone Observatory
http://www.criticalzone.org/sierra

This website is the home of the Southern Sierra Critical Zone Observatory. Staff are updating static webpage content for improved long-term management. Publications, events, videos, and news are regularly updated. Staff are also part of the network-scale Website Committee to continue improving content consistency, layout, features, and accessibility of the U.S. Critical Zone Observatory Network website.

Twitter - Roger Bales
http://www.twitter.com/rbalesuc

SSCZO PI Roger Bales started a Twitter page in November 2014. His page is active in conversations regarding water usage, hydrologic technology and infrastructure, hydrologic research, and intersecting news. He currently has over 1,500 followers.

Twitter - SSCZO Researchers
http://www.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 field of critical zone science and its researchers. Some of our researchers' accounts are listed below: Morgan Barnes (@Morgan_E_Barnes), Ryan R. Bart (@ryanrbart), Asmeret Asefaw Berhe (aaberhe), Russell Callahan (@russ_buss), Nicholas Dove (@nicholascdove), Cliff Riebe (@sedimentMatters), Safeeq Khan (@safeeqkhan), Naomi Tague (@naomi_eco_hydro), Melissa Thaw (@MelissaThaw).

U.S. Critical Zone Observatory Network Instagram

http://www.instagram.com/criticalzoneorg

SSCZO contributes photos to the CZO Instagram account. @CriticalZoneOrg represents all Critical Zone Observatories in the U.S. CZO network. The account became active in Spring 2016.

UCTV Sustainable California
http://www.uctv.tv/sustainable-cal

UCTV Sustainable California is a public online TV channel with videos focusing on natural resource management, biological and cultural diversity, and low-impact living. SSCZO personnel, field sites, and technologies are featured in several videos on the website. The videos show how research is influential in understanding California's water supply, its impacts on ecosystems and society, and how to improve the management of this precious resource.

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

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	1
Goulden, Michael	Co PD/PI	2
Riebe, Clifford	Co PD/PI	0
Tague, Christina	Co PD/PI	2
Berhe, Asmeret Asefaw	Co-Investigator	1
Glaser, Steven	Co-Investigator	0
Hart, Stephen	Co-Investigator	2
O'Geen, Anthony	Co-Investigator	3
Safeeq, Mohammad	Co-Investigator	2
Ackerer, Julien	Postdoctoral (scholar, fellow or other postdoctoral position)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Devine, Scott	Postdoctoral (scholar, fellow or other postdoctoral position)	2
Ma, Qin	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Yang, Yang	Postdoctoral (scholar, fellow or other postdoctoral position)	4
Busse, Matt	Other Professional	0
Choate, Janet	Other Professional	1
Davis, Frank	Other Professional	0
Gilmore, Michelle	Other Professional	12
McCormick, Cyril	Other Professional	1
Meng, Xiande	Other Professional	10
Stacy, Erin	Other Professional	12
Wagenbrenner, Joseph	Other Professional	1
Bart, Ryan	Staff Scientist (doctoral level)	2
Barnes, Morgan	Graduate Student (research assistant)	12
Callahan, Russell	Graduate Student (research assistant)	12
Dove, Nicholas	Graduate Student (research assistant)	9
Heckman, Christopher	Graduate Student (research assistant)	4
Lauder, Jeffrey	Graduate Student (research assistant)	9
Moreland, Kimber	Graduate Student (research assistant)	12
Rungee, Joseph	Graduate Student (research assistant)	6
Thaw, Melissa	Graduate Student (research assistant)	12
Tian, Zhiyuan	Graduate Student (research assistant)	4
Wilson, Stu	Graduate Student (research assistant)	4

Name	Most Senior Project Role	Nearest Person Month Worked
Ojeda, Nancy	Non-Student Research Assistant	4
Castro, Madeline	Undergraduate Student	5
Glasser, Susan	Undergraduate Student	4
Klotz, Paige	Undergraduate Student	1
Pinkus, Megan	Undergraduate Student	1

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: this award, 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: 1

Contribution to the Project: CZO co PI, groundwater surface water interactions, outreach & education direction

Funding Support: this award, 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: Co PI, flux towers, development of tower top remote sensing system, forest productivity and ET monitoring

Funding Support: this award, 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: 0

Contribution to the Project: landscape and critical zone evolution, geomorphology, geochemistry, geophysics

Funding Support: 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: 2

Contribution to the Project: ecohydrologic modeling

Funding Support: other funding

International Collaboration: No
International Travel: No

Asmeret Asefaw Berhe
Email: aaberhe@ucmerced.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 1

Contribution to the Project: Sediment transport & nutrient cycling, soil biogeochemistry

Funding Support: other funding

International Collaboration: No
International Travel: No

Steven Glaser
Email: glaser@berkeley.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 0

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

Funding Support: Other funding

International Collaboration: Yes, France
International Travel: No

Stephen Hart
Email: shart4@ucmerced.edu
Most Senior Project Role: Co-Investigator
Nearest Person Month Worked: 2

Contribution to the Project: Sediment transport, nutrient cycling

Funding Support: 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: Predicting spatial patterns in regolith thickness, integrating regolith thickness with ecological and management response

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: 2

Contribution to the Project: hydrology, USFS KREW collaboration; Using paired catchment data to investigate hydrologic and geomorphic impact of forest fuel management and climate across SSCZO gradient

Funding Support: other funding

International Collaboration: No
International Travel: No

Julien Ackerer
Email: jackerer@ucmerced.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 4

Contribution to the Project: UC Merced postdoc; hydrology and geochemistry, analysis and modeling of regolith and water chemistry at KREW watersheds

Funding Support: SSCZO

International Collaboration: No
International Travel: No

Scott Devine
Email: smdevine@ucdavis.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 2

Contribution to the Project: UC Davis Postdoc (O'Geen lab); terrain controls on regolith thickness

---

Funding Support: other funding

International Collaboration: No
International Travel: No

Qin (Christine) Ma
Email: qma@ucmerced.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 12

Contribution to the Project: UC Merced postdoc; vegetation response to disturbance and management in Sierra Nevada

Funding Support: SSCZO

International Collaboration: No
International Travel: No

Yang Yang
Email: yyang103@ucmerced.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 4

Contribution to the Project: UC Merced postdoc; biogeochemistry

Funding Support: SSCZO

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: advisory board, USFS Pacific Southwest Research Station

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: Technical support for RHESSys applications to SSCZO

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
Merced County Office of Education	School or School Systems	Merced, 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

Merced County Office of Education

Organization Type: School or School Systems
Organization Location: Merced, CA

Partner's Contribution to the Project:
In-Kind Support
Facilities
Other: Collaborative education/outreach

More Detail on Partner and Contribution:

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?

Collaborators and cooperators are involved for research and educational purposes.

* = collaborative work with this award's participants; ^ = cooperative site/data use

Research:

*J Wagenbrenner, K Mazzocco [USDA FS PSW] w Bales, Safeeq, Stacy, etc.

*A Visser, A Deinhart, R Bibby, M Sharp, E Oerter, B Esser [LLNL]; Y van der Velde [Vrije U. Amster.] w Thaw, Conklin

*E Aronson, M Maltz, S Aciego [UC Riverside] w Hart

*J Blankinship w Hart

*P O'Day, G Nwosu [UC Merced]; N Washton [PNNL] w Barnes, Berhe, Hart

*K McFarlane [LLNL] w Moreland, Berhe, O'Geen, Hart

*C Rasmussen [U AZ], R Lybrand [Oregon State U] w Berhe, Moreland

*J Richardson [U MA Amherst] w O'Geen (cross-CZO)

*E Moran [UC Merced] w Lauder

*T Watteyne & students [INRIA], Z Zheng [UC Berkeley] w Glaser, Bales

*B Jessup, S Miller [UWyo]; K Ferrier [GA Tech], J Dixon [MT State U], A Dosseto [U Wollongong], L Sklar [Concordia U] w Callahan, Riebe

*WS Holbrook [VA Tech] w Riebe

*D Johnson [U N Reno] w Stacy, Callahan, Riebe, others

*C Hunsaker [USDA FS PSW] w Stacy, Callahan, Riebe, Bales, others

*J Roche [US NPS] w Bales, Goulden

*K Son [CUNY] w Tague

*M Sohrabi, M Kniffin [UC Merced] w Safeeq, Conklin, Bales

*J Bolis & others [NEON] w Stacy, Bales

*N Stavros et al. [NASA Cal/Val] w Bales

^A Wlostowski [CO State U] (cross-CZO)

^H McMillan [San Diego State U]; F Branger, I Horner [IRSTEA]

^S Jepsen, T. Harmon [UC Merced]

^A Derer, P. Kumar [U Illinois] (cross-CZO)

^F Von Blanckenburg[FU Berlin, GFZ Potsdam], D Uhlig [FU Berlin]

Education:

*J Thebeau [Chronicles Group] w Bales, Conklin

*L Lillienfeld, J Pollak [CUAHSI] w Gilmore, Bales

*S Bynum, S Wilson, K Calderwood [Center for Adv. Res. & Tech.] w Gilmore, Stacy

*R Ayers, F Romo [Merced Co. Off. Edu.] w Gilmore, Conklin

*T Catchpole, D Savin-Dukoleth, N Carroll, and others [Soc. Am. Forest. High Sierra] w Gilmore

*S Byrd [So. Cal. Edison], N Carroll [Cent. Sierra Hist. Soc.] w Gilmore

Impacts

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

Cross-disciplinary advances in several areas have contributed to the overall discipline of critical-zone science. In addition to those highlighted as accomplishments, these mature results are showing potential impacts.

Research community resource: From the outset, the Southern Sierra Critical Zone Observatory and the other observatories in the NSF U.S. Critical Zone Observatory Network aimed to be resources for the critical-zone research community, in order to catalyze advancement in understanding the critical zone and refining Earth system models. Our team has supported others in using our CZO resources. The publication of multiple datasets in the past year has improved access to, and understanding of, data available to the larger research community. These datasets will increase scientific discussion and research within the critical-zone science community and related singular disciplines. In addition, over 20 research groups and 50 individuals without financial support from the current award are conducting research at SSCZO sites and with SSCZO data (see Other Participants list). Some of these research groups are closely collaborating with the core SSCZO team. Other independent researchers have chosen SSCZO as a natural laboratory because of the breadth and depth of research findings, sample and data archives, and infrastructure available at our sites.

Research syntheses: Work by postdoctoral scholar Ackerer and others to synthesize critical-zone findings will link long-term evolution of the critical zone with short-term processes, with impacts on our understanding of the evolution of soil and regolith, and our understanding of water quantity and quality in headwater catchments. The project helps to merge knowledge from hydrological, geochemical and modeling communities. Postdoc Yang's work also synthesizes research from multiple sub-disciplines of critical-zone science, including biogeochemistry, hydrology, and ecology.

Quantifying timing and pathways of hydrologic flow and storage: New field and lab techniques developed by Visser, Thaw, and others to measure S-35 in environmental water samples. Combined with use of Na-22 and tritium, as well as stable isotopes Visser et al. published the first study utilizing a combination of cosmogenic radioactive isotopes to reveal a catchment’s hydrochronology and water storage dynamics, such as preferential evapotranspiration of younger water. This information provides proof of concept for this combination of techniques, direction for future related research, constraints on the subsurface architecture of the critical zone, and insight into landscape evolution.

