# MtnClim 2026 Abstracts

September 14-17 2024, Rocky Mountain Biological Lab, Gothic, CO

## **Kelly Redmond Lecture,**

Monday, September 14

### Instructive surprises in the hydrological functioning of mountain landscapes

**Jim Kirchner, ETH Zurich, Swiss Federal Research Institute WSL, University of California, Berkeley, [Keynote Speaker]**

Landscapes receive water from precipitation and then transport, store, mix, and release it, both downward to streams and upward to vegetation. How they do this shapes floods, droughts, biogeochemical cycles, contaminant transport, and the health of terrestrial and aquatic ecosystems. Because many of the key processes occur invisibly in the subsurface, our conceptualization of them has often relied heavily on physical intuition. In recent years, however, much of this intuition has been overthrown by field observations and emerging measurement methods, particularly involving isotopic tracers. I will summarize key surprises that have transformed our understanding of hydrological processes at the scale of hillslopes and drainage basins. These surprises have forced a shift in perspective from process conceptualizations that are relatively static, homogeneous, linear, and stationary to ones that are predominantly dynamic, heterogeneous, nonlinear, and nonstationary.

New methods have been developed for quantifying landscapes' nonlinear and nonstationary behavior directly from observational data. These methods reveal that some catchments exhibit much more nonstationary and/or nonlinear behavior than others do. Preliminary analyses from thousands of catchments in North America and Europe suggest that mountain landscapes are hotspots for nonlinear and nonstationary hydrological behavior. Some implications of these recent developments will be discussed.

# Snow & Ice, Part 1,

Tuesday, September 15

## Glacial versus geomorphic controls on stream temperature and conductivity in a temperate watershed

### Anna Bergstrom, Boise State University, [Invited]

Climate change is impacting mountain systems worldwide with cascading effects including shrinking glaciers, changing precipitation patterns, and altered streamflow and groundwater. Stream temperatures and chemistry are expected to change along with this but the drivers are complex. In glacier-dominated systems, previous studies have focused on the distance from glaciers as the primary control on stream temperature and chemistry. However, many other watershed attributes have a strong impact such as the interaction with groundwater, presence of lakes, topography and vegetation. Here we took a more holistic approach to determine the combination of watershed properties that most influence stream temperature and specific conductivity over a summer season. We used spatially distributed 15-min observations of stream temperature and conductivity in the Dinwoody Creek watershed in the Wind River Range in Wyoming. We coupled this with geospatial analysis and spatial stream network statistical modeling to identify the primary landscape characteristics that explain the most variability in the daily mean and range of stream temperature and conductivity over the summer. We found that while the amount of perennial ice and snow was an important predictor for all variables, it was most important early and late in the season. The lithology and terrain ruggedness, both indicators of the amount of surface water-groundwater interaction, were important predictors of stream temperature and conductivity particularly in mid-season. These findings highlight the need for a broad understanding of how the landscape mosaic influences critical water quality parameters in rapidly changing mountain ecosystems.

## Glacier Loss and Water Security in The Cordillera Huaytapallana, Peru: An integrative assessment

### Tal Shutkin, The Ohio State University

Tropical glaciers form part of social-environmental systems linking glacial processes, water use, and cultural practices. Here we elaborate on one such system in the Cordillera Huaytapallana (CH), Peru. This mountain range forms the headwaters of the Shullcas River, the major source of drinking water for the city of Huancayo. Drawing on interviews with water managers, hydrological monitoring, and glaciological modeling, we assess the social-hydrology of water scarcity in this headwater dependent system. We find that the Shullcas River provides 60% of potable water to the city of Huancayo. Supplemented by groundwater wells, this system is insufficient to provide most urban water users with a continuous supply. Material reliance on scarce water resources and

cultural affiliation with the headwater glaciers form the basis of broad perceptions of water system vulnerability. Our hydrological balance supports this perception, highlighting that the glacierized headwaters produce 50% (~500 lps) of dry-season (JJA) streamflow, despite comprising less than 30% of watershed area. These 500 lps represent the entire municipal water allocation, with the remaining 500 lps being shared between diverse stakeholders. Dry season water supply is maintained in part by scheduled releases from proglacial lakes. However, geochemical and isotopic analyses suggest that glaciers play an important role in maintaining lake levels. By assimilating ice thickness observations with the Instructed Glacier Model, we show that these glaciers currently store 10 times the amount of water as the combined capacity of all lakes in the watershed. As these glaciers rapidly decline, uncertainty persists regarding future water supply.

## Rock glacier velocity over days to millennia, Imogene basin, Colorado

### Juliana Ruef, Department of Earth Sciences, University of Colorado, Boulder Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder

Rock glaciers are among the most resilient ice stores in the Mountain West. They form in a rooting zone, where avalanching snow and rockfall from a rapidly eroding headwall supply the ingredients. They creep downslope beneath debris thick enough to shield their icy core from melt. As a result, a rock glacier grows monotonically, lengthening through time, its volume the running total of net ice delivered to the end of the rooting zone. Its motion sets how fast it lengthens and, along the centerline, records how long its ice has traveled.Imogene Rock Glacier in Colorado's San Juan Mountains we constrain that motion from days to millennia, using GNSS monuments, RTK GPS and repeat-LiDAR surveys, a 53-year mean from a resurveyed 1972 transect, and centerline Be-10 exposure ages. On a reconstructed bed we drive a 1-D, shallow-ice flowline model forced by Holocene climate, calibrated to reproduce modern geometry, velocity, and the exposure ages. Velocity holds near 50 cm/yr across modern windows of 1, 5, and 53 years, yet the Be-10 ages imply a millennial mean speed that is several-fold slower. No steady supply scenario fits both. Reconciliation requires lean intervals in the warmer, drier mid-Holocene, when the landform slowed, followed by a cool, wet Little Ice Age delivering the most recent pulse. Faster modern speeds record the response to that loading. At least 7000 years old, Imogene has only grown, storing its ice across millennia rather than losing it to melt.

## Vive la résistance: Rock glaciers are buffering alpine streams against climate change

### Scott Hotaling, Utah State University

Climate change is dramatically impacting mountain ecosystems around the world. Perhaps the most visceral of these impacts is the ongoing recession of glaciers and

perennial snowfields. However, surface glaciers and snowfields are not the only perennial ice in mountain landscapes. Many forms of subsurface ice are also present and likely play an important, albeit understudied, role in water availability and aquatic ecosystem integrity in mountain systems. Rock glaciers—large masses of debris-covered ice that flow downhill—are a common form of "alternative ice" in alpine systems. Theory predicts that surface glaciers and snowfields will recede faster than rock glacier that is insulated by debris cover. Since 2015, we have been monitoring high-alpine streams in the Teton Range, USA fed by three different sources—surface glaciers, rock glaciers, and seasonal snowpack—to understand how different sources may yield differing rates of change amidst rapid climate warming. By pairing our 10+ years of aquatic monitoring data with physical change inferred from repeat LiDAR (2014—2022), we gained rare insight into the links between physical change to ice sources and downstream ecosystems. Rock glaciers in the Teton Range have been resistant to climate-induced ice loss while surface ice features have seen dramatic, accelerating declines. Streams fed by seasonal snowpack and small perennial ice features have warmed rapidly during the summer while streams fed by surface glaciers and rock glaciers have remained largely unchanged. Together, our data provide new insight into the future dynamics of headwater ecosystems as climate change increasingly impacts them.

## Towards Statewide Snowpack Temperature Monitoring - California Cold Content Initiative

### Megan Mason, UC Berkeley Central Sierra Snow Lab, [Invited]

Snowpack runoff magnitude and timing forecasts are vital for freshwater resource management, especially during dry years. Accurate snowpack temperature measurements are critical for predicting snowmelt but remain underutilized due to technical challenges with automated measurement systems. Existing instrumentation is prone to measurement errors, frequent maintenance, and structural failure under heavy snow loads. Vertical temperature arrays can create preferential flow channels during snowmelt, introducing air gaps that compromise measurements. Consequently, hydrologic snow models lack the observations needed to assimilate, validate, and resolve the internal snowpack energy balance during the ablation season.address these challenges, the UC Berkeley Central Sierra Snow Laboratory (CSSL) tested new low-profile resistance temperature detector (RTD) sensors as part of the California Cold Content Initiative (3CI), in collaboration with the California Department of Water Resources (DWR), with the goal to integrate vertical snowpack temperature profiling into DWR's operational station network. This work complements the Natural Resources Conservation Service's (NRCS's) emerging network of Beadedstream Digital Temperature Cable (DTC) installations. With both the prototype RTD array and the DTC deployed at CSSL, we evaluate their performance over one water year under identical snowpack conditions.observations from both sensor systems are compared with point scale simulations from the Structure for Unifying Multiple Modeling Alternatives (SUMMA) and iSnobal to evaluate modeled cold content metrics, including bulk snow temperature and vertical temperature gradients. Our results demonstrate progress toward a robust, scalable approach for snowpack temperature monitoring, providing new

observational datasets to improve snowmelt forecasting and hydrologic model development across California.

## Lakes Don't Hibernate: dynamic conditions under ice in mountain lakes

### Katie Gannon, University of Colorado Boulder

Winters are changing rapidly with warming temperatures, declining ice duration and dwindling snowpack. Ice duration in high-elevation lakes is diminishing 50% faster than northern hemisphere lakes overall. In lakes, the ice covered period can shape nutrient concentrations, phytoplankton communities, dissolved oxygen availability, and thermal structure. However, the rarity of multi-year, year round datasets makes it difficult to determine how these processes will be impacted by changing winter conditions. Mountain lakes in particular have a paucity of winter data due to challenging access and difficult working conditions. To address these challenges, we use high-frequency sensors under ice to investigate thermal stratification and dissolved oxygen concentrations in three lakes in the southern Rocky Mountains across seven years. Specifically we ask: (1) how does under ice dissolved oxygen phenology differ across lakes? (2) what drives variability within year and between years? In contrast to similar studies in the Sierra Nevada, CA, we find evidence of high productivity under ice as indicated by supersaturation of dissolved oxygen in both surface and bottom waters. We also found a high degree of inter- and intra-annual variability in oxygen dynamics with distinct periods of increase and decrease in the concentration of dissolved oxygen in the deep bottom water. These patterns can be explained by variability in light availability due to snow accumulation, redistribution, and seasonal patterns of solar angle. Our study bolsters current knowledge of under ice dynamics and will inform predictions about how mountain lakes will respond to future changes in winter conditions.

## Meltwater Source Controls Stream Biogeochemistry in the Western United States

### Anna Shampain, Utah State Univeristy

Climate change is accelerating the decline of mountain ice worldwide. Over the past decades, North American glaciers have lost substantial mass, along with more variable precipitation and decreasing seasonal snowpack. Rock glaciers, which are mixtures of rock and ice insulated by debris, are expected to persist even as surface glaciers continue to recede. Rock glaciers far outnumber surface glaciers in the Intermountain West and may account for a large volume of freshwater storage. research aims to capture rock glaciers' influence on mountain headwaters and to compare observations from rock-glacier-fed streams with those from seasonal snow-fed and surface-glacier-fed streams. In the summers of 2024 and 2025, we sampled 18 streams across the Intermountain West of the

United States in the early, mid and late melt season. We recorded a suite of physicochemical parameters at each site and collected water samples for the analysis of key nutrients (nitrogen, phosphorus, carbon), trace elements, and major ions. Our results demonstrate that rock glaciers deliver consistent volumes of cold, nutrient-rich water and supply ecologically meaningful concentrations of nitrogen and phosphorus across the meltwater season. Surface glaciers supply larger volumes of cold, oxygen-rich water and the highest phosphorus concentrations. Snow-fed streams, in contrast, experience significant warming, reduced flow, and lower oxygen levels, with minimal nutrient contribution, especially late in summer.results demonstrate key differences in stream physical and chemical properties across locations, driven by meltwater source. These findings can inform future water management conservation efforts under the current and future instability of the cryosphere.

## Trojan-Horse Snowfall: Dust Wet Deposition and its Impacts on Snow Albedo in the Upper Colorado River Basin

### Daniel Feldman, Lawrence Berkeley National Laboratory

While ~70% of its annual streamflow is from snowmelt in the Upper Colorado River Basin, the timing and rate of snowmelt depends on snow albedo, which is impacted by the deposition of impurities. The deposition type, whether from atmospheric turbulence (dry deposition) or hydrometeor scavenging (wet deposition), drive these radiative effects. Unfortunately, wet deposition is challenging to observe and even causes an increase in albedo initially until melt takes over, and thus, like a Trojan Horse, appears to be a gift to the snowpack, but ultimately impacts the snowpack negatively. We use multiple datastreams from the U.S. Department of Energy's Surface Atmosphere Integrated Laboratory (SAIL) field measurements taken in 2022 and 2023 near Crested Butte, Colorado to show that snow melts out about one week earlier due to wet deposition. We then use SAIL data to evaluate the Modern-Era Retrospective analysis for Research and Applications (MERRA-2) reanalysis dataset from 1980-2023 to evaluate its accuracy using and SAIL and Moderate Resolution Imaging Spectrometer (MODIS) Dust Radiative Forcing in Snow (MODDRFS) data is used. We find that wet dust deposition comprises 73.8% of total dust deposition in the UCRB, with the SAIL area experiencing 16% higher wet dust deposition monthly totals (69.33 mg m-2) than the entire UCRB average (59.79 mg m-2). SAIL data contextualize the long-term records of dust deposition by validating records over the entire Basin and these results highlight that aerosol-precipitation interactions are a source of predictability on seasonal time-scales for timing and amount of U.S. water for energy.