Vegetation response to drought and changing climate: Recent results from Lauder, Moran, and others point toward drought-induced mechanisms of tree mortality that run counter to prevailing hypotheses of how trees die under stress. This research will be leveraged to improve forecasting of likelihood of drought-induced forest mortality and shifts in forest dynamics under climate change. Further, methods currently being developed to quickly measure C allocation in trees can significantly improve data throughput in physiological studies of drought impacts.

Elemental cycling: Findings from research by Dove, Hart, and others will be useful in determining the effect of fire on carbon and nitrogen cycling in the Sierra Nevada in evaluating different forest management strategies. In addition, Barnes, Hart, Callahan, and others are working to fill critical knowledge gaps in our understanding of how the P dynamics are regulated by climate and depth, particularly in low-P-containing parent material. Although many have investigated the conceptual model of Walker and Syers (explains how P pools evolve through time), few have coupled climate change studies with a fractionation technique, examined P pool transformations with depth, or observed organic P speciation changes with climate. In addition, only a small number of studies have examined content and P pools within temperate Mediterranean ecosystems and drylands and shifts in chemical composition of the organic pool are largely unknown. Barnes’s dissertation project works to fill in these gaps in knowledge using a integrative approach by coupling classic methodology (i.e. fractionation) with advanced techniques (XANES, NMR, and FTICR-MS). This work spans multiple disciplines including soil science, ecology, geology, biogeochemistry and agricultural science.

Scaling of evapotranspiration: Our approach to scaling of evapotranspiration, using satellite data calibrated with flux-tower measurements, is potentially transformational for estimating water balances. The high correlation between annual

evapotranspiration and satellite measured greenness, typically indicated by NDVI, provides unprecedented accuracy and detail. Without calibration, satellite data provide relative values for evapotranspiration. Without satellite data for scaling, flux-tower measurements provide point data. The combination of the two provide powerful data for establishing water balances, constraining hydrologic modeling, estimating critical-zone properties, identifying areas vulnerable vs resistant to drought, and prioritizing areas for landscape restoration. All of these applications are currently proceeding, involving our team and others.

Ecohydrologic modeling: 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 these tools 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). An additional evapotranspiration product in progress can be used as input into hydrologic models, to maintain an accounting of subsurface water storage drawdown and to better understand how evapotranspiration responds to climate extremes ultimately affecting runoff. This product can also be used to provide insight for observed responses and changes to the landscape, combined with soil porosity data to better understand plant rooting depth, and explain vegetation responses to climate extremes.

What is the impact on other disciplines?

Novel approaches and critical findings that have resulted from numerous projects by our core team and collaborators over the 10+ year lifetime of SSCZO have advanced singular disciplines that are connected through critical zone science. These impacted disciplines include electrical engineering, isotope hydrology, geomorphology, forest management, agricultural science, fire ecology, forestry, soil science, ecology, geology, biogeochemistry, geochemistry, and hydrology. We highlight two discipline-focused impacts from recent and ongoing projects below:

Improving dendrochronology research methods: Lauder and others are currently developing a new method to quickly quantify differences in carbon and lignin concentrations in annual tree rings. This method promises to cut assessment time of carbon and lignin down by ~75% and remove the need for dangerous and costly chemical extractions.

Filling forest management knowledge gaps: Many forest managers do not realize that soil survey does not fully document the total thickness of regolith. This is because soil survey does not exceed a depth of 2-m. Thus, we have an incomplete inventory of carbon, nutrient, and water storage throughout the Sierra Nevada where regolith is thicker. O'Geen and others are working with stakeholders such as the Tree Mortality Task Force (appointed by the Governor) and University of California Cooperative Extension to extend this knowledge. In addition, incorporation of results from Lauder's work into models of forest mortality will shift predictions of forest die-off and coincident wildfire incidence and intensity, as well as hydrologic outlooks.

Utilizing findings for carbon sequestration and stabilization: Members of our research team (Bales, Conklin, Goulden, O'Geen) are collaborating with several other climate, economic, and social scientists, as well as stakeholder outreach specialists, in a new Innovation Center for Advancing Ecosystem Climate Solutions. This three-year, six-million-dollar program co-led by SSCZO co-PIs M. Goulden and R. Bales was created through an award from the Strategic Growth Council's competitive Climate Change Research Program. As detailed in a UC Merced press release, "...goals for the Innovation Center include reducing wildfire risk, improving long-term carbon sequestration and bolstering resilience in the face of climate change, with an emphasis on California's rural regions and low-income communities" (https://news.ucmerced.edu/news/2019/new-project-build-climate-resilience-through-improved-land-management).

Advancing applications & methods of isotope hydrology: The development of new hydrologic tracers, combinations of tracers, and sampling methods by Lawrence Livermore National Laboratory and UC Merced researchers impacts the discipline of isotope hydrology (Visser et al., 2019). Sodium-22 is being used at P301 and P300 as a new isotopic tracer to complement tritium and sulfur-35 water tracing. Tritium can be used to detect relatively older water, from about 10 to 60 years old since it precipitated, while sulfur-35 can be used to detect younger water that is less than two years old. The decay rate of sodium-22 is between those of tritium and sulfur-35, which results in a higher-resolution picture of water ages older than two years and younger than ten years. The researchers have also streamlined sulfur-35 water sampling using a novel approach, with proof-of-concept completed at the Providence Creek Catchments site. Low concentration of sulfur-35 in water requires at least 20 liters of water to reach a concentration within detection limits. Thus, several hundred

liters of water would typically be required to remove from the field monthly using prior sampling methods. Using ion-exchange resin columns, sulfur-35 can be concentrated in-situ as stream water is pumped through the column. This new method streamlines the chemistry procedures required in the lab, eliminates the step of researchers transporting hundreds of liters of water from the field site to the lab, and reduces ecosystem disturbance. Additionally, work is being carried out to fill the knowledge gap of quantifying the impact of air mass trajectory on atmospheric tritium variation.

What is the impact on the development of human resources?

The SSCZO has been engaged in the development of future critical-zone researchers, educators, K-16 students, and other professionals in related STEM and environmental-management fields. We also engage in public outreach to increase interest in and knowledge of the critical zone.

Fundamental training and professional development of M.S., Ph.D., and postdoctoral scholars working directly with SSCZO investigators continues. SSCZO scholars have been awarded travel and research fellowships, completed fellowships at US National Laboratories, attended research and career-related workshops, and gained experience presenting their work to a variety of audiences. Details on these students and their activities and training are found in Personnel, Products, Training, and other sections of the report. Early-career professionals who were supported by this award as students or postdocs have accepted positions at universities, governmental agencies, and non-governmental organizations.

Research conducted at SSCZO also impacts the development of scholars and early-career researchers who have not been financially supported by this award, listed as other participants in the Personnel section; these are externally funded researchers are utilizing SSCZO datasets and field areas. In addition, Tague advised a group of students pursuing Master's degrees in Environmental Science and Management, the second Bren Master's project that has incorporated SSCZO-related findings in just as many years. The thesis developed a strategy for incorporating wildfire into forest management plans, completed in spring 2019.

Graduate and undergraduate courses incorporating research are taught by SSCZO investigators at multiple institutions. We estimate that these courses collectively share concepts related critical-zone science and findings from SSCZO and the broader CZO network with at least 200 students each year. In fall 2019, Berhe's Critical Zone Science course included a field trip to Providence Creek Catchments, where students learned soil profile characterization methods and ground-truthed depth to groundwater in meadow wells.

Several undergraduates have been employed by SSCZO researchers. We highlight some examples from UC Merced below. Multiple undergraduate students with the Hart research group were employed to assist with critical-zone field and laboratory research (e.g., M. Castro, O. Elias). Castro was also employed to assist with outreach efforts; she is now employed by the CA Dept. of Water Resources. Lauder's research supports undergraduate volunteer and course-based research projects, with four undergraduate students completing independent research using some of his samples and data. Recently-graduated N. Ojeda, who worked as an undergraduate field assistant last summer, was rehired again this summer to assist with data processing, instrument maintenance and other field sampling projects. She is now employed by Merced Irrigation District. Most students are planning to pursue jobs related to soil science, hydrology, or environmental engineering, or apply to graduate school programs. A majority of students assisting with SSCZO work identify with one or more demographic groups (e.g., gender, race, ethnicity, socioeconomic background) traditionally underrepresented in geosciences and STEM.

The University of California, Merced, where a large number of our core team is located, provides critical opportunities to students underrepresented in STEM fields through coursework and research assistantships. UC Merced is a minority-majority school and the most diverse university in the UC system. In the 2017 to 2018 undergraduate student body, 91% of students identify as non-white or international students; 53% as Hispanic. And 71% of undergraduate students enrolled are first-generation college students.

Two teacher workshops hosted by Merced County Office of Education in the last year reached approximately 60 educators who work in Merced County. Gilmore presented about dust sources and impacts on ecosystems and public health (2018), and the math, science, and importance of snowpack (2019). Both of these topics carry local importance in the region. Activities and content used in classrooms by these teachers will reach local students, a large number of whom are from backgrounds traditionally underrepresented in STEM fields; Merced County 2015 census indicates 58% of the reported population identifies as Hispanic or Latino.

At the high school level, Moreland facilitated a soil science activity for Merced high school students. Gilmore presented about Sierra Nevada headwaters research to 9th grade students from Tulare Basin. Three juniors and one senior from the Center for Advanced Research and Technology (CART) Environmental Science and Field Research Lab participated in this year's snow survey research project mentored by Gilmore and Stacy. CART students gained experience in field navigation and measurement, data analysis and visualization, research collaboration, and science communication.

At the elementary level, we reached over 900 5th grade students from southern Sierra foothill and mountain communities: ~800 students at Gilmore's soils station at the Society of American Foresters' fall Conservation Week at Sequoia Lake, and ~125 students at the spring Conservation Day in Tollhouse. Southern California Edison's Science Days were cancelled this year due to inclement weather.

In addition to the numerous research presentations given by our researchers at the AGU 2018 Fall Meeting, our team reached new audiences in education-focused sessions. Gilmore and Conklin shared the meaning and importance of Earth's critical zone with ~50 AGU attendees in a lightning talk; over two-thirds of the audience did not know what the critical zone was at the beginning of the presentation. Gilmore and others shared the CART mentored project's structure and summaries of recent evaluations in an education-focused session at the AGU 2018 Fall meeting.

Public screenings and on-demand availability of The Chronicles Group's film Beyond the Brink have provided opportunities to increase public interest in and knowledge of water issues in California and potential impacts at national and international scales. This documentary focused on water scarcity and issues in California, and how these issues have potential impacts at national and international scales. This documentary focuses on water scarcity and security in California's agricultural heartland and features footage from interviews with SSCZO investigators Bales and Conklin. Additional videos have been created using footage from this production. Through a CUAHSI Let's Talk About Water Challenge Grant awarded to Gilmore & Bales this winter, a forthcoming screening and discussion panel will be held at UC Merced in September 2019 (https://www.cuahsi.org/education/lets-talk-about-water/challenge-grant-awardees/).

We also engaged with ~50 members of the public at the Merced River Fair in June 2019. SSCZO-related activities included snow depth sensor demonstration and soil texture analysis methods. Copies of comics What is the Southern Sierra Critical Zone Observatory? and A Tale of Two Dust Specks were also distributed.

SSCZO is also active in network-level, cross-CZO efforts to impact human resources. Our educational resources have been added to the CZO National Office Educational Resources page (http://criticalzone.org/national/educationoutreach/resources/), which continues expansion and refinement. Notice and Wonder: Foundations for Scientific Inquiry in the Critical Zone, an activity guide by Gilmore, was distributed to teachers in fall 2018 as part of the American Geoscience Institute's 2018 Earth Science Week package. This handout will also be listed in a vernal pools resource guide for #ProjectPhenomena that is under development by Merced County K-12 teachers and UC Merced researchers and educational specialists (https://sites.google.com/site/sciencephenomena/home).

What is the impact on physical resources that form infrastructure?

The Glaser-Bales team continues to install the new generation of wireless-sensor stations across the Sierra Nevada, using technology developed at the SSCZO. With multiple sources of federal, state and local support, that technology has been applied at the river-basin scale in the American-Consumnes Rivers watershed and other headwaters regions including the Feather River watershed. The wireless-sensor network of nodes, repeaters, and hubs can be viewed as a platform for real-time, spatially distributed environmental monitoring, and can be adapted for applications beyond our current research.

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 data and research sites. We are making the data availability sustained over the long term through both CZO network collaboration and archiving in the California Digital Library.

We also share information with water resources and forest managers and policymakers in order to identify limitations of current data, create more informed measurement and management decisions, and optimize best management practices.

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. We are participating in the US NSF CZO network's ongoing transition to data archival in CUAHSI's database. Flux tower datasets are also cross-posted as part of the AmeriFlux network.

SSCZO Digital Library data catalog.
https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW
The Sensor Object Library (SOL), base station software, and data preservation/visualization tools (e.g. InfluxDB and Grafana) being tested for the wireless sensor network will improve data standardization and preservation. Development on these tools is open source, meaning any researchers can benefit from and contribute to their development. See http://github.com/realms team/sol.

In addition, Lauder is constructing the first tree ring data repository strictly focused on Sierra Nevada living and drought-killed trees. This dendrochronology database is constructed using standard tree ring data standards, and consists of a curated collection of tree cores along with associated location, tree status, growth, and pest attack meta data. Such a database can be leveraged for numerous Sierra Nevada projects.

Web and social media. Online efforts complement our written and oral presentations. The main SSCZO online presence is through the SSCZO website (www.criticalzone.org/sierra) and the SNSJHO digital library (https://eng.ucmerced.edu/snsjho/files/MHWG/Field/Southern_Sierra_CZO_KREW). SSCZO also maintains a Facebook page and Twitter account, and collaborates with the US NSF CZO Network's Instagram account. Social media provide an informal counterpart where we share field activities, real time information on conference presentations, and pertinent updates on research and current events. Detailed descriptions are listed in Products.

What is the impact on technology transfer?

Our wireless-sensor systems have been implemented in multiple watersheds in the state: Consumnes River Basin (under development), American River Basin (completed in 2014), and Feather River Basin (completed in 2016). These projects are in collaboration with public agencies and private firms (i.e. CA Dept of Water Resources, Pacific Gas & Electric). Additional proposals to expand these systems are pending with state and local agencies. We also have installed a transect along Tioga Road in Yosemite National Park.

We are making the wireless-sensor network methods under development 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. See http://github.com/realms team/sol. Live network connectivity data is also accessible on http://snowhow.io, a website developed by French collaborators at INRIA.

Combined approaches using remote-sensing and in-situ measurements could be adopted as new practice for predicting spatial soil-water storage variability in addition to remote sensing.

In addition, our scaling approach for estimating forest evapotranspiration has been extended using Landsat data, which at 30-m pixel size is better suited to the scale of forest management than is our previous work with MODIS data.

What is the impact on society beyond science and technology?

SSCZO's work has critical links to society. We strive to communicate about our activities and findings with a variety of audiences in order to (1) improve public understanding of and attitudes toward the critical zone, forest management, ecosystem and critical-zone services, and water resources; and (2) help decisionmakers including policy makers, resource managers, and large and small landowners make more informed decisions and improve societal, economic, and ecological resilience.

Our CZO has a high profile with resource- management stakeholders in California and the broader region. Ultimately our

work will lead to improved forest management practices. Our research addresses fundamental knowledge gaps around management of water supplies, nutrient supplies, forests, hydropower, carbon, 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. 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. Ecosystem response to climate change will also shift carbon fluxes; a fundamental question vital to carbon budgeting that our work relates to is, how will carbon sources and sinks change as climate changes?

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. Recent intense and consecutive drought years and forest mortality 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.

The newly-formed Innovation Center for Advancing Ecosystem Climate Solutions, which several members of our team are involved in, will combine findings from SSCZO and other existing research and new work, and share information and tools with resource managers, community members, and other project partners in order to reduce wildfire risk, improve long-term carbon stability and sequestration, and increase ecological and societal resilience in some of the state’s most vulnerable communities.

Ongoing debates at the local, state, and national level are focused on forest health across the west, with a particular focus on drought and fire. Our results provide some first steps to assessing drought susceptibility at the state level using individual tree-scale measures of resilience. The ultimate goal of Lauder’s dissertation is to scale up from individual trees to the whole Sierra Nevada and predict likelihood of drought-induced mortality across the range. By combining cellular, stand-level, competition, and large-scale climate data, his research can help support the on-going conversation about what makes a “healthy” forest, and what kinds of management strategies should be implemented and where they should be targeted moving forward.

Our work is also improving the understanding of the impacts of fire suppression and resulting novel, high-severity fire on microbial communities and soil biogeochemistry, which are increasingly being recognized as critically important in forestry and agriculture industries.

Research focused on elemental nutrient stocks also have important societal implications. Ongoing work will help us understand how carbon and phosphorus biogeochemistry is impacted by temperature, precipitation, and the response of temperate ecosystems to climate change. It is anticipated that nitrogen limitation will be alleviated in temperate ecosystems, leading to phosphorus as the primary limiting nutrient in ecosystem development. It is estimated that phosphorus stocks in the US, which are used for agricultural fertilization, will be depleted by 2025. Current lack of understanding of phosphorus biogeochemistry often results in excess fertilizer applied to agricultural sites, leading to leaching and eutrophication of waterways, which can impair water use for industry, drinking, fisheries, and recreation.
Deep-soil and regolith research

Our findings linking bedrock lithology and geochemistry to other aspects of the critical zone, including regolith depth, primary productivity, and vegetation resilience to climate change and drought, provide insights that may help improve prediction of ecosystem change in coming decades and thus inform better decision making in forest management.

Additional impacts related to society, management, and public understanding of our research and related sciences are also described in responses to prior questions.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them
Nothing to report.

Changes that have a significant impact on expenditures

Carryover because of delay in hiring postdocs

Significant changes in use or care of human subjects

N/A

Significant changes in use or care of vertebrate animals

N/A

Significant changes in use or care of biohazards

N/A

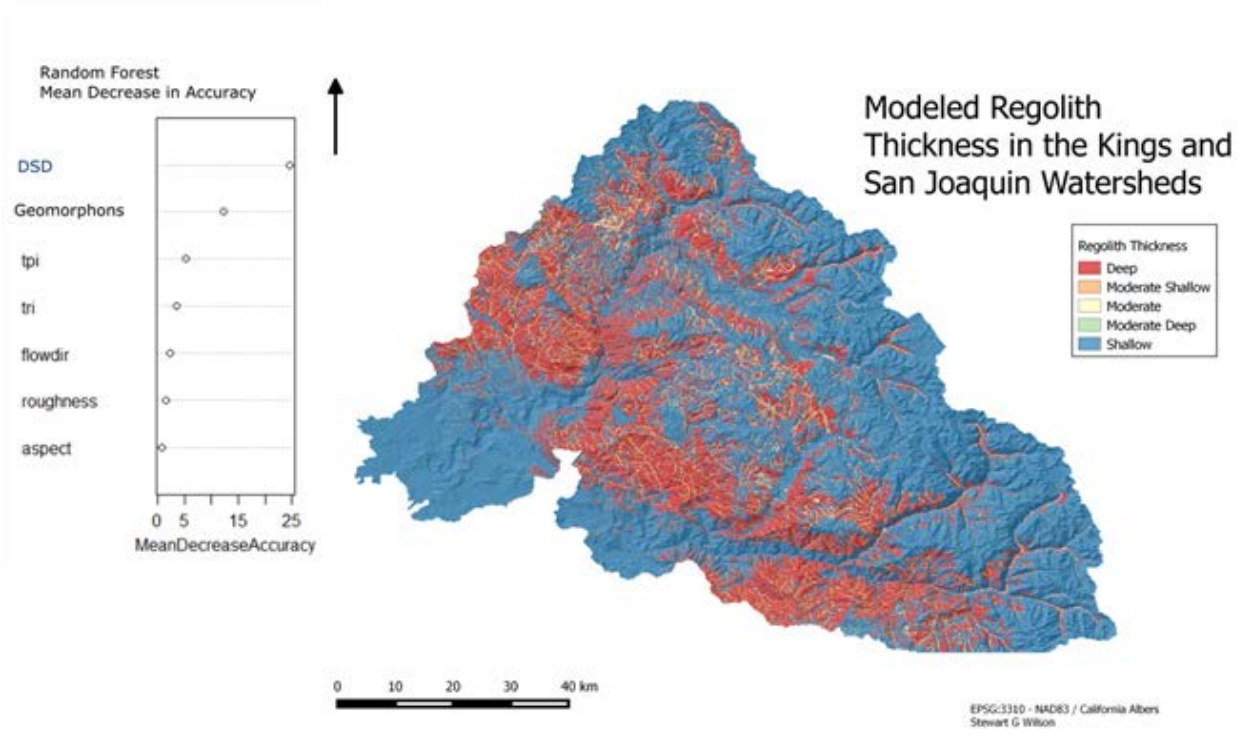


Figure 1. Regional model of regolith thickness for Upper Kings and San Joaquin River basins. Random forest classification model accurately predicts shallow (less than 1 m) and deep regolith (> 7 m) with 15 % and 17 % misclassified respectively. Intermediate depth class predictions are classified with much less accurately. Variable importance plot depicts the key variables in the model. The variables with large mean decrease in accuracy are more important for classification of the data. O'Geen et al., in preparation.