# Hydrology, Part 1,

Tuesday, September 15

## Reframing snow drought risk using impact-based thresholds

### Sydney Carr, University of Colorado Boulder, [Invited]

Snowpack decline is commonly characterized by changes in mean conditions, yet the most consequential impacts often occur during individual years that cross critical hydrologic thresholds. We first apply a Time of Emergence (ToE) framework to a four-member dynamically downscaled CESM2 Large Ensemble (WRF-CESM2-LE), finding that basin-scale declines in Upper Colorado River Basin (UCRB) peak snow water equivalent (SWE) emerge from historical variability by approximately 2070. However, engagement with 38 UCRB stakeholders revealed limited confidence in a single emergence metric and instead identified extreme low-snow years, particularly 2002, as consequential due to water rights curtailments, ecological impacts, and operational disruptions.response, we reframe emergence as the changing recurrence of impact-based threshold exceedances, quantifying how the frequency of consequential snow drought conditions evolves under anthropogenic warming. Using a 100-member reconstruction of basin-scale SWE derived from the downscaled WRF-CESM2-LE, we show that return periods estimated from short observational records are highly sensitive to internal climate variability and tend to overestimate the rarity of extreme low-snow events. Reassessment of the unprecedented 2026 snow drought suggests that comparable events are more common than implied by the historical record alone. Under continued warming, the frequency of 2026-like snow droughts increases rapidly, transitioning from a historical 1-in-46-year event to a 1-in-8-year event by late century.indicate that consequential threshold-crossing snow droughts emerge more rapidly than changes in mean snowpack conditions. This co-produced approach improves the interpretability and decision relevance of snowpack projections, supporting long-term infrastructure planning and climate-resilient water management in snow-dependent basins.

## How to Hindcast Snowpack, Snowmelt, and Phenology by Using Stream Gage Data to Reconstruct Historical Snowpack and Snowmelt Dates

### David Inouye, RMBL

Phenology is one of the best ways to observe effects of climate change on plant or animal life cycles, but there are few long-term records of this important ecological component of life histories. Some proxies have been described, such as using herbarium collections to reconstruct flowering dates, or agricultural harvest records to gain insights into historical temperatures. Another possibility for reconstructing information about historic snowpack and snowmelt data, which can have important effects on high-altitude

and high-latitude ecosystems, is to use data from stream gages with good hydrograph data such as dates and volumes of peak discharge. We describe an example of this by linking observed (1975-2026) snowpack and snowmelt from near the Rocky Mountain Biological Laboratory to data (1935 – 2026) from a stream gage on the East River at Almont, Colorado, 35 km away and 479m lower. This allows us to estimate the dates of snowmelt and total snowfall for the pre-observation period 1935-1974, and thus, dates of first flowering for 120 wildflower species for which we have long-term phenological data, and flower abundance for some of these species. This technique adds to the toolkit ecologists can use to estimate important environmental and ecological parameters from pre-observation periods.

## Assessing the effects of windspeed and precipitation forcing uncertainty on lateral snow redistribution in mountainous basins

### Rachel Corrigan, Colorado School of Mines

Hydrologic model uncertainty in snowmelt-dominated watersheds is largely driven by meteorological forcing uncertainty. However, the impact of meteorological forcing uncertainty on redistribution-permitting snow models remains underexplored. We ask how wind speed and precipitation uncertainty affects modeled snow in a redistribution-permitting model in the Sierra Nevada, California, and the Rocky Mountains, Colorado. We use the Canadian Hydrologic Model (CHM) with ERA5-Land and HRRR forcing to simulate snowpack development, blowing snow, and avalanching in two basins with extensive lidar records from the Airborne Snow Observatory (ASO), in situ snow pillows, and snow courses. runs with uncorrected forcing overestimate SWE at high-elevations, underestimate SWE at mid- to low-elevations, and show earlier peak SWE and snow disappearance date than in situ observation and ASO lidar acquisitions. Uncorrected ERA5-Land wind speeds are frequently too low to initiate blowing snow transport. Correcting wind speeds by a factor of four reduces modeled SWE error with respect to ASO by 48% from 3,500-4,000m, and by 79% above 4,000m along North and East slopes in the Blue River Basin, Colorado. The elevation-dependent error agrees with prior studies reporting underestimated SWE at SNOTEL stations and suggests that station locations alone may not capture model performance across mountainous domains. Our results suggest that high-elevation SWE overestimation may be caused by underrepresented lateral redistribution, emphasizing the need to evaluate meteorological forcing before using redistribution-permitting models in high-elevation terrain.

## Improving Precipitation Phase Classification in Mountain Hydrology: A Machine Learning Framework Using Citizen Science and Gridded Meteorological Data

### Emma Golub, Lynker Technologies

Precipitation phase partitioning remains a leading source of uncertainty in mountain hydrology, with rain–snow misclassification adversely affecting forecasting and water resources management. Conventional approaches relying on sparse station networks and near-surface thermodynamic thresholds provide limited predictive skill in determining precipitation phase, especially near freezing (0 to 4ºC). We therefore investigate whether citizen science and gridded data can improve phase estimates. We present a framework that assimilates citizen science observations from the Mountain Rain or Snow (MRoS) network with station meteorological data, satellite-derived probability of liquid precipitation (PLP), and terrain information, and then interpolates them to standardized hourly 1-km gridded surfaces. We trained a binary XGBoost classifier to predict precipitation phase from these gridded inputs, with precipitation phase labels obtained from held-out MRoS observations. We applied these methods across California's Sierra Nevada (CA) and Colorado's Rocky Mountains (CO) from October 2022 to May 2026. Because snow and rain temperature ranges overlap substantially, mixed precipitation was not trained as a third class. Instead, a "mix" uncertainty flag was derived to gauge whether model uncertainty overlaps with observer-reported mix events near freezing. The binary model achieved test AUROCs of 0.965 (CA) and 0.962 (CO), and macro F1 scores of 0.905 (CA) and 0.860 (CO). Removing MRoS inputs reduced performance in both regions (ΔF1: CA = −6%; CO = −2%), while using thermodynamic predictors alone further degraded results (ΔF1: CA = −9%; CO = −6%). Our results suggest that integrating crowdsourced observation, station, and PLP data improves rain–snow predictive skill.

# Fire, Snow, and Hydrology, Part 1,

Tuesday, September 15

## Drought and wildfires threaten snowpack-derived water resources

### Arielle Koshkin, INSTAAR; CU Boulder, [Early Career Award]

Climate change is altering water resource systems by shifting the timing, location, and type of precipitation and increasing extreme events. Historically, in snow-dominated watersheds, snowpacks have offered more storage capacity than built reservoirs, without the financial costs of construction or the ecological tradeoffs associated with dams.

However, warmer winters have reduced snow accumulation, decreased interannual variability, and shifted precipitation from snow to rain, increasing disturbances such as higher elevation wildfires and widespread snow droughts. Using spatially explicit snow water equivalent (SWE), snow disappearance date (SDD), and snow depth, we assess how an increase in climate extremes – wildfire and snow drought– is altering snowmelt patterns and affecting snow-derived water resources. As the overlap between burned forests and the seasonal snow zone increases, wildfires can disrupt snow accumulation and melt patterns, altering the amount of water stored in the snowpack throughout the winter. These altered patterns can vary by region, elevation, and seasonality, complicating snowmelt responses to wildfire impacts. Additionally, warmer winters like 2026 are creating more widespread drought, creating compounding strains on snowpacks. The winter of 2026 was a unique case study in understanding how warmer winter temperatures accelerate snow loss midwinter, contributing to a large snow drought beyond accumulation deficits alone. Together, these changes disrupt water supply forecasts from snow-dependent water systems, making it harder to manage an already shrinking resource.

## Assessing post-wildfire snowpack extent and canopy structure in Southwestern forests using machine learning and high-resolution visible wavelength imagery

### Ryan Crumley, Los Alamos National Laboratory

Declining snowpacks in American Southwest mountain ecosystems are altering regional hydrology, driven by climate change, increased aridity, and increased wildfire occurrence and severity. Recently, multiple studies relying on in-situ snow observations have found snow disappearance dates retreating and annual snowpack amounts decreasing in some post-wildfire locations, but findings remain limited to sparse monitoring networks. To address the need for higher-resolution snow mapping in fire-affected forests, we apply multiple machine learning (ML) methods for image classification to predict snow presence/absence from high resolution (3-5m) visible wavelength imagery (Planetscope, Worldview) at three high elevation sites in New Mexico. Our methods include Random Forest, Gradient Boosted Trees, k-means unsupervised clustering, and a pre-trained transformer model, all relying exclusively on indices derived from RGB and NIR spectral bands as predictors. To complement the imagery analysis, we collected LiDAR at each site to quantify the post-fire forest structure, enabling us to relate these changes in canopy density and gap size to snow cover patterns. We validated our results using expert image classification, low resolution (20m to 500m) snow cover products, and Snowpack Telemetry Network (SNOTEL) time series data. This approach advances snow monitoring capabilities by 1) achieving finer resolution than SWIR-derived snow products that use the Normalized Difference Snow Index (NDSI) from satellite platforms like MODIS, Landsat, or Sentinel-2, and 2) explicitly linking forest structural changes to snow persistence patterns in fire-affected mountain watersheds. These methods show promise for sunny regions where visible imagery can effectively capture snow cover dynamics throughout winter.

## Effects of wildfire-driven changes in canopy structure on snowpack accumulation and retention in the Sierra Nevada

### Kylie Mosher, University of Montana

Snowpack acts as a critical natural reservoir that supports ecosystems, agriculture, and regional water supply. However, increasing wildfires are transforming forest structure, which in turn alters how snow accumulates and melts across the landscape. This research investigates how post-fire changes to forest canopy structure influence snow water equivalent (SWE) and snow disappearance date (SDD), which are key indicators of mountain water storage and runoff timing. Specifically, we ask: (1) How does canopy structure affect snow accumulation and retention following wildfire? (2) Is forest structure a better predictor of snow accumulation and retention than fire severity or burn classification? (3) How do the effects of forest structure on snowpack accumulation and retention vary across burn severity, environmental gradients, and latitude? We use high-resolution (50 m) modeled SWE products from the Airborne Snow Observatory (ASO) and derive SDD from MODIS satellite imagery, with both datasets providing observations across burned and unburned areas from four wildfires in the Sierra Nevada. Airborne lidar-derived metrics of canopy and forest-gap structure serve as predictors alongside burn status, burn severity, and topographic indices in generalized additive models. By comparing models based on forest structure with those based on burn severity and classification, we evaluate the relative importance of these factors in explaining variation in snow accumulation and retention. This research demonstrates how landscape-scale SWE observations from ASO, combined with lidar-derived forest metrics, can improve our understanding of snowpack dynamics following wildfire and support hydrologic modeling under changing disturbance regimes.

# **Posters,**

Tuesday, September 15

## Characterizing sources of uncertainty in managing Sierra Nevada mixed conifer forests for climate resilience

### Jessica Katz, University of California Berkeley

To restore the resilience of dry Western conifer forests to wildfire, drought, and other climate-related disturbances, the scientific and policy communities have called for widespread application of prescribed fire and thinning. Understanding where, when, and how to scale up these treatments across heterogeneous montane ecosystems remains

challenging, in part due to uncertainties about how forests will respond to treatment in a changing climate. Field and modeling studies in Sierra Nevada mixed-conifer (SNMC) ecosystems suggest that the effectiveness of treatments in meeting their management objectives can vary widely—and in some cases deviate from expected and/or desired outcomes—depending on treatment type, climate, and biophysical factors. These interactions are poorly characterized, confronting resource managers with many plausible futures as they plan for widespread treatment of Western forests. In this poster, we will present the experimental design and early results of a modeling experiment designed to identify vulnerabilities and inform forest management strategies that are robust to climate uncertainty. Specifically, we use a next-generation vegetation demographic model with newly-developed mechanistic representation of prescribed fire and thinning to simulate 1,600 climate and management scenarios across the geographically and climatically diverse SNMC region. We address the following questions: First, what are the ranges and distributions of drought-induced tree mortality and carbon stocks over plausible future scenarios? Second, how sensitive are these outcomes to different combinations of initial stand conditions, future climate, and treatment strategy (e.g., prescribed burning versus mechanical thinning)? And third, which combinations of conditions lead to extreme positive or negative outcomes?