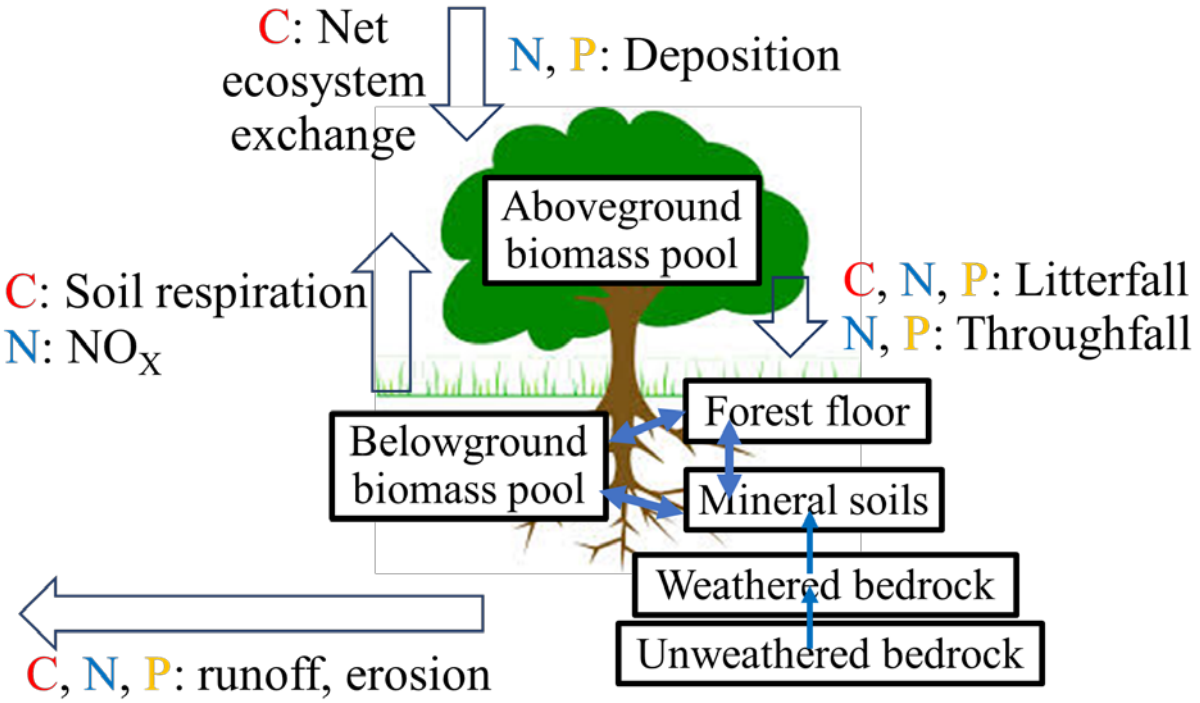


Figure 2. Conceptual model for synthesis of carbon and nutrient fluxes at Southern Sierra CZO. Yang et al., in preparation.

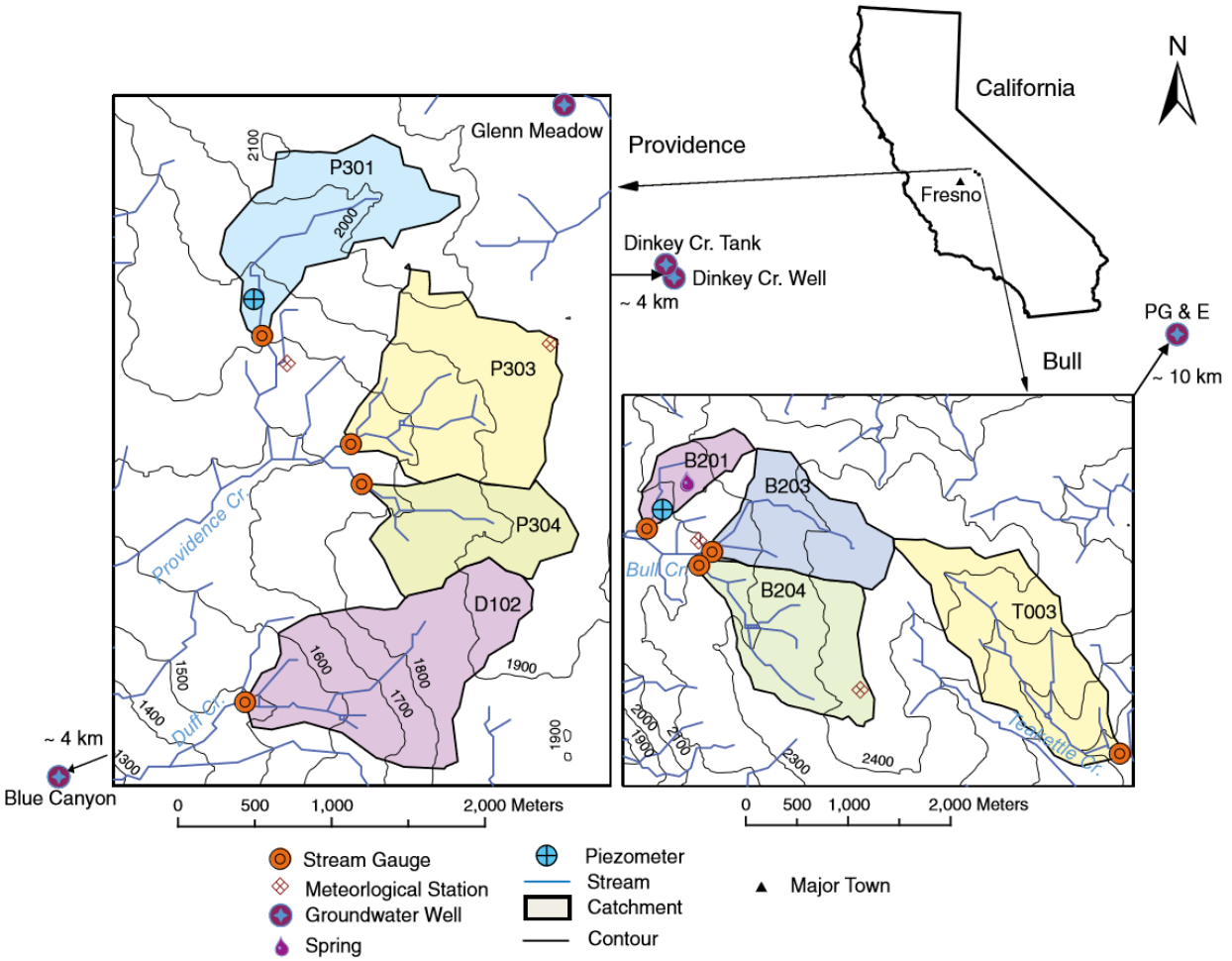


Figure 3. Catchments used for geochemical modeling. Providence (left panel) catchments average 1600-2100 m. Bull catchments (right panel) average 2100-2500 m elevation. Adapted from Liu et al., 2013, for Ackerer et al., in preparation.

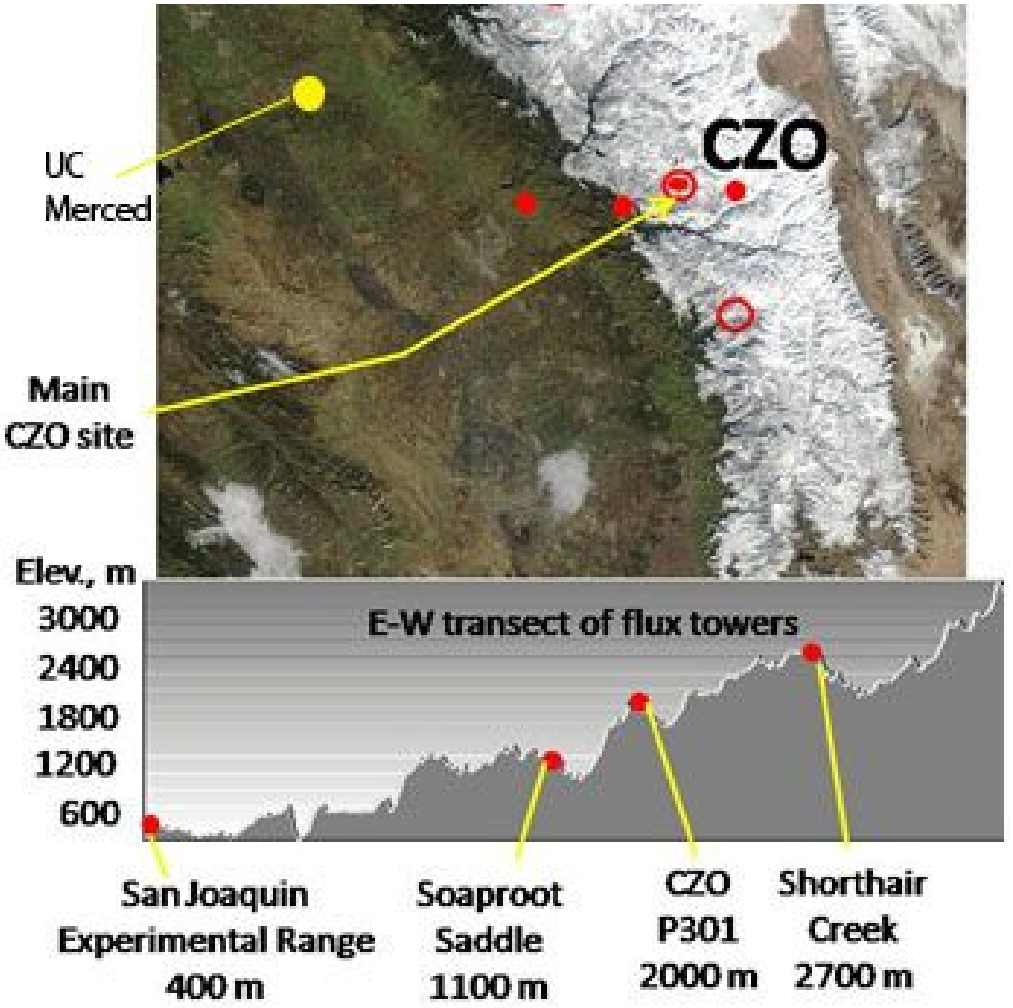
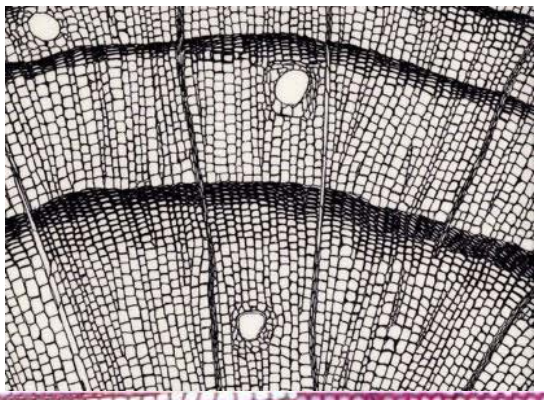


Figure 4. Southern Sierra CZO sites used to synthesize fluxes and pools for carbon and nutrients. Adapted from Southern Sierra CZO website, for Yang et al., in preparation.

A



B

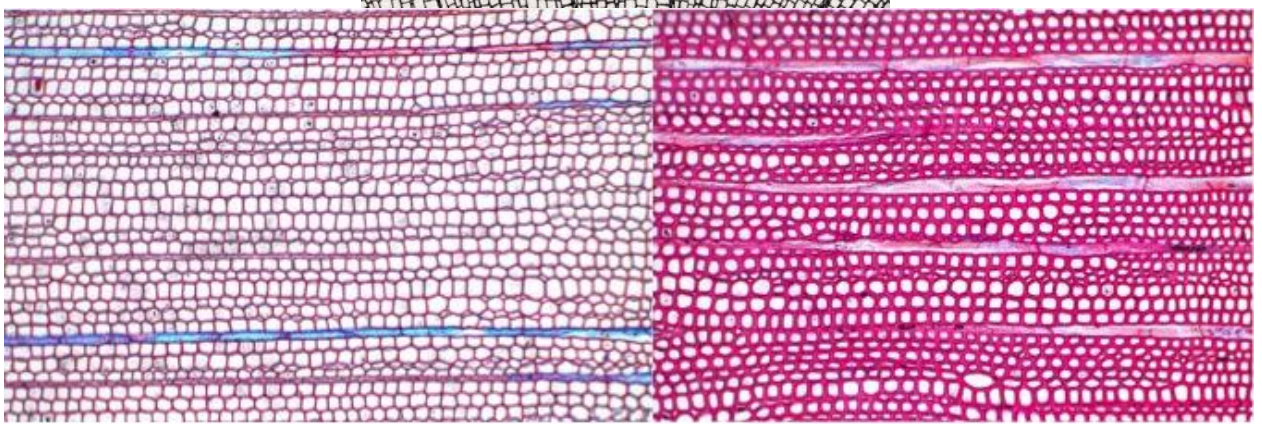


Figure 5. A) Annual tree rings are made up of xylem cells that vary in thickness form early in the season to late in the season, and between years. B) Example cross-sections of earlywood xylem cell tissue from *Pinus ponderosa* in the Sierra Nevada. Tissues with a higher ratio of wall thickness to cell area ("Thickness-to-Span") are considered less likely to collapse under drought, and are thus considered "safer". The image on the right represents "safe" tissue, and the image on the left "unsafe". Lauder et al., in preparation.

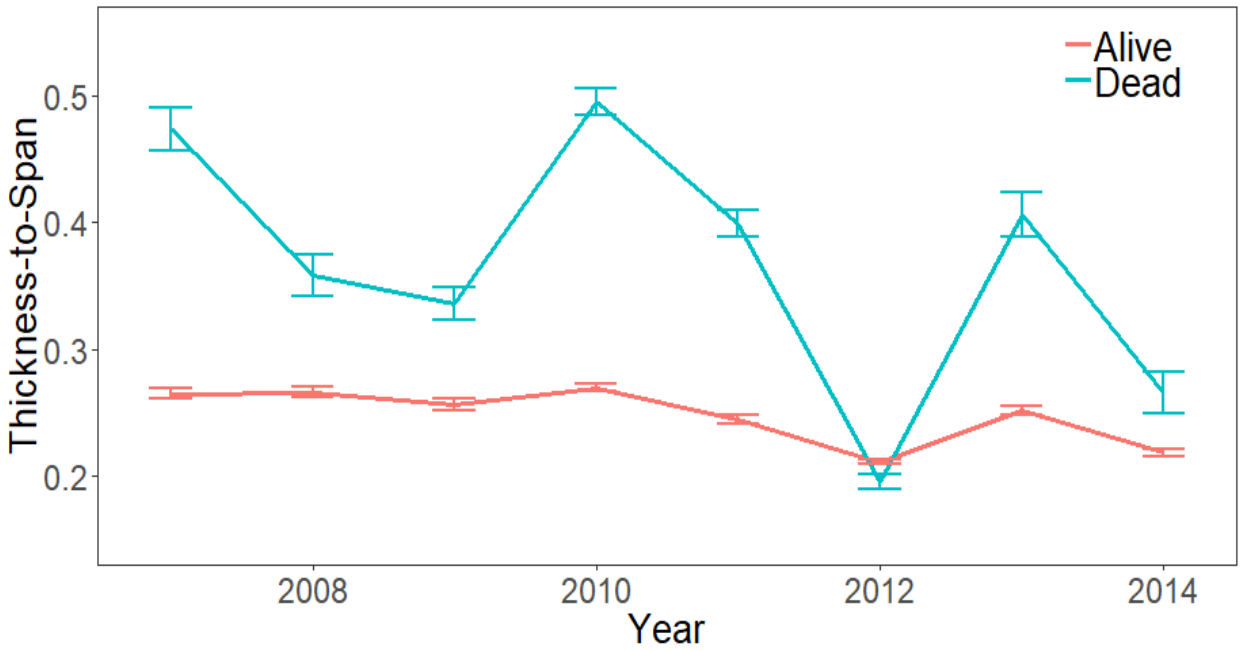


Figure 6. Xylem Thickness-to-Span (ratio of cell wall thickness to cell diameter, an indicator of drought resistance) of living and drought-killed Pinus ponderosa and P. jeffreyi in Sequoia National Park and the SSCZO Soaproot and Providence sites. Drought-killed trees grew “safer” cells, counter to expectations. Lauder et al., in preparation.

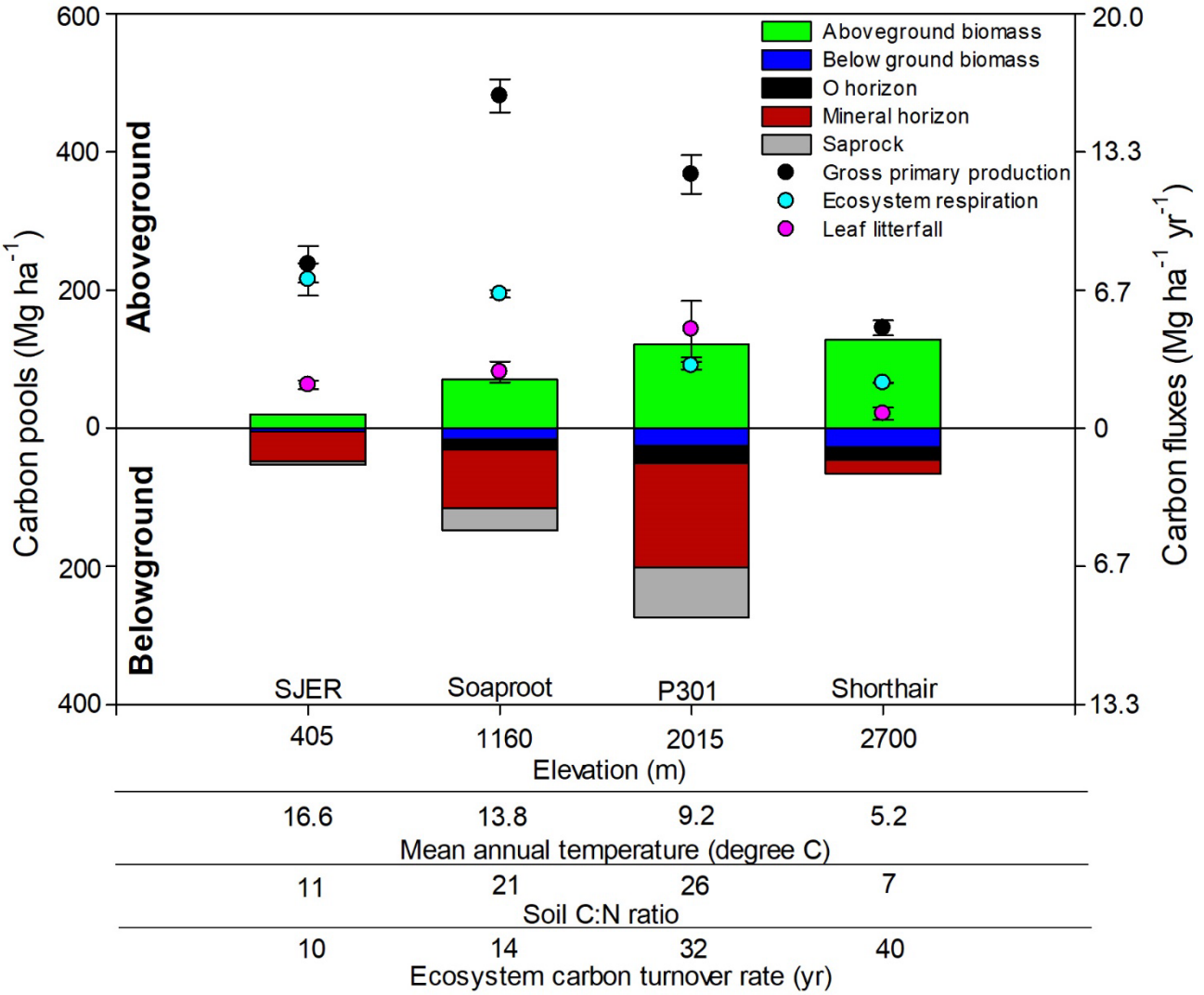


Figure 7. A synthesis of carbon fluxes and pools along an elevational gradient at Southern Sierra CZO. Yang et al., in preparation.