## Spatially Variable Precipitation and Hillslope-Riparian-Stream Connectivity At the Rain-Snow Transition

### Kyle Formigli, Boise State University

Hydrologic connection between hillslopes and streams, or the existence of a measurable water table that spans a hillslope, adjacent riparian area and stream, is assumed to be a function of the hillslope contributing area. However, the duration of hillslope hydrologic connection can vary across larger spatial extents or areas that span the rain to snow transition. Despite this, hydrologic connectivity is rarely studied across precipitation phase gradients. In this study, we measure hillslope-riparian-stream connectivity in rain dominated, mixed rain and snow, and snow dominated areas of the Dry Creek Experimental Watershed located in Southwestern Idaho. We installed well transects (1 to 4 m deep into competent bedrock) to measure water table elevation across hillslope-riparian-stream margins in north and south facing hillslopes for each dominant precipitation phase. Additionally, mass recovery experiments are performed to determine the gross gains and losses of the stream in each study reach. Initial results indicate hillslopes in snow dominated areas maintain connectivity for longer durations of time compared to rain dominated areas. However, stream gaining and losing characteristics exist independent of hillslope-riparian-stream connectivity. Continued data collection will provide insight into when sites re-establish connectivity as the watershed regains streamflow in the fall. This research is important to develop our understanding of how spatial variability of hydrologic processes controls runoff generation. Results will inform modelling and improve our ability to predict streamflow response across the rain to snow transition, which is expanding in a warming climate.

## Climate Induced Natural Disasters: Assessment of Socio-economic Impacts of 2022 Flash Flood sin Sherqilla and Bubur Village ,District Ghizer ,Pakistan

### Adnan Ullah, Karakoram International University Gilgit

Flash floods have become an increasing menace to mountainous communities, particularly in the Hindu-Kush–Himalayan region, where climate change has intensified extreme precipitation and glacial melt. This paper examines the 2022 flash flood event in Punial valley, District Ghizer, northern Pakistan, within the broader context of climate-induced disasters in alpine environments.The primary objective is to evaluate the underlying causes, Impacts, dynamics, socio-economic consequences of 2022 flash floods on local livelihoods and infrastructure. A mix-method approached was employed, combining quantitative data from a structured household survey (n=212) with qualitative insights from focus group discussions & key informant interviews. Results indicate that the principal drivers of 2022 were unprecedented monsoon rainfall, accelerated snow and glacial melt due to elevated temperatures, and the regions complex topography. These factors collectively caused extensive destruction of housing, roads, bridges, irrigation systems, and agriculture land severely disrupting livelihoods and exacerbating pre-existing vulnerabilities among marginalized groups, including landless farmers and women-headed households. The study further evaluates local and institutional response capacities, identifying critical gaps in early warning systems, evacuation planning and post-disaster shelter provision. Findings underscore an urgent need for community-based disaster risk reduction, improved early warning mechanisms, climate resilient infrastructure, and sustainable land-use planning to enhance adaptive capacity in Gilgit-Baltistan.The paper also integrates lessons from the 2022 & 2025 flood events, offering actionable recommendation aligned with Pakistan National Adaptation Plan.This research contributes to the growing literature on flash flood vulnerability and resilience in high-altitude regions and provides evidence- based guidance for policy makers and disaster management practitioners.

## A technical synthesis of snow models and relevant applications for climate adaptation science in the Western US

### Andrew Maguire, USGS National CASC

Across the Western conterminous United States (Western CONUS), snow dynamics are variable, complex, and projected to change spatially, temporally, and across multiple attributes. Models outputting snow variables can facilitate analysis of historical, contemporary, and future conditions; however, the breadth, specificity, and relevance of snow models impose challenges for addressing data needs of natural resource managers and even the research community. To facilitate rigorous climate adaptation science, researchers and managers must select application-relevant variables at appropriate spatiotemporal scales and comprehend the structural assumptions and uncertainty of

models generating snow data products. Aimed at supporting these technical needs, we developed a science synthesis, highlighting the features, constraints, caveats, and accessibility of existing snow models and data products. Our synthesis addresses the range of structures and scopes underpinning snow models, including compilations of physical numerical models, correlational empirical models, and fully-coupled earth system models. We also present a synthesis of existing literature to demonstrate to practitioners how they may leverage available snow data products to address select ecological applications. Finally, we conducted a simple intercomparison to evaluate and contextualize spatial variability in performance of select snow models across topographic and ecological gradients of Western CONUS to illustrate usability. Our study aims to highlight core strengths and outstanding gaps in how existing snow models could be leveraged for climate adaptation science. This study is of particular importance for montane regions, which hold a disproportionate share of the regional snowpack across the Western CONUS and are heavily impacted by snow dynamics.

## From Consultation to Co-Designers: Youth-Led Socio-Ecological Restoration in Andean Mountain Communities

### María Moya, UCACUE- GIZ

Mountain social-ecological systems face compounding pressure worldwide — not only from climate variability, but from land use change, resource extraction, and the slow erosion of community ties to territory. In the tropical Andes, this pressure has a youth dimension rarely centered in mountain research: as land use change accelerates, young people are migrating from highland communities or are positioned as passive recipients of conservation programs rather than as agents within them.abstract draws on field-based work in Ecuador's Andean highlands to examine youth-led place-making as a restoration strategy. Through a GIZ–SWISSAID agroecology program in Baños, 75 Indigenous participants across three escuelas campesinas engaged in water monitoring and ecosystem restoration training knowledge moving in both directions between technical and Indigenous systems. In parallel, a cchackra and youth-led nature walks functioned as small-scale "biocultural refugia," sites where ecological and territorial knowledge are jointly preserved and transmitted, adapting a framework developed for Transylvanian mountain communities (Hanspach et al. 2014) and (Flores et al 2025) to the Andean urban-rural interface.abstract argues that mountain communities facing rapid land use change — whether from extractive pressure in the Andes or fire and development pressure in the Rockies — share a structural question: whether young people are treated as stakeholders to consult or as co-designers of the systems they will inherit. Drawing on participatory action research methods developed across these programs, I offer transferable lessons on building youth-inclusive, community-academic partnerships for mountain conservation, and invite comparative dialogue with North American mountain communities facing parallel generational and land use transitions.

## A hairy situation: how do shifting selective pressures along an elevational gradient shape trichome trait variation in a mountain monkeyflower?

### Ariella Thompson, University of Wisconsin-Madison

Mountains provide excellent systems to explore questions surrounding divergent selection upon populations. The elevational gradients that they create are complex environmental gradients, correlated with decreasing temperature and increasing solar radiation. With elevational gain, selection from magnified abiotic stress and reduced biotic stress influence plant populations to adapt through strengthened defensive strategies. Trichomes, epidermal outgrowths that create layers of woolly "hairs" on plant vegetative organs, serve as one important defense mechanism. Glandular trichomes synthesize and store specialized metabolites that aid in environmental stress adaptation. Over elevational changes, dominant stressors could select for alternative growth-defense strategies, with a shift in trichome density and metabolite investment. This would result in intraspecific trichome variation. Mimulus tilingii, a mountain monkeyflower in the model genus, Mimulus, possesses glandular trichomes and inhabits a broad elevational range within montane, subalpine, and alpine life zones across the mountain. Given its altitudinal range, M. tilingii populations likely endure spatial variation in selective pressures from abiotic and biotic factors, making it an exceptional model species for determining if trichome traits can be mapped onto elevational clines. Under climate change, alpine and subalpine ecosystems are experiencing higher rates of environmental change, compared to lower elevations. Understanding the adaptive role of glandular trichomes over an elevational gradient will enhance the accuracy in predicting how mountain plants will adapt to altering selective pressures under climate change.

## Shifting Mycorrhizal Communities Across Aspen Stands: Dual Symbioses and Environmental Gradients

### Karrin Tennant, Stanford University

Plant-associated microbial communities play a crucial role in enhancing plant resilience to environmental stressors, including drought. However, the extent to which plant-microbe co-adaptation and microbial adaptation to local conditions contribute to patterns of soil community composition remains unclear. This study investigates how aridity influences symbiotic interactions of Quaking Aspen (Populus tremuloides) trees by examining microbial community composition and aspen physiology along an elevational precipitation gradient in the Intermountain West. Using DNA metabarcoding of root and soil samples, we characterize and quantify the aspen mycobiome across an array of sites in the San Juan National Forest, CO. We also use a field-based reciprocal transplant experiment to assess plant performance when paired with local or non-local microbial communities under drought conditions. We found that microbial community composition varies predictably along climatic gradients and with stand composition. Ectomycorrhizal

fungal richness and abundance peaked in monodominant aspen stands, and soils with these fungal communities resulted in the greatest seedling establishment success in reciprocal transplant trials. By integrating microbial ecology with plant physiology, this research advances understanding of plant-soil feedbacks under climate stress, informing conservation strategies for drought vulnerable tree populations. Findings may have direct applications for assisted migration and restoration efforts, highlighting the role of microbial symbionts in enhancing plant resilience to climate change.

## Crowded out: How species interactions may drive alpine plant population dynamics

### Alexandra Cisneros Carey, UCLA

Climate change threatens to rearrange global patterns of biodiversity, altering the distributions of species and dynamics of plant communities. Alpine ecosystems are recognized as potentially vulnerable to changing climate due to demographic lags and competition with more resource-acquisitive low-elevation species. While many population models already incorporate abiotic factors, biotic interactions may also shape population dynamics under changing climates. To understand how population forecasts might be altered by incorporating species interactions, I re-censused populations of an alpine plant across its elevational range and compared population forecasts based on an integral projection model (IPMs) parameterized with 2014-2018 demography data with 2025 populations. The original forecasts over-predicted population size at lower elevations and under-predicted at the higher elevation. In future work, I will incorporate neighborhood species interactions as interspecific and intraspecific crowding terms in an IPM, to understand how both biotic and abiotic factors influence population dynamics.

## Seasonal LT50 Dynamics Reveal Climate-Vulnerability in Candidate Trees for Intermountain Landscapes

### Jonathan Martin, Colorado State University

Cold hardiness is a dynamic physiological trait that influences tree survival under variable winter climates, yet tree suitability is often assessed using static hardiness ratings that may not capture seasonal periods of vulnerability. We examined the use of season-long LT50 trajectories to provide a more informative framework for identifying climate-related freeze-injury risk in candidate tree genotypes.tissue from 14 genotypes representing five tree species growing in Fort Collins, Colorado, was sampled biweekly from fall acclimation through spring deacclimation. Cold hardiness was estimated using electrolyte leakage methods, and LT50 values were interpreted relative to concurrent ambient temperature conditions.taxa achieved sufficient hardiness to avoid injury during acclimation and deacclimation periods. However, marked differences emerged during midwinter temperature fluctuations. Several genotypes maintained large margins between LT50 and

ambient minimum temperatures throughout the season, whereas others experienced periods when LT50 values approached or overlapped observed winter minima, indicating elevated freeze-injury risk. Notably, genotype rankings based on seasonal minimum LT50 differed from rankings based on midwinter vulnerability, suggesting that static cold-hardiness metrics may not adequately describe climatic risk.results highlight the importance of temporal hardiness dynamics—particularly hardiness stability during midwinter—as a potentially useful trait for evaluating tree performance under increasingly variable winter climates. Seasonal LT50 trajectories provide a quantitative approach for identifying climate-vulnerability and may help inform species and genotype evaluation efforts in regions where episodic cold events interact with warming trends and increasing climate variability.

## Earth, Wind, and Fire: Climate-Driven Disturbance Regimes Recorded in Rocky Mountain Subalpine Lake Sediments

### Christy Briles, Department of Geography and Environmental Sciences, University of Colorado Denver, Denver, CO 80204

Climate change is altering disturbance regimes throughout western North American subalpine forests by increasing wildfire activity, insect outbreaks, extreme hydrologic events, and the cumulative effects of human land use. Interpreting these recent changes requires long-term records that capture the natural variability and interactions among multiple disturbance processes. Lake sediments provide continuous archives capable of preserving evidence of these disturbances over millennial timescales.examine sediment records from Decker Lake (Sawtooth Mountains, Idaho), Cottonwood Lake (Taylor Park, Colorado), and Lily Pond (Taylor Park, Colorado) to evaluate how climate variability has influenced different disturbance regimes in subalpine ecosystems. At Decker Lake, repeated declines in pine pollen during the past 10,500 years coincide with increased charcoal accumulation and mistletoe abundance, suggesting interactions among drought, wildfire, mountain pine beetle outbreaks, and subsequent forest succession. Cottonwood Lake preserves evidence of avalanches, floods, and density currents associated with changing hydroclimatic conditions and snowpack dynamics, demonstrating the value of integrating particle-size distributions, magnetic susceptibility, and geochemical analyses to reconstruct geomorphic disturbances. At Lily Pond, pollen, charcoal, diatom, and geochemical records document how historical mining, logging, grazing, and recreation have interacted with climatic variability to alter watershed processes and ecosystem resilience., these records illustrate how multiple disturbance processes respond to climatic forcing over centennial to millennial timescales. While quantitative methods for reconstructing wildfire have advanced considerably, approaches for identifying geomorphic disturbances, insect outbreaks, and windthrow remain comparatively underdeveloped. Integrating multiple paleoecological proxies provides a more comprehensive framework for reconstructing climate-driven disturbance regimes and establishes the long-term baseline needed to evaluate the unprecedented environmental changes now occurring across Rocky Mountain subalpine forests.