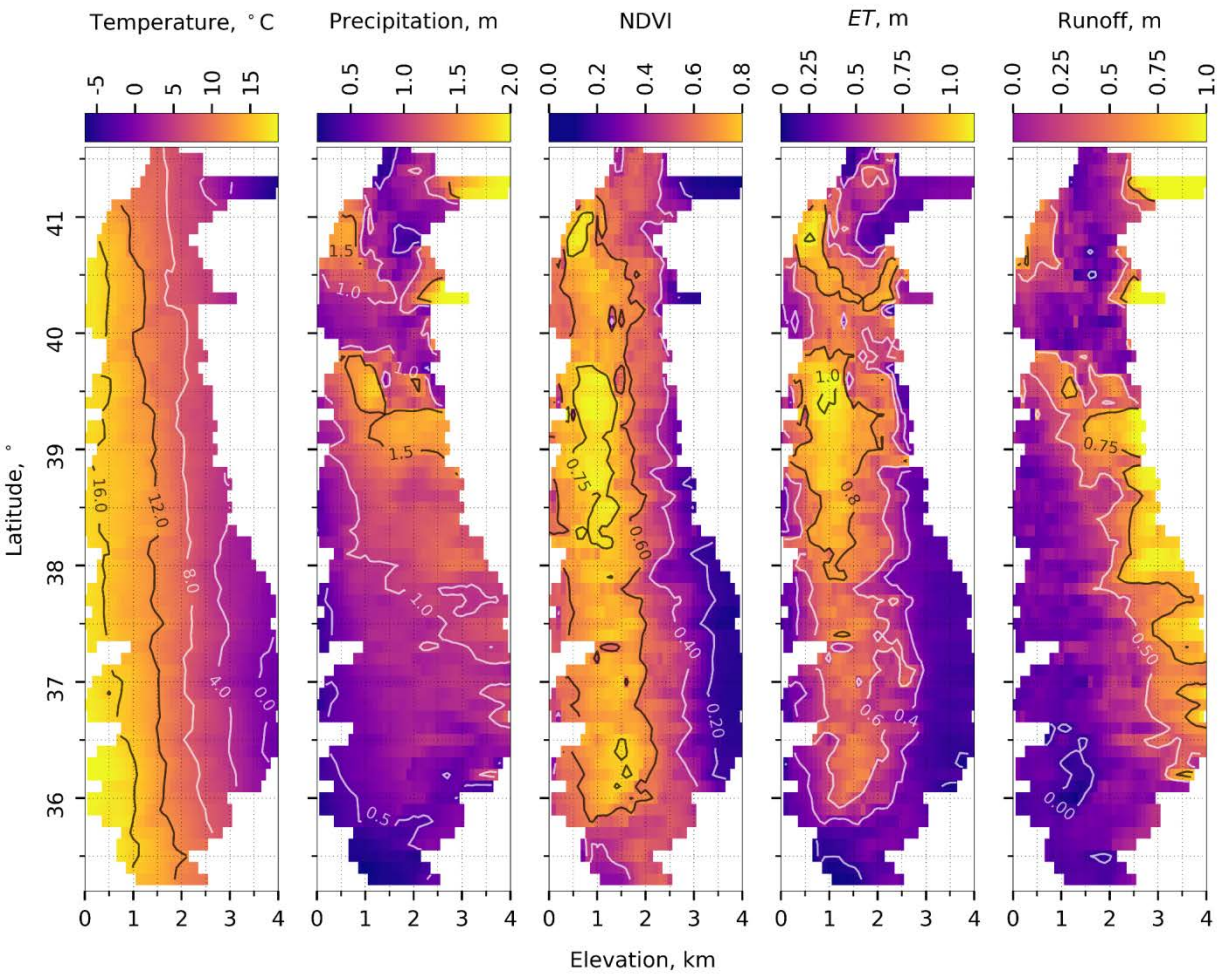


Figure 8. Variability of 800-m PRISM temperature and precipitation, MODIS NDVI, modeled evapotranspiration, and runoff calculated as the difference of precipitation and evapotranspiration (P-ET) by latitude and elevation. Different color contour lines are to improve clarity only. Rungee et al., submitted.

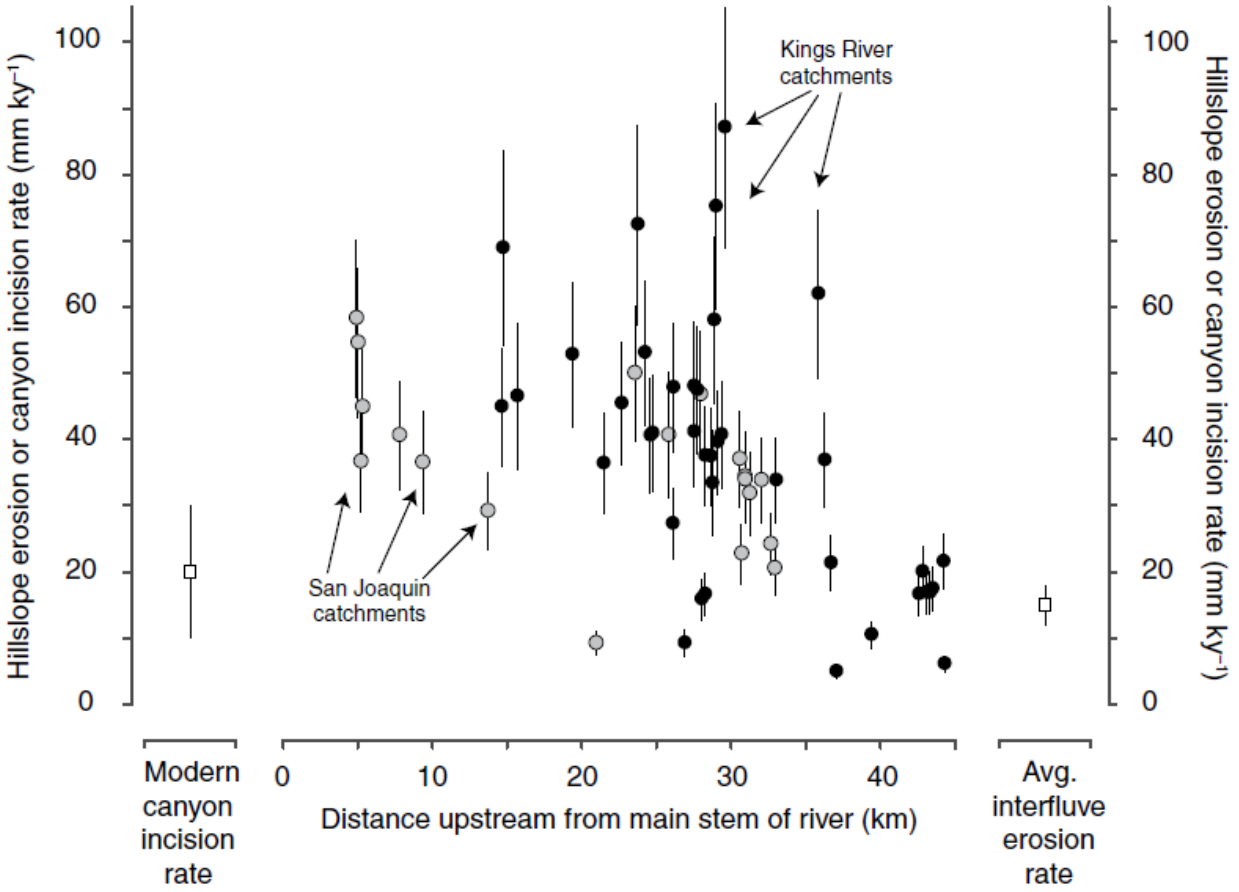


Figure 9. Rates of hillslope erosion and canyon incision from the southern Sierra Nevada. Average hillslope erosion rate of interfluve sites roughly matches modern incision rate of Kings river measured by cosmogenic nuclide burial dating in previous work. Hillslope erosion rates at intermediate flow distances are more variable than the interfluve erosion rates over time. Average interfluve erosion rate includes data from this study and other references. Callahan et al., 2019.

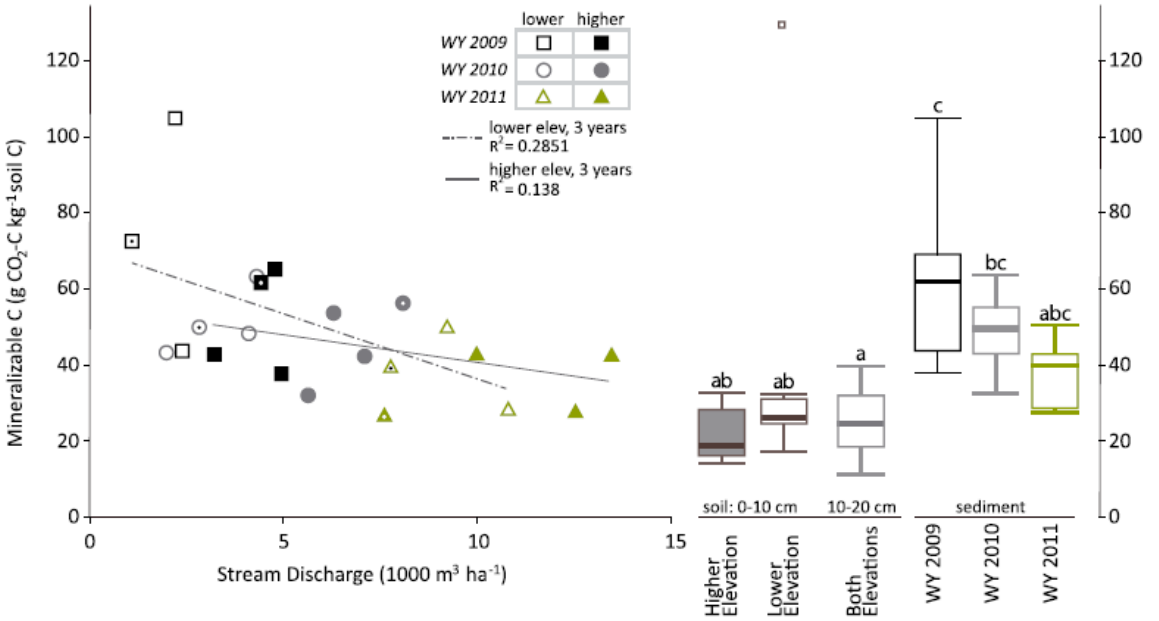


Figure 10. Mineralizable carbon in sediment declined with increasing stream discharge at both the higher- and lower-elevation catchments, reflecting greater export at higher flows. Mineralizable C is expressed as cumulative carbon dioxide carbon evolved from the sediment and soil under saturated conditions during a 43-day laboratory incubation relative to total C concentration in the sediment or soil. Box plots are means and quartiles, with one outlier (10–20 cm values and sediments combined across elevations; letters mark significantly different means). Small dots mark the upper and lower catchments that were selected for the sequential extraction in 2009 and 2010. Stacy et al., 2018.

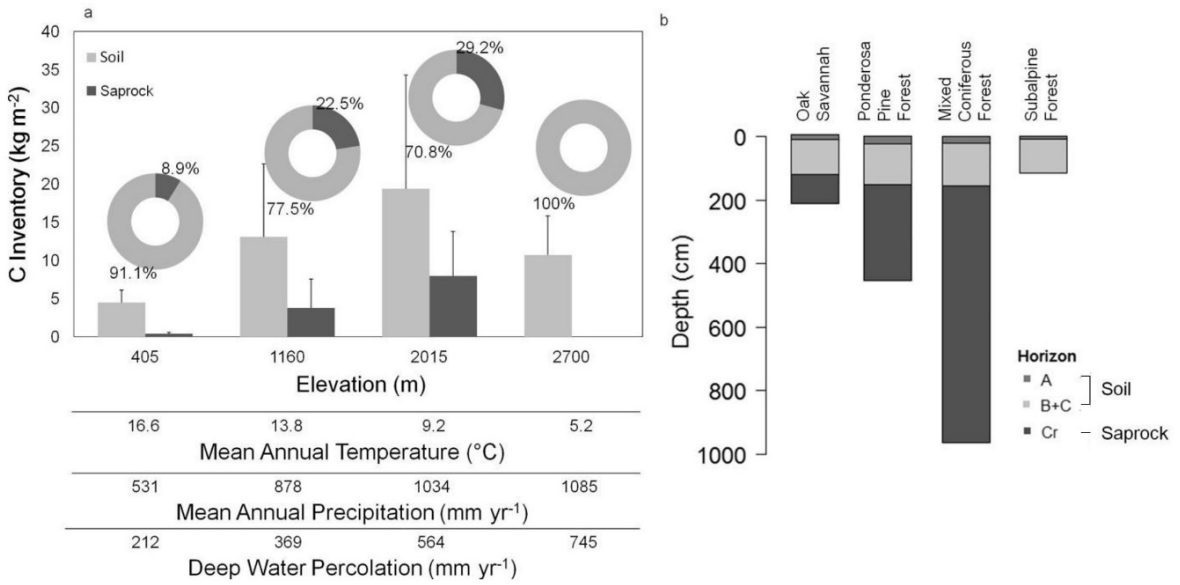


Figure 11. Allocation of organic carbon (OC) in soil and saprock across the bioclimatic gradient along the western slope of the southern Sierra Nevada. (a) Bar charts represent the OC pool (error bars represent standard deviations) in soil and saprock. Pie charts represent the proportion of OC stock among four study sites: oak savannah, ponderosa pine/oak forest, mixed-conifer forest, and subalpine forest; (b) mean thickness of soil and saprock at each study site . Tian et al., submitted.

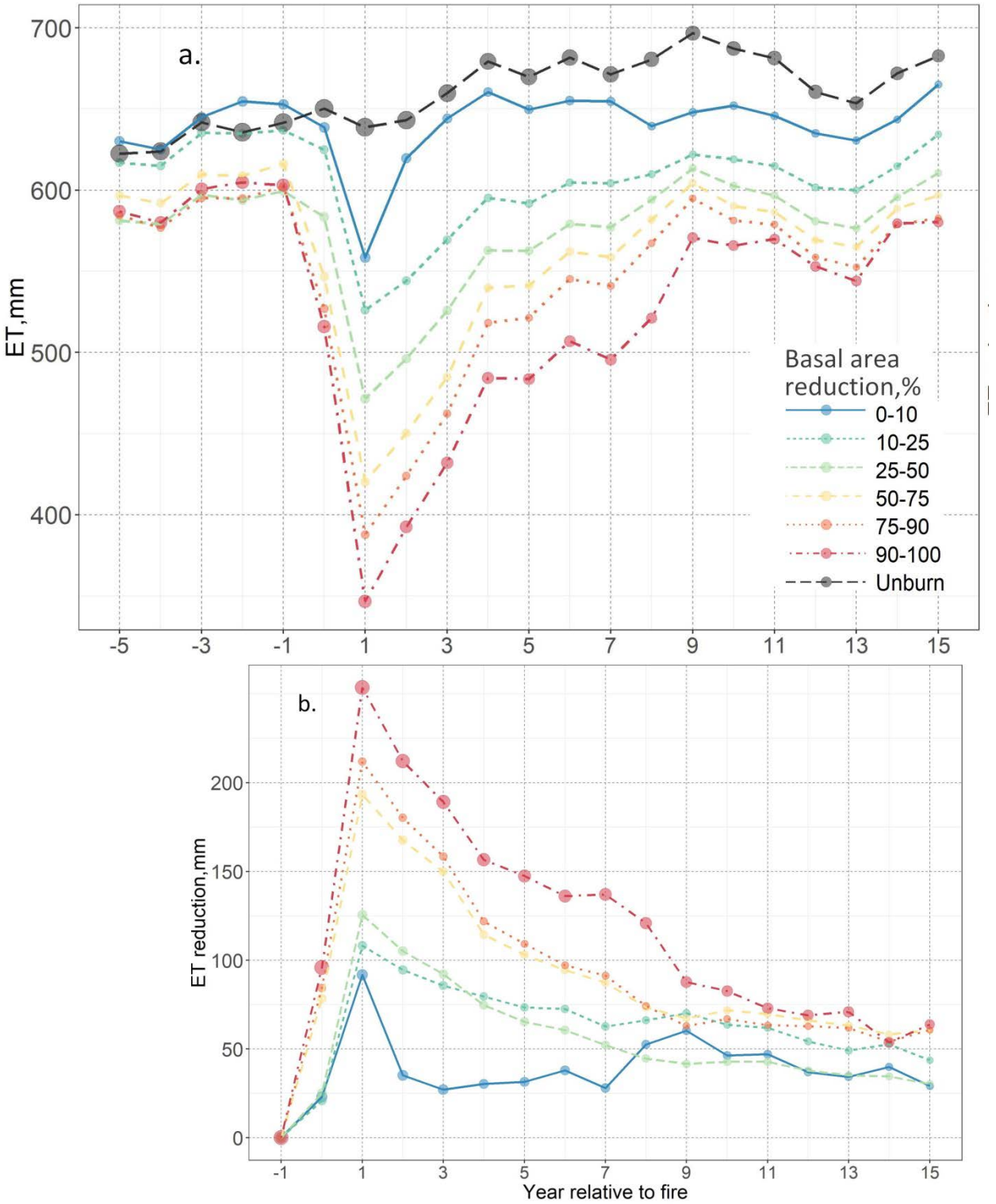


Figure 12. Top panel (a): Temporal changes of evapotranspiration values at burned and corresponding unburned areas in the sierra Nevada from up to 5 years before to 15 years after a fire. Values are averaged for all 579 fires occurred during 1985-2015 period. All the evapotranspiration values are averaged by the fire severity type and the corresponding unburned areas, respectively. The size of dots is proportional to the area included in the statistics. Lower panel (b): difference between pre- and post-fire evapotranspiration. Ma et al., in preparation.

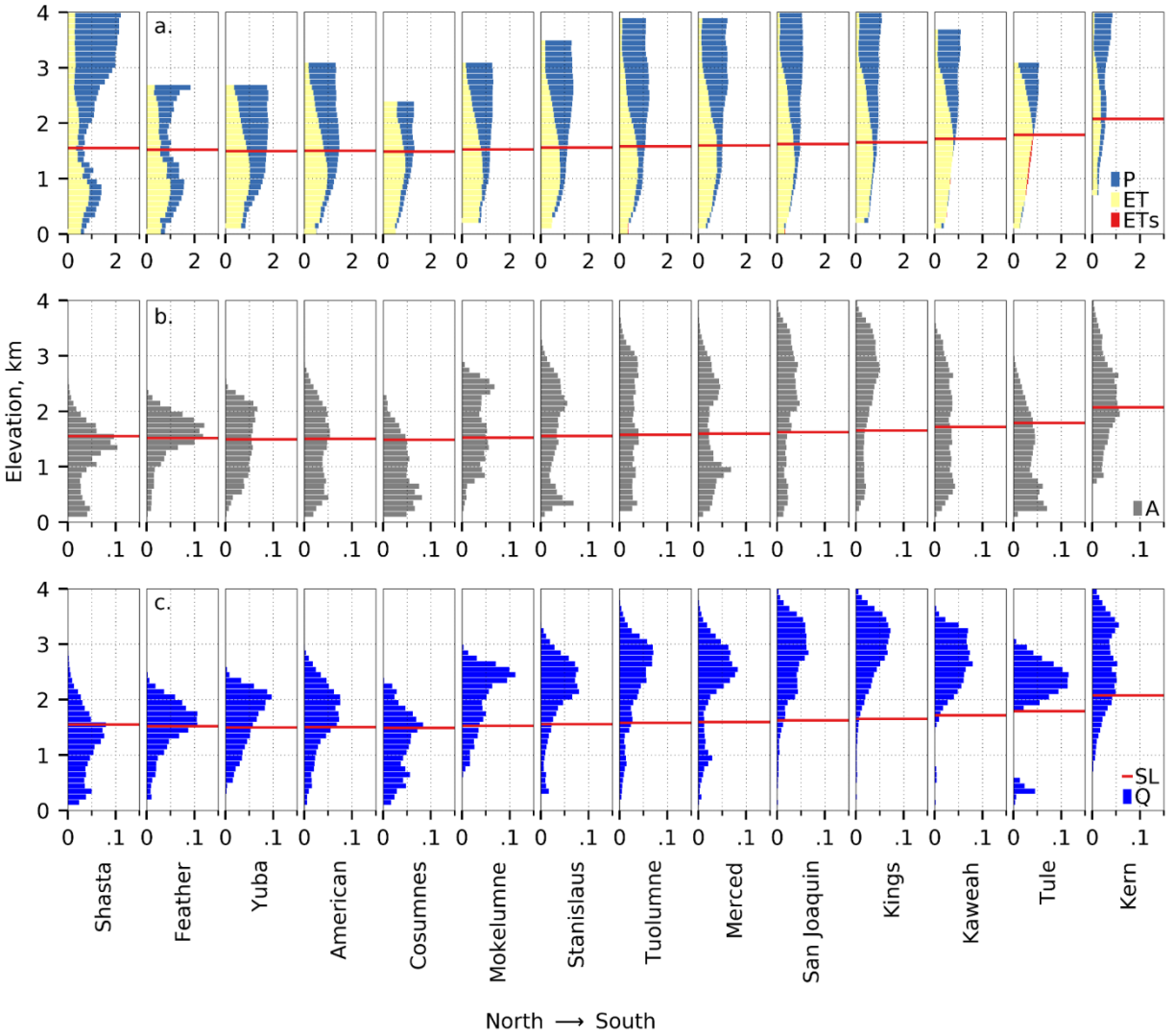


Figure 13. a) mean-annual precipitation (P), modeled evapotranspiration (ET, MOD800m_All) and evapotranspiration from storage (ETs) by basin and per 100 m in elevation measured in km; b) is a normalized histogram of area by elevation; c) is a normalized histogram of volumetric runoff by elevation. SL indicates the historical rain-snow transition. . Rungee et al., submitted.