## Investigating Alpine Forb Recruitment across Geospatial Gradients

### Nyika Campbell, University of Colorado Boulder

Changing temperature and moisture regimes are driving plants to shift upward in elevation or latitude to track their climatic optima, a process hypothesized to buffer plant communities from the adverse effects of climate change. Migration success, however, is limited by early life stages—germination, establishment, and survival—the dynamics of which remain understudied. Because recruitment shapes future community composition, understanding how early life stages respond to changing conditions is critical. We ask: Q1: What microclimatic factors affect plant reproductive success at early life stages? Q2: How do patterns in early life stage success change under future conditions? address these questions, we are investigating seed viability and germination in Colorado alpine forbs. In 2025 we collected 6,000 seeds from six alpine forb species spanning a variety of microclimate sites in the Rocky Mountains, USA. Here, declining snow cover may expose seeds to increased freezing risk, limiting the buffering potential of range shifts even where conditions are otherwise favorable for adult plants. Consistent with this, our laboratory germination experiment found that exposure to freezing temperatures (-20°C) during cool-wet stratification (4°C) significantly reduced germination from 42% (SE 3.5%) to 12.6% (SE 1.5%) across six species. Significant variation across collection sites indicated that some populations may be particularly vulnerable. In 2026 we expanded this work with additional collections, co-located with a microclimate sensor array at the Niwot Ridge LTER site, adding six species spanning multiple plant functional groups to test how fine-scale microclimatic heterogeneity shapes germination success.

## Microclimate Drivers of Alpine Plant Community Change at the Pecos GLORIA Target Region: A 10-Year Assessment

### Michael Remke, New Mexico Highlands University

Alpine plant communities are among the most climate-sensitive systems on Earth, yet fine-scale microclimatic controls on species abundance remain poorly resolved for the sky-island ranges of the southern Rocky Mountains. We present a decadal (2016–2026) analysis of vegetation change across the Pecos GLORIA (Global Observation Research Initiative in Alpine Environments) target region, located in the Sangre de Cristo Mountains of northern New Mexico. Following standardized GLORIA multi-summit protocols, we surveyed vascular plant cover and frequency across four summit plots spanning an elevational gradient, paired with continuous soil and near-surface air temperature data from dataloggers installed at each summit. We evaluated whether summit-level warming trends, growing-season length, and snowpack persistence predicted shifts in species abundance, richness, and community composition over the study period. Preliminary trends indicate warming of near-surface soil temperatures at lower-elevation summits outpacing higher summits, accompanied by upslope range shifts in several graminoid and forb taxa and modest declines in cold-adapted cushion-plant specialists. Interannual variability in snowmelt timing emerged as a stronger short-term predictor of abundance

than mean annual temperature, suggesting that microclimatic buffering—particularly snow-derived moisture availability—mediates species-level responses to broader warming trends. These findings contribute to the global GLORIA network's assessment of alpine vulnerability and offer region-specific evidence that Southwestern sky-island summits may be tracking climate change through both thermal and hydrological pathways, with implications for conservation prioritization in increasingly fire- and drought-affected high-elevation refugia.

## Quantifying synchrony and lag between snowpack and streamflow across the Western US

### Keira Johnson, Cooperative Institute for Research in Environmental Sciences

As temperatures warm and alter snowpack-streamflow relations, increasing attention has been devoted to understanding how changes in snowpack propagate through watersheds to generate streamflow. Quantifying synchrony (e.g., similarity in shape) and lag (e.g., temporal offset between peaks) between snowpack and streamflow time series can provide insight into watershed storage and routing processes, while helping to improve early-warning for management decisions. In this work, we compile SWE and streamflow data from nearly 300 snow-influenced, minimally anthropogenically impacted watersheds across the western US to ask: 1) How synchronous and lagged are snowpack and streamflow across snow dominated basins in the western US? 2) How temporally variable are synchrony and lag within a given watershed? and 3) What describes spatial and temporal variation in synchrony and lag? We hypothesize that watersheds with larger proportions of precipitation falling as snow and faster melt rates will exhibit higher synchrony and lower lags. Further, we hypothesize that watersheds with limited subsurface storage capacity and more variable topography will exhibit more variation in interannual synchrony and lag because streamflow will be less buffered by subsurface water storage, and heterogeneous topography will result in more variable interannual snow storage on the landscape. Results from this work will provide insight into watershed storage and routing processes, with the potential to inform reservoir operations, water-supply forecasting, and flood-risk management.

## Declining flow duration in headwater streams of the East River Basin from 2024-2026

### Mia Groff, Colorado State University

Intermittent headwater streams are one of the most sensitive hydrologic systems to climatological disturbances. In the Western US, warming temperatures and declining snowpacks are stressing headwater catchments. The Rocky Mountains provide a crucial study area for understanding how these climatic pressures alter intermittent streamflow dynamics. At over 8,500 ft, in the high alpine East River Catchment near Crested Butte, CO a

network of seasonal stream channels flow over shale and granite to deliver water to the major rivers in the Upper Colorado Basin. We have monitored 113 headwater stream sites since 2024 to quantify how long these streams flow each year. Peak average daily snow water equivalent (SWE) decreased over the three-year period (WY 2024–2026), falling from 16.0 inches to 14.7 inches, and sharply declining to 8.4 inches in 2026. From 2024 to 2025 we saw a decrease in flow fraction at 48 sites (42.5%) and an increase at only 8 sites (7.1%). Monitoring for 2026 began in June with initial (snapshot) results capturing early season (June) flow conditions compared to 2024 and 2025. 57 sites (50.4%) have been flowing every June. Between June 2024 and June 2025 20 sites (17.7%) shifted from flowing to not flowing, and an additional 8 (7.1%) sites were not flowing in June 2026. Understanding the snowpack, geologic variables, and basin attributes that affect water flow in the alpine near-surface and vadose zone will be vital to predicting future water flow duration and location for downstream communities.

## Hydrologic Source Driven Differences in Alpine Stream Chemistry Across Two Mountain Watersheds

### Abby Ross, University of Colorado Boulder

The cryosphere, and the various features within it (glaciers, rock glaciers, and snow), are biogeochemically distinct and their meltwaters play a major role in shaping the structure and function of downstream aquatic systems. For example, glacier-fed lakes tend to have increased nitrate concentrations relative to snow-fed lakes. Further, rock glacier meltwater itself has higher nitrate concentrations, pH, and specific conductivity compared to glacier meltwater. Here, we characterized the impacts of differing hydrologic sources on stream chemistry in two hydrologic networks from snowmelt to baseflow: Loch Vale Watershed (LVWS, 2026) and Green Lakes Valley (GLV, 2025). Historical water chemistry data from both watersheds shows that summer baseflow nitrate concentrations are 5.5 (LVWS) and 6.8 (GLV) times higher in glacial meltwater compared to snow-fed streams. We found that streams closest to glaciers had the highest concentrations of nitrate, phosphate, and total dissolved nitrogen and those concentrations decreased as the distance from glaciers increased. As the watershed transitioned from snowmelt to baseflow, concentrations of most constituents increased and may be modified by the presence of lakes in the aquatic network. Our next step is to analyze metagenomic samples collected alongside the water chemistry, which we hypothesize will show distinct communities and functions, particularly during baseflow when residence time is longer and the diluting effect of snowmelt and no longer apparent. Since microbes control the cycling of nutrients within watersheds, characterizing their communities throughout headwater networks is important for understanding downstream water quality.

## Precipitation, streamflow, and evapotranspiration trends in a semi-arid mountain catchment

### Zoe Flanzer, Boise State University

Mountain catchments provide nearly 70% of the municipal and agricultural water supply in the western US, but current and projected increases in climatic extremes are resulting in more uncertainty in downstream water supply. This study evaluates 20+ years of precipitation (P), evapotranspiration (ET), and streamflow (Q) data in the mid-elevation, semi-arid Reynolds Creek Experimental Watershed, Idaho, to assess water budget partitioning trends and better understand the susceptibility of ET and Q to changes in P. An analysis of catchment-scale spatiotemporal data reveals that ET significantly increased from 2000 to 2023, whereas P and Q have not shown significant change. Further, annual P and Q magnitudes are highly correlated and exhibit high annual variability; ET magnitudes are independent of P and Q magnitudes and exhibit low annual variability. Tree canopy cover data suggest the increase in annual ET over the study period may be influenced by juniper expansion. The relationships, or lack thereof, between P, Q, and ET indicate that Q is likely more susceptible to weather extremes such as droughts and floods, whereas ET likely has plant physiological controls preventing large interannual variability. These results provide important context for water managers regarding catchment-scale water outputs in a more volatile climate.

## Using hemispherical photography to validate canopy inputs to snow models

### Otto Lang, Boise State University

Seasonal snowpacks across the Intermountain West provide critical water resources for mountain ecosystems while serving as natural reservoirs that delay runoff into summer, when water demand for agricultural and municipal use is highest. Process-based snow models have advanced considerably in recent decades, simulating snow accumulation and melt at sub-daily timesteps. Despite these advances, accurately representing forest canopy structure remains a major source of uncertainty because many models rely on simplified vegetation parameterizations that do not capture the spatial variability and disturbance history of many forests in the Intermountain West. To improve canopy representation, we derived canopy sky view factor (SVF) from recent Sentinel-2 effective leaf area index (LAI) products for conifer forests in the upper Henry's Fork watershed, Idaho, and incorporated these data into the process-based snow model, iSnobal. To validate the vegetation inputs, multiple field campaigns collected hundreds of hemispherical photographs spanning a wide range of forest types, canopy densities, tree heights, and disturbance histories. SVFs calculated from hemispherical photographs were compared directly with the model inputs. Results indicate that LAI-derived canopy inputs provide a substantially more accurate representation of forest canopy structure than the default model parameterization. Simulations further suggest that canopy SVF exerts a

much stronger control on snowmelt timing than vegetation height, highlighting the importance of accurately characterizing canopy openness for improving snowmelt simulations beneath conifer forests.

## Controls on Post-Fire Channel Incision across the Cameron Peak and East Troublesome Burn Scars

### William Keenan, Colorado State University

A channel head is defined as the most upstream point in a catchment where water and sediment begin to move between two definable banks. The locations of channel heads in some watersheds is related to slope, with steep catchments requiring less contributing area to generate the erosive force required for channel initiation. However, perhaps because of their dependence on wildfire, channel heads in semi-arid mountain headwaters do not conform to this slope-area relationship. In this study, we tested the hypotheses that (1) post-fire channel initiation is driven more by catchment morphology and burn severity than by slope, and (2) high, snow-dominated, elevations have different post-fire channel erosion than lower elevations. Using high resolution aerial photography, we identified post-fire channel initiation points across the Cameron Peak and East Troublesome fire areas and delineated their contributing areas using a 1m-resolution LiDAR derived DEM. Our dataset shows that post-fire erosion was much more prevalent in the East Troublesome fire compared to the Cameron Peak fire. Within each fire perimeter, low elevations had twice as much channel incision despite similar burn severity to high elevations. We also used a random forest model to predict the likelihood of channel incision based on attributes of the contributing area and found that catchments with greater proportions of valley and hollow landforms were less likely to incise, potentially because these landforms break up overland flow pathways.

## Exploring Ways to Better Understand Soil Moisture Variability in the Mountains

### Asa DeHaan, Aspen Global Change Institute

Soil moisture governs how water and energy are partitioned at the land surface, yet much long-term monitoring relies on point measurements whose representativeness of the surrounding landscape is rarely tested. The Roaring Fork Observation Network (iRON), operated by the Aspen Global Change Institute, has recorded soil moisture and meteorological conditions across a 6,000 - 12,000 ft elevational gradient in the Roaring Fork watershed, a headwaters tributary of the Colorado River Basin, for up to 15 years. Each of its 10 stations, however, characterizes a single point.test how well that point represents its surroundings, we conducted a field campaign at the network's highest station (12,000 ft), where a team of 15 scientists, partners, and community members collected more than 800 volumetric water content measurements using handheld soil

moisture probes across a 160 × 160-meter study area. Measurements were collected at 5-meter intervals, at each sampling point, soil moisture was recorded in triplicate, and soil temperature was measured.results show that across the grid, volumetric water content varied widely (median 11.9%, SD 5.73%). Moran's I confirmed that this variation is spatially structured rather than random ($I = 0.037$, $p < 0.001$), though the weak magnitude indicates that much of the variance occurs at scales finer than our sampling interval.

## Private Sector Perspectives on Decision Making at the Fire-Water Nexus

### Riley Hammond, University of Colorado Boulder

As wildfire intensity and frequency rise in the Intermountain West, the quality and quantity of water systems surrounding and downstream of burn areas are increasingly affected. While research focusing on how the public sector is responding to this nexus is plentiful, a large yet imposing gap exists in the private sector. The goal of this project was subsequently to improve our understanding of private landowners' and users' attitudes, actions, needs, and concerns at the Fire-Water Nexus. Through group and individual interviews with private landowners and managers, our group set out to understand 1) how private landowners are thinking about how fire might be impacting their water access, 2) what information they use and trust to make decisions in this space, and 3) how research and science can aid in their decision-making process. Looking forward, we hope that this research will impact landowners who are looking for guidance, researchers who would stand to gain knowledge from this group, and policymakers who may be interested in topics that are front of mind for their constituents.

## Toward Updated ALFRESCO Simulations of Fire Regimes in Alaska

### Spencer Vieira, Alaska Climate Adaptation Science Center

Alaska fire regimes are changing with climate, with substantially increased fire activity in boreal and tundra ecosystems. ALFRESCO (ALaska FRames-based EcoSystem Code), a landscape fire model previously run under CMIP5 climate scenarios, projects median area burned will double in Interior Alaska (and proportionally more in Arctic and Western Alaska) by the end of the 21st century. However, ALFRESCO climate-fire algorithms were developed from observations (1950-2003) prior to recent physical and ecological changes. The model's ability to project future fire regimes could improve by including nonstationary climate and fuels. The Alaska Fire Science Consortium's collaborations with managers and scientists identified interest in further developing regional-scale models (like ALFRESCO) and generating information on how fire regimes may depart from historical variability.propose updating ALFRESCO by: (1) integrating CMIP6 climate and expanding climate-fire relationships via flammability, fire season length, and ignition, including water balance, snowpack, and lightning; (2) improving representation of landscape transformation at the boreal–tundra transition, including

novel reburning; and (3) exploring how ALFRESCO can best represent fire management actions given its coarse spatial resolution.climate-driven fire modeling for Alaska could help frame regional information on anticipated fire risk in coming decades. Adaptation responses may differ from historical experience, and this work represents initial steps in collaboration on modeling to explore future fire management scenarios.

# Fire, Snow, and Hydrology, Part 2,

Wednesday, September 16

## Distinguishing Wildfire and Anthropogenic Sources of Nitrogen Deposition in Loch Vale Watershed, Rocky Mountain National Park

### Lauren Magliozzi, Desert Research Institute

Wildfires can alter key hydrologic and biogeochemical processes in mountain catchments. The timing and magnitude of post-fire sediment and solute export remain uncertain, particularly in arid mountain streams where hydrologic connectivity is highly episodic. Following the 2024 Davis Fire in the eastern Sierra Nevada, USA, we monitored water quality across one unburned and two burned headwater catchments with up to 65% of the upstream basin area burned. We measured total suspended solids (TSS), dissolved organic carbon, nutrients, and metals to evaluate how the burn extent and hydroclimatic drivers influenced post-fire transport processes. Burned catchments exhibited stronger storm runoff responses than the unburned catchment. Export of TSS and dissolved metals increased with a delay of nearly one year after fire containment in burned catchments, suggesting evolving stream connectivity and hillslope erosion patterns. Dissolved organic carbon, total dissolved nitrogen, and manganese were positively associated with precipitation, indicating mobilization of soil-derived organic matter during storm events; whereas aluminum, barium, and total dissolved nitrogen were positively associated with streamflow. These contrasting responses highlight how different solute groups are regulated by different hydrologic and biogeochemical controls following wildfire. Our results demonstrate that post-fire water quality responses in arid mountain systems may emerge gradually alongside altered watershed connectivity and emphasize the importance of multi-year monitoring to capture delayed sediment, metal, and nutrient export.

## Seasonal precipitation and flow regimes regulate post-fire solute dynamics in arid mountain catchments

### Kelly Loria, Desert Research Institute

Atmospheric deposition of reactive nitrogen affects the ecology and biogeochemistry of mountain lakes across the western United States, with increased algal productivity, shifts in algal assemblages, and nitrogen saturation documented in many alpine systems. Agricultural sources have long been recognized as major contributors to nitrogen inputs at Loch Vale watershed in Rocky Mountain National Park. However, the role of wildfire smoke plumes as vectors for reduced nitrogen deposition in the form of ammonia and ammonium remains poorly understood. Quantifying smoke's impact is particularly critical as wildfire frequency and intensity increase across the West. Using the long-term water quality dataset from Loch Vale, this study examined relationships between smoke events and nitrogen deposition patterns by combining water quality data with satellite-derived smoke location data. Temporal correlations were calculated between major ammonium wet deposition events, fine particle carbon concentrations, ammonia from a passive ammonia collector, and wildfire smoke presence, and Seasonal Autoregressive Integrated Moving Average with Exogenous Variables (SARIMAX) models were applied to assess associations between smoke and lake chemistry while controlling for precipitation and hydrologic discharge. Preliminary analyses suggest that wildfire smoke is associated with elevated reactive nitrogen species and dissolved organic carbon in Loch Vale. Lag time analysis indicated that some smoke impacts on lake chemistry were immediate, with most effects emerging and persisting over 7–14-day periods following smoke events. This work helps distinguish between wildfire and other anthropogenic contributions to nitrogen deposition and lake biogeochemistry in RMNP, informing air quality management strategies and predictions of how intensifying fire regimes may affect this sensitive alpine ecosystem.

## Tracing Pre-Ignition Pathways from Snow Drought to Wildfire using Remote Sensing and Hierarchical Clustering

### Kelsey Warren, University of Colorado, Boulder

Wildfires and snow droughts are increasing across western US public lands. Although wildfire plays a fundamental ecological role, rising fire severity and encroachment on human communities cause substantial ecological and societal damage. Snow drought may compound these risks by altering fuel buildup and drying, yet the mechanisms linking snowpack variability to wildfire vulnerability remain poorly understood. This study will address this gap by identifying pre-fire trajectories of snowpack, fuel buildup, and fuel drying within recent wildfire perimeters (2001-2024) in the seasonally snow-covered western US. We will integrate high-resolution data fusion snow water equivalent (SWE) estimates, MODIS-derived net primary productivity (NPP) and normalized difference vegetation index (NDVI), and Variable Infiltration Capacity

model outputs of potential evapotranspiration (PET) and surface water inputs (SWI). To identify whether distinct archetypes of pre-fire behavior emerge across fire events, we will apply hierarchical clustering within and across pre-fire time series of each metric (i.e. SWE, NPP, NDVI, and PET/SWI). These trajectories will be examined across LANDFIRE-defined ecosystem types and compared between snow drought and non-snow drought years to assess whether snowpack conditions systematically intensify or accelerate pre-fire signals. To resolve pre-fire timing uncertainty, we will iteratively test multiple pre-ignition time windows to determine when trajectories most consistently emerge, thereby defining a critical pre-ignition window. By producing a mechanistic framework to understand when and where lands are particularly vulnerable to burning, this project will support land managers in prioritizing sites for prescribed burns and other proactive management actions.

## Earth, Air, Water, and Fire: Classical Elements get Complicated

### Gabrielle Boisrame, Desert Research Institute

Mountain ecosystems have been dramatically altered by both fire and fire suppression. The movement of water through these ecosystems helps to determine resilience to future fires and drought, as well as the amount of water available downstream. However, the exact hydrologic effects of a fire (or lack of fire) can be very difficult to quantify in a given location due to the various interacting processes involved. Many of the common assumptions about wildfire (that it increases soil hydrophobicity, reduces transpiration losses, increases snowmelt rates, etc.) are only true under certain circumstances. We present examples of post-fire soils and hydrology observations which challenge expected behavior. Many fire scars in California's Sierra Nevada, for instance, exhibit increased snow water storage despite common expectations that the opposite will happen. Measurements in many mountain regions also show that soil hydrophobicity is not necessarily highest in recently burned areas, with important implications for landslides and the water balance. Long-term observations across broad geographic areas are vital when attempting to understand patterns in the complex behavior of fire, soils, and water. Unfortunately, the existing literature on post-fire hydrology mainly covers high severity fires in the Western United States, leaving many geographic regions and fire types under-studied. In addition, most of these studies cover fewer than five years post-fire. Despite many important advances in post-fire hydrology in recent decades, there is still much to learn.

## Hydrological Processes in Paired Burned and Unburned Watersheds on the Eastern Slope of the Sierra Nevada

### Kabir Rasouli, Desert Research Institute

Wildfires can change watershed hydrology by modifying soil infiltration capacity, vegetation cover, and patterns of snow accumulation and melt. In the western United

States, where wildland–urban interfaces continue to expand, understanding these hydrologic shifts is increasingly crucial. This study investigates postfire hydrological processes using the paired-watershed method, comparing burned and unburned watersheds. The Davis Creek Watershed, located upstream of the residential area of Pleasant Valley near Reno, Nevada, on the eastern side of the Sierra Nevada, will serve as the control watershed. The neighboring Winters Creek Watershed, with almost 60% burned area, will be used to attribute changes in snow and runoff to the 2024 wildfire. To quantify post-fire hydrologic impacts, we used the process-based Cold Regions Hydrological Modeling (CRHM) platform, driven by hourly air temperature, relative humidity, wind speed, and precipitation data. Model performance was assessed by its ability to simulate snow water equivalent, streamflow, and post-fire runoff. Changes in soils, canopy, and understory vegetation resulting from the wildfire were analyzed to evaluate their impacts on runoff generation, peak flow magnitude, and timing. The results indicated increased flood potential in the study area under post-fire conditions, particularly during spring snowmelt and high-intensity rainfall-on-snow events. Airborne Snow Observatory (ASO) lidar data for snow, streamflow observations, and model outputs suggested a heterogeneous reduction in snow persistence and a substantial decrease in high-flow magnitude, both contributing to unexpectedly less flashy hydrologic responses in the burned watershed. These findings show the importance of incorporating post-fire conditions into flood risk assessments, especially in rapidly developing wildland–urban interfaces. This research supports improved flood forecasting and mitigation planning in post-fire landscapes and emphasizes the value of physically based hydrologic modelling for understanding wildfire–hydrology interactions in semi-arid regions.

## Postfire water yield changes estimated from multi-control BACI applied to remotely sensed evapotranspiration.

### Charles Luce, USDA Forest Service

After wildfires, we expect increased water yield, but substantial uncertainty remains. Finding control basins for conventional paired-watershed, or Before–After–Control–Impact (BACI), analyses is increasingly challenging. Calibrated pre-fire climate-runoff relationships have been applied as pseudo-controls, but where robust BACI analyses can be done, they can starkly disagree model approach. To address these limitations, we developed a multi-control BACI framework using remote sensing-based evapotranspiration from the OpenET ensemble to infer post-wildfire water-yield changes, obviating the need for large basins to remain undisturbed for control. We gridded the watershed into tiles small enough to represent spatial burn patterns. Unburned, vegetation-stable tiles were used as controls; and for each burned tile, a weighted ensemble using all control tiles generated a composite BACI model for the watershed. This structure reduces spatial bias and quantifies the strength of post-fire hydrological responses. We applied the approach to the Middle Fork Salmon River watershed in Idaho, which experienced three major wildfires (2003, 2006, 2007). We obtained consistent hydrological outcomes from a streamflow based analysis with a 36 mm year−1 increase, while AET decreased by 31 mm year−1. The composite AET model reproduced these patterns with low total uncertainty

($\sigma$total ≈ 0.4 mm/year), while resolving spatial variability associated with burn severity and extent. The low uncertainty derives from use of multiple controls and spatial and temporal autocovariance of errors in the OpenET estimates. The framework enhances the reliability of post-wildfire water yield assessments, providing a generalizable tool for ungauged basins and a new pathway to integrate remote sensing and hydrologic modelling in disturbance hydrology.

# People and Mountains,

Wednesday, September 16

## When Coping Reaches Its Limit: Climate Thresholds, Visitor Behavior, and Intent to Return in New Hampshire Parks and Protected Areas

### Maddie Smith, University of New Hampshire, [Early Career Award]

Across the United States (U.S.), outdoor recreation participation has steadily increased over the past 15 years, reaching a record-breaking 175.8 million participants in 2023. Research suggests that the Northeast and North Central regions of the contiguous U.S. are projected to experience notable climate-related changes in outdoor recreation participation. This mixed-methods study examined New Hampshire (NH) residential visitors' perceptions of environmental and infrastructural impacts associated with annual changes in climate conditions representative of long-term trends (e.g., extreme weather events, water/wildlife, forest/foliage, and season-specific conditions), and how those impacts shape coping behaviors and intent to return to NH's Parks and Protected Areas (PPAs). Web-based survey data (n = 1,364) were collected in winter 2023 as part of the New Hampshire Statewide Comprehensive Outdoor Recreation Plan (NH SCORP). Findings revealed that visitors perceived some level of climate-related impacts across all areas measured, and that those impacts were predominantly negative, particularly in relation to winter recreation. Modeling showed that behavioral coping sometimes helped visitors adapt to winter, water/wildlife, and extreme-weather impacts, and that winter conditions even retained a small positive direct link to intent to return. However, water/wildlife and extreme-weather impacts were also linked to displacement, and summer heat bypassed coping entirely, producing a direct negative effect on intent to return. As climate conditions continue to shift, embedding standardized visitor impact and coping metrics into statewide recreation planning frameworks offers PPAs a transferable model for navigating climate adaptation in outdoor recreation management and providers information on where behavioral coping is no longer effective.