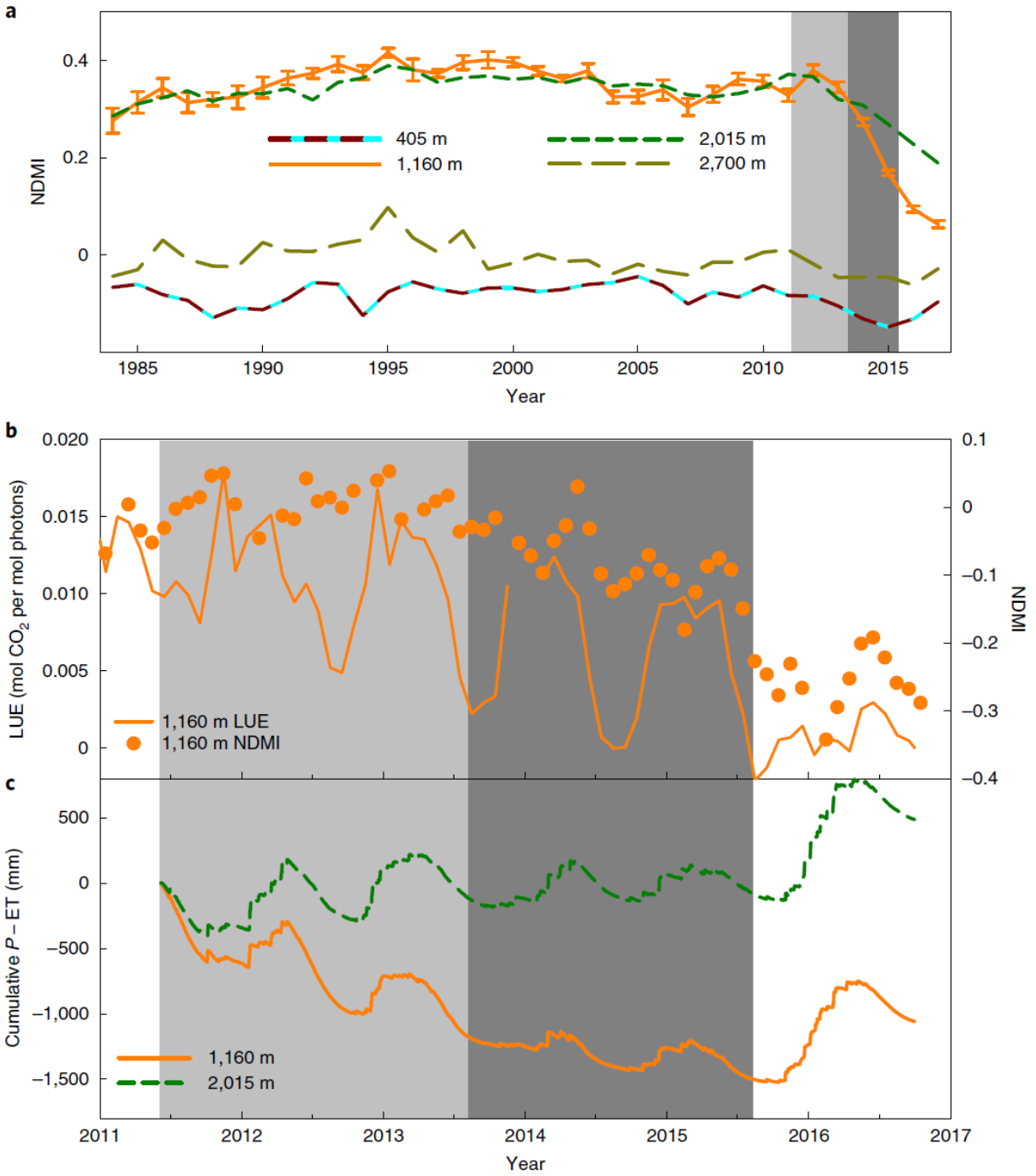


Figure 14. Sequence of events leading to forest die-off at field sites. **a**, Late dry season NDMI at focal sites. 95% CIs based on spatial variation are shown for 1,160 m. CIs at the other sites were similar. **b**, Photosynthetic whole-ecosystem LUE at 1,160 m (LUE is CO2 uptake divided by incident light; solid lines connect monthly means) and monthly seasonally detrended NDMI (filled circles). **c**, Cumulative water balance at 1,160 and 2,015 m (solid lines connect daily observations). Light grey (June 2011 to August 2013) represents the main period of moisture overdraft (the drying phase). Dark grey (August 2013 to August 2015) is the period of obvious vegetation decline (the stress phase). Major tick marks on the *x* axis for **b** and **c** represent 1 January for each year. Goulden & Bales, 2019.

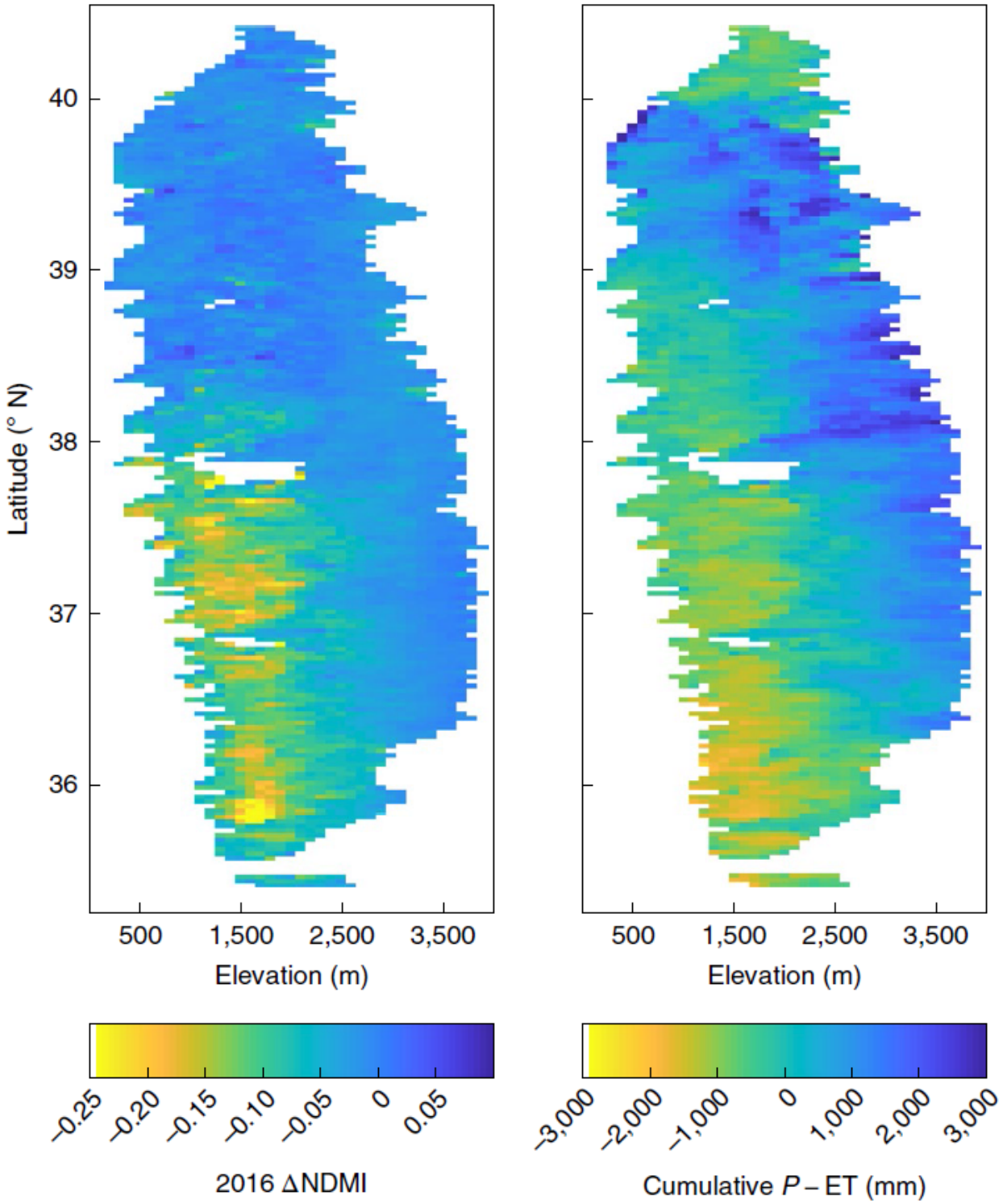


Figure 15. Spatial patterns of die-off and moisture overdraft across the Sierra Nevada. **a**, Change in late dry season NDMI over the drought (2016 NDMI minus 2009–2011) binned by latitude and elevation. **b**, Cumulative *P* − ET over 2012–2015. Negative values indicate a greater NDMI drop in **a** and greater overdraft in **b**. Canopy dieback and cumulative *P* − ET overdraft were greatest at 35.69° to 37.65° N latitude and below 2,300 m elevation.

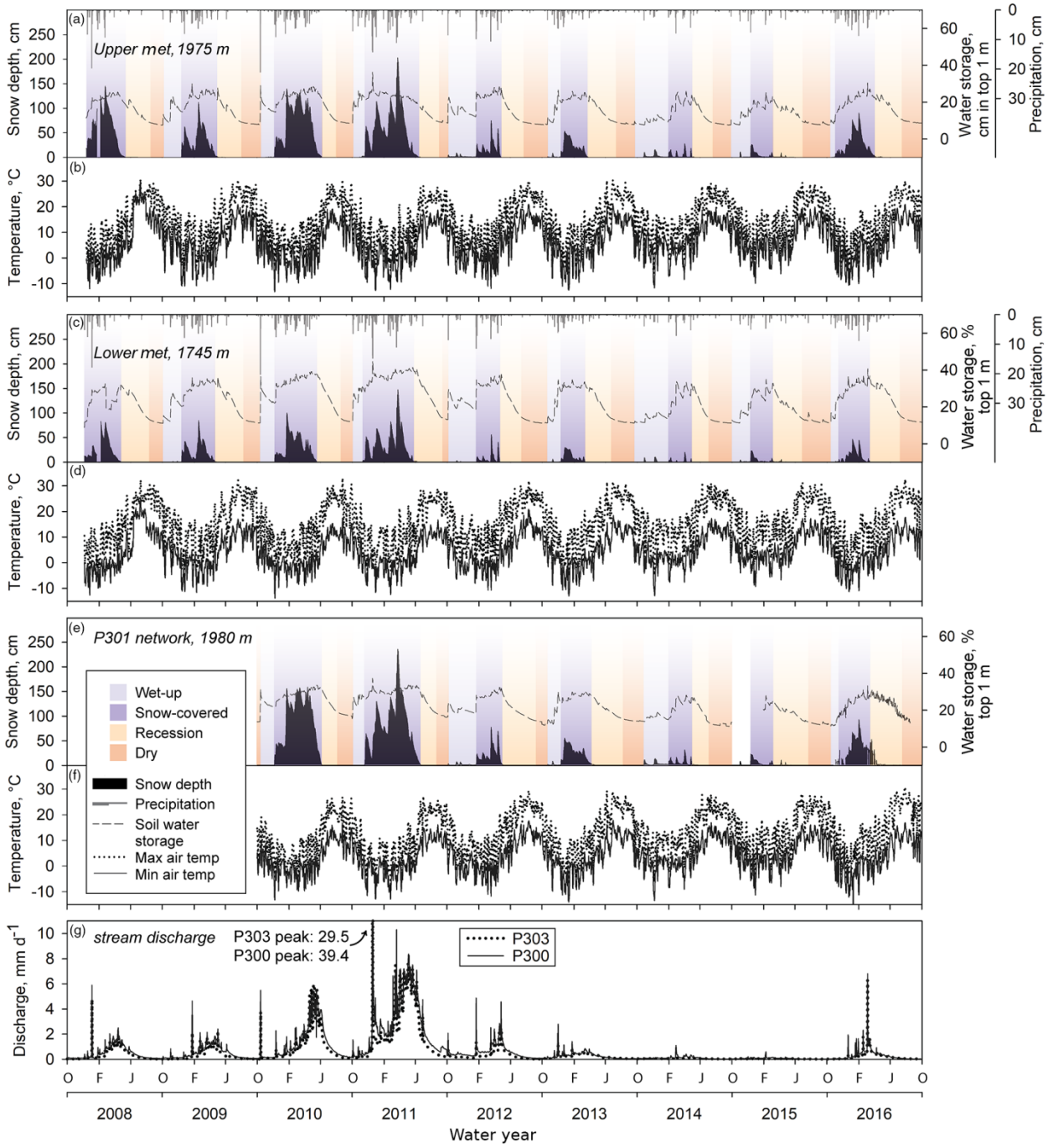


Figure 16. Partial record of (a, c, e) precipitation (black bars), soil water storage integrated over 1m depth (dashed lines), and snow depth (black shaded area), (b, d, f) maximum and minimum air temperature (dotted and solid lines) at the Upper and Lower Met stations and P301 sensor network, and (g) stream discharge at subcatchment P303 and the integrating P300 catchment. Background colors in (a, c, e) generally indicate wet-up, snow-coverage, soil-moisture recession, and dry periods. The 10 and 15 min data have been averaged to daily values shown here. Bales et al., 2018.