## The Spiritual Danger of Climate Change: Braiding Western and Indigenous Climate Knowledge in the Rockies

### John Hausdoerffer, Western Colorado University, [Invited]

In July of 2025, Ute Mountain Ute leader Regina Lopez Whiteskunk visited the Rocky Mountain Biological Laboratory (RMBL) in Gothic, CO. Touring the RMBL Research Meadow, Whiteskunk learned about how climate change is causing sagebrush to replace wildflowers, the scent of wildflowers to change, and spring to emerge two weeks early for plants and pollinators alike. Whiteskunk felt a deep connection with pollinators struggling to adapt, as Whiteskunk has found that plants necessary for Ute ceremonies such as the Bear Dance and the Sun Dance have also been disrupted by climate disturbance. This talk will share clips from a film (Directed by Julian Rubinstein and edited by Sarah Hamilton) seeking to capture how RMBL scientists and Regina's fellow elders are blending ways of understanding, to enhance how each informs climate resilience from the headwaters to the Four Corners regions of Colorado.

## ROOTED: A short film & discussion on Indigenous land access in Southwest Colorado

### Treston Chee, Trees, Water & People, [Invited]

Land trusts and conservancies have increasingly partnered with tribal communities, as landowners and donors have increasingly supported homecoming efforts on ancestral land. The Montezuma Land Conservancy has shown humble yet effective leadership in this field across the southwest. On this panel, Treston will screen his short film "Rooted," featuring efforts between the Montezuma Land Conservancy, Trees Water People, and youth from regional tribes to restore ancestral lands.

# Snow & Ice, Part 2,

Wednesday, September 16

## Harmonizing operational snow model forcing inputs and assessing runoff relationships in sub-catchments of the Upper Colorado River Basin and Great Basin

### Matthew Olson, Utah Valley University, [Invited]

Snowmelt derived mountain streamflow is a valuable and heavily managed commodity across the western US, contributing 70-85% of the available annual surface water input across key catchments of the Upper Colorado River Basin and Great Basins. Physically based snow models, such as the iSnobal energy and mass balance model, have been evaluated for operational water supply forecast frameworks to deliver more reliable estimates of the timing and magnitude of snowmelt and supplement current forecasting approaches. Recent iSnobal model developments have focused on harmonized forcing inputs from the High-Resolution Rapid Refresh (HRRR) numerical weather prediction model to adapt for production use; however, forcing inputs provide course (3 km) spatial resolution and often omit transient variables needed in process-aware downscaling to adequately resolve snow energy balance in complex terrain. In this study, we implement a physically based terrain downscaling approach for HRRR radiative forcing input and test this technique using specialized instrumentation in the East River Watershed, CO. We further demonstrate the utility of the updated iSnobal model by assessing snowmelt and streamflow relationships in several heavily managed sub-catchments of the Jordan River Basin, a major tributary of the Great Salt Lake Basin. These contributions advance operational integration through consistent forecast forcing inputs and demonstrate the benefit of physically based snow modeling in assessing sub-catchment surface water supply for relevant basins.

## SnowSmart Forestry: Leveraging a decade of measurements and modeling to design forest management prescriptions for snow conservation and resilient forests

### Joel Biederman, USDA-ARS Southwest Watershed Research Center

Mountain forests in the western United States face accelerating shifts in snow accumulation, melt timing, and disturbance, creating a need for decision support tools that integrate snow science with forest management. Building on a decade of measurements and modeling of fire, harvest, and pathogen impacts on snowpack, SnowSmart Forestry applies these lessons to design treatment prescriptions that prioritize snow conservation while meeting stakeholder objectives in Colorado's Dolores Watershed. A two year round table with land managers and researchers co develops and evaluates thinning scenario

predictions, helping stakeholders weigh tradeoffs, enhance snow retention, and align fuel reduction strategies with watershed resilience. To link treatment design more directly to wildfire risk, we are evaluating dendrometers and GNSS microwave signals to index live fuels moisture and tree water status, integrating forest–snow management with emerging fire danger assessment tools.SnowSmart Forestry is our recent work with SnowPALM in Arizona, where high resolution, physics based modeling clarifies when canopy changes enhance or diminish snow storage across varied terrain. Supported by Snowtography observations and airborne lidar, SnowPALM illuminates forest–snow interactions at scales relevant to operational projects and informs treatment design or disturbance assessment in both managed and fire affected landscapes.enable regional scalability, we are developing SnowPix, a harmonized field site network and data archive integrating daily automated snow depth imagery, soil moisture profiles, and site climate data across more than 30 stations in the Colorado River Basin. SnowPix provides standardized observations needed to evaluate how forest structure and management influence snow accumulation, melt timing, and water availability, strengthening the capacity to assess hydrologic outcomes of forest treatments and support resilient, fire adapted watersheds.

## Why does snow melt when it gets hot? A case study of the March 2026 heatwave in the Sierra Nevada

### William Rudisill, Lawrence Berkeley National Laboratory

Snow supplies over half of runoff in western North America. It is recognized that solar radiation is the most important ablation forcing, but this poses a paradox: why are “snow-eater heatwaves” so effective at ablating snow? Using the three-$\sigma$ heatwave of March 2026 in the Northern Sierra Nevada as a case study, we pose these questions: what are the energy balance mechanisms influencing ablation during heatwaves? Do forest and high clouds matter? We combine reanalysis, remote sensing, models, and measurements from the Central Sierra Snow Laboratory, to investigate.high temperatures, ablation rates are dominated by solar radiation and snow-albedo feedbacks in open areas. Downwelling longwave is more important under forest canopy and as a function of increasing specific humidity. We show that the canopy-longwave effect scales with increasing air temperature, but combined with shortwave shading yields lower rates of snow ablation in the forested site relative to the open (18 vs 25 mm/day). Cirrus clouds contribute a ~4-5 W m-2 of surface radiative forcing. Sublimation and sensible heating are relatively minor— theory shows that atmospheric buoyancy effects mitigate turbulent exchange as temperatures rise, particularly during calm winds. Sublimation is limited by the maximum vapor pressure of ice, meaning an increasingly narrow range of atmospheric humidities permits evapo-sublimation of 0°C snow during heatwaves., our findings suggest moderate canopy cover adds resilience against heatwaves and that future synoptic-scale analyses of snow-heatwave interactions should focus on the covariance of heatwave conditions, wind speed and humidity.

## Fire and Ecology,

Wednesday, September 16

### Faster, bigger, more severe: extreme wildfire spread sets the stage for forest ecosystem change in western and boreal North America

#### Jonathan Coop, Western Colorado University, [Invited]

A relatively small number of rapidly spreading wildfire events burn disproportionately large areas. But beyond area burned, do fast fires produce distinct postfire ecological outcomes? Here, we measure daily linear fire growth rates and assess relationships between fire spread, burn severity, and metrics of postfire landscape resilience from 3499 fires occurring between 2012 and 2023 in conifer-dominated forests of Canada and the western US. We find that as linear spread rate increases, so too does fire severity, proportion of area burned at high severity, and distance to surviving live tree seed sources. Thus, not only do the fastest fires burn outsized areas, but these areas have less remaining tree cover and reduced capacity for recovery, setting the stage for long-term vegetation shifts. Given anticipated increases in extreme fire spread as fire seasons lengthen and weather becomes more fire-conducive, our findings highlight growing needs to effectively reduce undesired impacts, manage postfire landscapes to sustain forest ecosystem functions, and foster social-ecological adaptation.

### Fire-fuel feedbacks dampen climate-driven increases in area burned projections across boreal North America

#### Anna Spiers, Alaska Climate Adaptation Science Center, [Invited]

North American boreal forests are vast, carbon-rich landscapes with increasingly anomalous wildfire regimes. Many climate models project continued increases in fire activity. Existing area burned projections describe what climate allows, but not what landscape fuels can actually sustain.produced ecoregional projections of area burned across North American boreal forests for the 21st century that explicitly account for fire-fuel feedbacks. We developed models based on historical relationships between area burned and climate-driven fire danger ratings (i.e., Canadian Forest Fire Danger Rating System, CFFDRS), and projected them under CFFDRS calculated from downscaled CMIP6 models. We used remotely-sensed recovery trajectories of historical tree cover post-fire (MODIS) to constrain the fraction of annually burnable landscape under future climate. Fire-fuel feedbacks dampened projected area burned relative to climate-only projections, but this effect varied widely across ecoregions and climate models, reflecting the historical

degree of fuel- or flammability-limitation and changes in the seasonality and magnitude of projected precipitation. This suggests that where precipitation kept pace with temperature-driven increases in evaporative demand, post-fire vegetation recovery constrained subsequent burning;where it did not, ecoregions progressed toward fuel depletion.results point to a fundamental shift in how we prepare for future wildfire. Whereas climate drivers cannot be engineered and suppression cannot overcome fire regime shifts, adaptation strategies may support wildfire planning. Much of the future area burned is not expected to recover to the same ecosystem type, and that reality can inform how we reshape landscape management and support the communities most exposed to wildfire risk.

## Projecting Long-Term Impacts of Management Actions and Climate on Boreal Forest Fuel Reduction Treatments

### Nick Link, Northern Arizona University, [Early Career Award]

Communities across the globe are becoming increasingly vulnerable to wildfires as the climate changes and wildland-urban interface rapidly expands. To protect lives and infrastructure, fuel reduction treatments are widely employed in flammable, coniferous forests. Despite their widespread usage, we lack long-term data on the effective longevity of fuel treatments or how ecological succession proceeds following their installation. It is unclear over long-timescales whether self-replacement by flammable conifers is inevitable or if the fuel treatments could promote the recruitment of low-flammability deciduous trees. Land managers may be interested in deliberately directing succession towards low-flammability species to create living fuel breaks, which would enhance socioecological resilience to wildfires. However, attempts to do so are yet untested at scale or over long time periods. Recent advances in process-based models now enable us to generate long-term projections of succession following fuel treatments, all under variable future climates. We evaluated how fuel treatment type, demographic constraints, soil fertility, and climate affect successional trajectories in fuel treatments in boreal Alaska by pairing a field experiment with multi-decadal simulations. Results from our field experiment demonstrated that exposing mineral soil has a consistent positive effect on seedling growth rates. Model projections, parameterized from our field data, identified that background seed rain rates could promote deciduous stands if mineral soil was exposed. Our work can help inform how to establish living fuel breaks, thereby increasing the socioecological resilience of boreal communities to wildfire.

## Microbial Biogeography: The Spark of Forest Recovery Across the Western United States

### Johan Eckdahl, University of California, Berkeley

Increasing fire severity and intensity will reshape forest disturbance over the coming decades of global change. Considerable effort has contributed to a better understanding of the geographic variation of changing fire regimes, with focus placed on the interaction between the fire front, vegetation, and surface fuels, which in turn can partially shape the subsequent recovery of plant communities. Yet for years after a high-severity fire, the landscape may consist of little more than scorched ground. Comparatively little is known about the belowground processes that contribute to initiation of forest recovery after fire, as this knowledge is derived from only a few fire complexes, providing sparing insight into how these measurements might generalize across their broader fire regimes.study has demonstrated the importance of geographic variation of fire severity, microbial succession, and nutrient cycling in shaping postfire carbon cycling and plant recovery in boreal forests. Building on this, we present preliminary results from a survey of burned montane conifer forests across the western United States. Our findings suggest that belowground fire responses are far more context dependent than previously recognized, with fire increasing microbial diversity in some regions and taxa conventionally considered pyrophilic or pyrophobic exhibiting contrasting geographic responses.findings motivate our current aim of developing a more systematic approach to microbial biogeography, with the goal of upscaling these belowground processes for remote, space-based monitoring of the biota that kickstart postfire recovery, offering early predictive insight into vegetation recovery trajectories as fire regimes shift under future climate.

## The Last Stand: Examining whitebark pine restoration efforts in Glacier National Park

### Marissa Ng, Montana State University

Whitebark pine (Pinus albicaulis) is a threatened, high-elevation five-needle pine whose population has dramatically declined across its range due to white pine blister rust, mountain pine beetle, climate change, and historic fire exclusion. These long-lived trees are slow to reproduce, compounding the consequences of the species' high rates of mortality. The loss of mature, cone-producing trees has severely limited the species' ability to naturally regenerate, leading the vegetation program in Glacier National Park to implement restoration efforts. Since 2000, over 26,000 rust-resistant whitebark pine seedlings have been outplanted with about 6,000 of those trees monitored for growth and survival every five years after planting. Leveraging this 25-year monitoring dataset, we will examine factors such as topography, climate, and competition to determine their influence on whitebark pine outplanting success. Much of what is known about the drivers of whitebark pine survival or general restoration planting success comes from predictive models and studies of natural whitebark pine regeneration or other conifer species. The limited

research on outplanted whitebark seedlings specifically reduces the ability of managers to make empirically guided planting decisions that maximize restoration success. The results of this research will improve the identification of suitable planting sites and increase the likelihood seedlings survive to cone-producing age for the conservation of this keystone species.

## Growing Back Together: A Collaborative Post-Fire Reforestation Strategy for Northern Colorado

### Libby Pansing, American Forests, [Invited]

Across the western United States, wildfires are burning larger and more severely, pushing forests past the limits of natural recovery and leaving extensive high-severity patches at risk of delayed regeneration or permanent conversion to non-forest. Meeting this challenge demands reforestation at a pace and scale that current seed, nursery, and workforce pipelines cannot yet support. Over the past several years, American Forests has built a portfolio of climate-informed post-fire reforestation strategies across the West—from the Camp Fire footprint in Butte County, California, to integrated post-fire resilience planning in south-central Oregon and a reforestation needs, capacity, and pipeline assessment spanning Oregon and Washington. Each effort sharpened a transferable approach to identifying where, and how, to reforest under a changing climate.Northern Colorado Post-Fire Reforestation Strategy represents the maturation of this work into an all-lands, partner-driven plan. Developed with the Arapaho and Roosevelt National Forests and a Core Team of federal, state, local, and non-governmental partners (2023–2024), the strategy addresses 14 wildfires that burned nearly 450,000 acres since 2000. Using three geospatial assessment approaches, we identified approximately 190,876 acres at risk of regeneration failure, then applied a Core Team–weighted, eight-variable prioritization framework that integrates ecological opportunity (climatic moisture deficit, distance to seed source, topographic wetness and heat-load indices, and projected winter temperature change) with watershed and community values, tempered by real-world accessibility and policy constraints. The result is a living roadmap organized around five strategic goals, from strengthening the reforestation pipeline to advancing monitoring and research.talk situates the Northern Colorado strategy within American Forests' broader portfolio of Western post-fire reforestation efforts, then focuses in on how it was built—the science behind the assessment and prioritization, the collaborative process that shaped it, and lessons for scaling climate-informed reforestation through durable science–management partnerships.

# Weather and Climate,

Thursday, September 17

## Extreme high-elevation snowmelt amplified aspect control over western US snowpacks in 2026

### Bea Gordon, DRI, [Invited]

Water year 2026 (WY2026) produced regionally extensive mountain snowpack deficits across much of the western United States (WUS), where snow supports ecosystems, people, and diverse industries. However, the mechanisms driving observed conditions in WY2026 remain unclear. We compare WY2026 snowpack with the 1990–2025 record using 703 stations and MODIS (2003–2026) across WUS hydrologic basins, elevations, and aspects, drawing upon snow accumulation, melt, and temperature metrics. Anomalously warm conditions persisted throughout the accumulation season, and by March compound warm–dry conditions emerged across much of the network above 2200 meters and strengthened with elevation. Widespread warming and drying produced March 14-day snowmelt rates 3.8 standardized departures above historical averages. Above 2900 meters, stations lost ~48% of their WY2026 peak snow water equivalent (SWE) in a single fortnight, and 88% set records for March snowmelt, reversing the historical trend of snowmelt decreasing with elevation and weakening the coupling between peak and April 1 SWE. This reversal was consistent with a threshold-like transition, as median March temperatures above 2900 meters exceeded 0°C for the first time in the observational record. As elevation's ability to protect snowpacks against melt weakened, aspect exerted increased control over where March snow persisted. Results indicate aspect-based differences in March snow cover at higher elevations where historically, at the scale of our analysis, there have been none. As acute hydroclimatic disruptions become more frequent, protection of snowpacks against accumulation-season melt may contract toward favorable aspects within higher-elevation terrain.

## Storylines of Change: Coupling community narratives of extreme events with climate projections for western Alaska

### Keith Musselman, University of Colorado

As climate change reshapes Alaska's landscapes, Indigenous communities are disproportionately impacted. Our project, guided by an Indigenous Advisory Council, developed model simulations of historical and projected mid-century conditions for climate, snowpack, streamflow, river temperature, and wildfire for the state of Alaska. These results are resolved at both community and watershed scales. Projections indicate regionally variable increases in winter snowmelt, localized shifts from snow to rain, and reduced snowmelt contributions to streamflow. Increases in evapotranspiration offset some of the runoff expected from higher precipitation. Combined with more frequent

lightning, higher fire indices point to greater summer wildfire risk. River temperatures are projected to rise by about 1.5°C, doubling the number of river segments that reach 18°C—an important threshold for salmon survival—and amplifying the transfer of heat to the ocean. These shifts are causing cascading consequences leading to more extreme events. Many communities are experiencing events outside of historical norms, such as large tundra fires, extra-tropical cyclones, and warm winter temperatures. We have combined modeling results with community experiences collected via semi-structured interviews in the western Alaskan communities of Elim, Aniak, and St. Mary's to develop local storylines of change. Storylines can put modeling results into context and inform community preparedness, response, and recovery actions for future events. In this talk, I share findings and present storylines from the Arctic Rivers Project, a collaboration designed to understand how climate change influences rivers, fish, and communities across Alaska and the Yukon River basin.

## How well does the NWS National Blend of Models forecast precipitation phase in the central Sierra Nevada?

### Christine Albano, Desert Research Institute

Precipitation phase observations from the Mountain Rain or Snow citizen science data collection initiative provide new opportunities to evaluate the accuracy of model-derived gridded climate and weather products. In this study, we use these observations to evaluate precipitation phase forecast skill from the National Blend of Models (NBM), an ensemble of over 30 numerical weather prediction models that are compiled into a single weather forecast product. We compared observations of "rain", "snow", and "wintery mix" collected across the Central Sierra Nevada from January 2023-February 2026 and compared these to rain-snow level elevation, rain, and snow probabilities from the NBM ensemble at forecast lead times ranging from 2 to 92 hours. We found that 1) the observed elevation of the rain-snow transition was often higher than the forecasted ensemble range, especially at elevations over 1600 m and at shorter lead times when the ensemble is narrowest; 2) forecast accuracy– estimated as correspondence between the median forecast and observed elevations of the rain-snow transition– increased with shorter lead times, had a maximum R2 of ~0.6, and minimum average differences in elevation ranging between 170 and 310 m; 3) the magnitude of probabilistic snow (rain) forecasts tended to increase (decrease) with elevation. We further explore how temperature, humidity, and precipitation forecasts influence precipitation phase accuracy and bias.

## Alaska CASC Climate Services: Actionable Science for Adaptation

### Jeremy Littell, US Geological Survey, Alaska Climate Adaptation Science Center

Over its 15-year history, the Alaska Climate Adaptation Science Center's climate services work has become more deliberate in its attempts to bridge from relevant to actionable. Hewing to community of practice definitions and best practices, we aim to make

our climate services salient, credible, authoritative, and accessible. Here, we compare three recent efforts that demonstrate our climate services work and illustrate our approach to actionable science. First, we highlight results from a project developing a decision-relevant range of climate-fire futures for the western boreal of Alaska. This project used an ensemble of CMIP5 temperature and precipitation futures designed around risk framing and scenario planning to simulate boreal forest wildfire through the 21st century using the ALFRESCO landscape fire model. The results are useful for constraining potential Resist, Accept, Direct responses to fire and fuels management across a range of managed Alaska landscapes. A second project developed historical reference and future changes in CMIP6 fire danger rating metrics for the entire North American Boreal, and we highlight projected seasonal changes of fire risk in Alaska and their implications for wildfire preparedness and prescribed burning. Finally, using lessons learned from CMIP3 and CMIP5 generation statistical downscaling for Alaska, we describe advances in future climate scenarios for CMIP6, including unparalleled salience and accessibility for the region. We further describe the development of a new generation of tools to enable this accessibility, tailored simultaneously to guidance underlying best-available climate information and the current state of climate science.

## Aligning baseline climates for more accurate forecasts of moutnain hydrology, vegetation stress, and cone crop search

### James Thorne, Dept. Environmental Science and Policy, Univeristy of California, Davis

Natural resource managers need reliable climate projections when developing adaptation plans for increasingly stressed ecosystems and species. Biases in starting parameters and delays between Global Climate Model (GCM) editions can introduce adaptive opportunity cost risks. Using two editions of climate change projections in California, we found bias in climate model historical baselines, and underestimates in the rate of warming, particularly in mountain regions. The older CMIP5 projections permit a 20-year comparison of trend vs projection. These GCMs start annual minimum temperatures (Tmin) projections cooler by 0.89°C, with differences ranging from -0.3°C to -2.6°C across ten ecoregions. From 2006-2025, the GCM projections underestimated actual Tmin warming rates by 34.8%. Using Effective Climate Date, a simple calibration method, showed the GCM ensemble forecast actual 2016-2025 conditions to be reached in 2048 for annual Tmin and in 2064 for annual climatic water deficit. For two current GCMs (CMIP6), we again detected a cool bias of 0.5 and 0.8˚C compared to the reference for California, with higher biases in the Sierra Nevada, Cascades and Northwestern ecoregions. This pattern carried forward through projections, and produces overestimates of snowpack, and underestimates of climatic water deficit and conifer climatic stress zones. The underestimates represent a temporal lag of about 30 years for emergence of high-climate-stress snowpack zones, and 30-60 years for ponderosa pine. Both indicators have fixed extents; with greater magnitudes of change, proportion of extent stressed converges

spatially. However, even while proportion at risk converged, the extent of spatial disagreement grew larger by 35-46%.

## The Northeast Snow Survey (NESS) Feasibility Study: Interest Holder Needs and Spatial Design for Automated Snowpack and Weather Monitoring in the Northeastern United States

### Elizabeth (Liz) Burakowski, University of New Hampshire

In the northeastern United States, winter is warming at more than double the average rate of annual warming in the contiguous US. The rapid warming has contributed to a shorter snow season, ephemeral snowpack coverage, and a decreasing influence of snowmelt on spring hydrology. Trends and changes in snow-related metrics are derived largely from observations recorded at low-elevation weather stations in populated areas, with gridded interpolations and models to fill gaps at higher elevations and rural regions. To address the scarcity of high-quality, automated snowpack and weather observations, the Northeast Snow Survey (NESS) Feasibility Study was funded through FY23 appropriations to evaluate interest-holder needs in the region and propose a network design through a disciplined systems engineering approach. the first phase of the study, we gathered information from 230+ interest holders to identify three network objectives that would provide data to support: (1) flood and water supply forecasting, (2) safe community access to public lands and outdoor recreation, and (3) management strategies on working lands and enhance understanding of natural ecosystems. In the second phase, we focus on network design through systems engineering. Our spatial design has identified high-priority locations based on proximity to existing monitoring infrastructure (e.g., stream gauges), terrain characteristics (slope/aspect, elevation), land, soil, and snow cover classification, proximity to roads, and meeting the network objectives identified through interest holder feedback. In the final phase of the project, we are finalizing network design scenarios for small, medium, and large networks, with associated costs for maintenance and operations.

## Adapting the LoRaWAN sensor framework for science workflows

### Jehren Boehm, University Nevada Reno / Nevada System of Higher Education

Land and resource managers need increasingly timely observational data products from scientists to make effective and sustainable decisions. Traditional workflows balance the collection of in-situ and remotely-sensed field data across factors of cost/complexity, spatial coverage, and accuracy/reliability. The mountain science community has always pursued solutions for ground sensors that are small, simple, and accurate, in order to improve spatial coverage in complex terrain. A maturing technology in the industrial "Internet of Things" is the Long Range Wide Area Network (LoRaWAN) standard and associated software/hardware ecosystem. Unlike previous "smart meter" and similar

technologies, LoRaWAN contains real-world potential for science with promise of expansive geographical coverage, ease of deployment, low maintenance, and relatively low cost. Crucially, the premise of the framework is secure real-time data networking, which supports modern science and management requirements. Our research is focused on investigating and adapting the deployment methods and capabilities of open-source off-the-shelf LoRaWAN hardware and software elements for mountain science, leveraging an established state-wide research network backbone in Nevada. We will present the hurdles and successes of adapting this technology so far, some early science results, and our plans for the future. Recent results include piloting a gateway mesh architecture to reduce overall network complexity in mountains, developing offline data caching to mitigate network downtime, and preparing multi-season datasets for sensor benchmarking. Ongoing and future work includes integrating LoRaWAN with traditional sensor monitoring campaigns to further prove designs and best practices across a wider range of science questions, management applications, and team technical capability.

## NevCAN: Insights from a Decade of Observing a Great Basin Sky Island

### Anne Heggli, DRI

This presentation synthesizes a decade of observations (2012-2022) from the Nevada Climate-ecohydrology Assessment Network (NevCAN) to characterize hydroclimatic variability across a 1,566–3,354 m elevation gradient in the Snake Range in the Great Basin. Using 10 years (2012-2022) of 10-minute quality-controlled data from the 8 station basin-to-mountaintop transect, we characterize variability in precipitation, temperature, humidity, wind, radiation, and soil moisture across distinct vegetation zones from salt desert shrub to subalpine forest. Interannual variability over the decade includes both pluvial (2012-2016) and drought periods (2020-2022), providing context for natural variability in this under observed region. Across the transect, we observe orographic enhancement of precipitation and pronounced seasonal cycles in temperature, humidity, and radiation. Minimum temperatures are frequently lowest at valley stations due to cold-air pooling, while mid-elevation (pinyon-juniper and montane zones) exhibit the most moderate thermal regimes. Hydrologically, soil moisture dynamics delineate rain-dominated lower elevations from snow-dominated higher elevations, with snowmelt driving later soil moisture availability. This work highlights the value of long-term, high-resolution observations across elevation gradients to resolve complex mountain climate processes and provides a benchmark dataset for understanding hydroclimatic variability in Great Basin ecosystems. Emphasizing open access and reproducibility, this work supports model evaluation, cross-site comparison, and future interdisciplinary studies of mountain hydroclimate and ecosystem response. While the record length precludes formal trend detection, this synthesis establishes a valuable baseline for future change detection and model evaluation.

## 400 year reconstruction of lake levels for Summit Lake, Nevada

### Adam Csank, University of Nevada, Reno

Summit Lake is a closed-basin lake in northern Nevada that has been home to the Summit Lake Paiute Tribe since time immemorial. Summit Lake is home to a unique subpopulation of native Lahontan cutthroat trout. The trout are interconnected with significant cultural heritage for the region's indigenous people. Because Summit Lake is a closed basin lake, the population remains especially vulnerable to changes in precipitation and temperature (e.g., droughts) and their associated changes in watershed runoff, lake level, and stream flows. Our study had the goal of better understanding the history of Summit Lake by using tree ring records to reconstruct lake level. Using both new collections and chronologies from the ITRDB, we developed a ~400-year reconstruction of lake level for Summit Lake. Because instrumental records of lake level were too short for a full calibration, we used remotely sensed data as our target for reconstruction. Our reconstruction shows that the recent reduced lake levels seen in Summit Lake since 2020 are lower than any period in the 400-year record. This potentially has implications for the trout population and other species that depend on the lake.

# Alpine Plants,

Thursday, September 17

## From the Range of Light to Monts Chic-Chocs: GLORIA North American Synthesis of Alpine Plant Responses to Climate Change.

### Kaleb Goff, North Carolina State University / GLORIA Great Basin

Global Observation Research Initiative in Alpine Environments (GLORIA) is an international long-term monitoring program for assessing alpine vegetation response to climate change. At GLORIA target (study) regions, species composition, richness, cover, and continuous soilare collected worldwide. A North American synthesis project in collaboration with the National Park Service, GLORIA Great Basin non-profit, USGS North Central ClimateScience Center, Bureau of Land Management, US Forest Service, US Fish &Service National Wildlife Refuge System, and the GLORIA Coordination team in Vienna, Austria will assess how mountain ecosystems are changing across North America. For this synthesis, data are being managed, quality checked, and harmonized at over 27 GLORIA target regions and over 100 summits from Alaska to Arizona. This collaborative project will increase collaboration among GLORIA sites in North America, increase partnership with the GLORIA Coordination team in Vienna, and analyze trends in vegetation community

change observed over the last twenty years. Some focal research questions of interest include: 1) Can we assess vulnerability of specific species in a way that is applicable to management? 2) Do certain drivers lead to variation in vegetation changes across summits? 3) Do certain North American mountainous regions cluster in their response to changing climate? And 4) Over the last two decades, have alpine species shifted across microclimate gradients within the summit survey areas (Ie. across aspects.)? This project will be the first North American synthesis of GLORIA mountain summits, complementing syntheses in other continents and a current global GLORIA synthesis.

## Quantifying alpine tundra shrub expansion using multi-scale remote sensing

### Katya Jay, Institute of Arctic and Alpine Research, University of Colorado Boulder

Shrub expansion, driven by climate warming, disturbances, and altered nutrient cycling, is transforming ecosystems globally. This vegetation transition impacts ecosystem functions and services by altering energy, water, and carbon fluxes. Although shrub expansion has been widely documented in Arctic ecosystems, rates and spatial patterns of expansion in alpine tundra remain poorly quantified, limiting our understanding of how mountain ecosystems are responding to environmental change and the factors driving these changes. In this study, we use high-resolution aerial imagery (1 m) from the National Ecological Observatory Network (NEON) Airborne Observation Platform (available since 2018) to manually classify areas of willow shrub (Salix spp.), herbaceous, and other ground cover types (e.g., krummholz, rock, bare ground) across the Niwot Ridge Long-Term Ecological Research site in the Colorado Front Range. We collect spectral signatures from these features using BRDF-corrected NEON hyperspectral imagery (1 m). We then scale this approach by convolving to lower-resolution, multi-decadal Landsat imagery (30 m) and use Multi Endmember Spectral Mixture Analysis (MESMA) to decompose the study area into proportional spectral endmembers. This approach allows us to quantify changes in Salix cover across alpine tundra regions and provide spatially explicit estimates of multi-decadal Salix expansion rates. These analyses will enable assessment of spatial heterogeneity in shrub expansion across topographic and microclimatic gradients. Our findings will establish a framework for monitoring shrub expansion across mountain ecosystems and improve understanding of alpine tundra responses to environmental change.

## Ecosystem structure and function of managed ski trails in subalpine and alpine ecosystems in the Rocky Mountains of Colorado

### Jennie DeMarco, Sol3Carbon LLC and Western Colorado University

Alpine ski trails occupy about 60,000 km of land globally in alpine and subalpine mountain ecosystems. These managed trails represent human-dominated ecosystems that, although they may differ from their original natural ecosystems, can still provide important ecosystem functions. However, the structure and function of ecosystems on ski trails are often not measured, limiting our understanding of these unique ecosystems. Plant species richness, cover, and diversity, and ecosystem-level carbon storage were measured on four ski trails at a ski resort in the Rocky Mountains of Colorado to better understand the ecosystem structure and function of these human-managed lands. On each trail, 20 five-by-ten-meter plots were established, and in each plot, plant diversity, plant species composition, aboveground plant biomass, belowground plant biomass, aboveground plant carbon pools, belowground plant carbon pools, and soil carbon pools were measured. Plant diversity ranged from 16 to 23 species across the trails, with graminoids and forbs as the dominant plant functional groups in three of the four sites. Belowground plant biomass was two times greater than aboveground biomass. The largest amount of carbon was stored in the soil and was 80 and 15 times greater than aboveground and belowground plant carbon stocks, respectively. This study provides observational, baseline measurements of ecosystem structure and function on ski trails and can provide a starting point for assessing and informing management to enhance ecosystem function. With over 6,000 ski resorts globally, the ski industry could be a significant player in improving land management to enhance ecosystem function.

## Delayed snow accumulation and reduced snow depth drive variable plant and ecosystem responses in Colorado subalpine

### Claire Parsons, University of Colorado Denver // Coastal Maine Botanical Gardens

Climate change is altering snowpack dynamics in subalpine ecosystems by shifting both the timing of snow accumulation and the depth of winter snowpack, with consequences for ecosystem processes, plant communities, and individual species. Snow cover insulates soils and vegetation from extreme winter temperatures and provides seasonal cues that regulate vegetation phenology but increasing temperatures and changing precipitation regimes are disrupting these functions. To evaluate the ecological effects of altered snow timing and depth, we conducted a two-year in situ snow manipulation experiment in a Colorado subalpine forest that simulated two climate scenarios: postponed snow cover and reduced winter snow depth via snow removal. At the ecosystem level, snow removal led to a 17.6% reduction in early-season productivity and slowed decomposition by 29%, likely driven by warmer and drier soil conditions. At the community level, postponed snow cover reduced forb cover and diversity, whereas snow

removal dramatically decreased graminoid abundance by 88.5%. At the species level, two focal species were observed. Achillea millefolium advanced leaf phenology by nine days and exhibited pronounced trait shifts under snow removal, indicating high phenotypic plasticity and an opportunistic growth strategy. In contrast, Fragaria virginiana showed limited phenological or trait responses but declined in abundance under both treatments, decreasing by 44.4% under postponed snow cover and 82.6% under snow removal, suggesting greater population sensitivity to altered snow regimes. Together, these results demonstrate that changes in snow timing and depth have distinct effects across scales, linking ecosystem processes to community reorganization and species-specific strategies. As climate change continues to modify snow regimes, understanding these mechanisms is critical for predicting the stability and functioning of subalpine ecosystems.

## Patterns of taxonomic and phylogenetic diversity of alpine plant communities along the North American Continental Divide

### Carlisle Segal, Montana State University

Alpine plant communities include range-restricted species, which may be threatened by climate change. Responses of alpine plant communities to climate change are dependent on geography and the mechanisms driving their assembly. The latitudinal diversity gradient hypothesis predicts increased species richness towards lower latitudes for many taxonomic groups; this spatial biodiversity pattern may be driven by different ecological and evolutionary mechanisms. Therefore, to investigate drivers of alpine floral diversity, we analyzed taxonomic and phylogenetic alpha and beta diversity along the latitudinal gradient of the North American Continental Divide. We selected eight historical sites – four on each side of the Divide to compare both latitudinal and longitudinal differences. We used species composition data to estimate measures of alpha species diversity, Jaccard-based beta diversity, and a megaphylogeny, to assess Faith's phylogenetic diversity and other measures of phylodiversity. Results of correlation tests revealed neither latitudinal nor longitudinal patterns in taxonomic or phylogenetic alpha diversity. While we did not detect a biodiversity pattern along latitudinal or longitudinal gradients, we did find evidence of non-random community assembly in multiple sites. Both the net relatedness index (NRI) and nearest taxon index (NTI) revealed phylogenetic clustering (species are more related than expected by chance) in our mid-latitude sites on each side of the divide. The NRI and NTI scores also revealed phylogenetic overdispersion (species are less related than expected by chance) in a north and western site. We explore the importance of local abiotic conditions to alpine plant community composition and discuss the conservation implications of these patterns.

# Snow & Ice, Part 3,

Thursday, September 17

## Advancing spring relationships between snow cover and SWE using AI and regional snow cover patterns

### Justin Pflug, University of Maryland & NASA Goddard, [Invited]

Melt season fractional snow-covered area (fSCA) has long been connected with snow mass. However, in regions with deep snow, more than half of the snow volume can melt between peak snowpack and the date with the first observable decrease in snow cover, limiting the utility of fSCA for real-time snow water equivalent (SWE) predictions. Using an artificial intelligence (AI) concept called attention, we identify the pattern of fractional snow cover most informative for daily SWE predictions at individual 500 m grid cells in the Southwest Colorado San Juan Mountain Range. We compare versus SWE and fSCA relationships defined 1) at the grid cell level, and 2) using fSCA averaged from neighborhoods of pixels surrounding each grid cell. We find that the spatial attention approach had 1) little annual variability in the SWE and snow cover relationship, 2) learned to connect higher elevation snow mass to snow cover patterns from lower elevations with earlier snowmelt, and 3) could provide estimates of SWE only 1 day later than peak snowpack timing. This was approximately 22 days earlier than the relationship between snow cover and SWE at the grid cell level, and 8 days earlier than the model using fSCA averaged from neighboring cells. This shows how AI approaches can identify and advance the timing of annually stable relationships between snow cover and snow mass in areas where seasonal snowmelt is vital for municipal water supplies and local ecosystems.

## The 2026 western U.S. snow drought was about four times more likely due to climate change

### Adrienne Marshall, Colorado School of Mines

In the spring of 2026, anomalously low snow conditions in the western U.S. threatened winter recreation and water supplies. Here, we investigate: to what extent was this snow drought attributable to the climate change that has occurred since the pre-industrial period? We find that a snow drought this severe across the western U.S. was approximately 4.4 [95% CI: 2.6, 9.4] times more likely in the current climate than in the pre-industrial period. In the Upper Colorado River Basin, the snow drought was approximately 14 times more likely [0.09, 4300]. Given a projected increase in the frequency of snow droughts at least this severe in a moderately high emissions warming scenario, the lived experience of this event may help scientists, resource managers, and the public consider what western U.S. snow might look like if greenhouse gas emissions are not aggressively reduced.

## Synoptic patterns driving snow-eater heatwaves in the Western United States

### Dan McEvoy, Desert Research Institute

Spring heatwaves in the Western United States (WUS) often trigger rapid snowmelt events in the mountains that can lead to dramatic shifts in seasonal runoff timing, cause major flooding if enough snow is present, drive snow drought onset, or worsen existing snow drought conditions. Recent work has characterized WUS snow-eater heatwaves (SEHWs), a type of spring heatwave defined by strong (at least 6 □C above average) and persistent (at least three days) 2 m temperature anomalies accompanied by persistent above freezing 2 m temperatures. In this study we expand the SEHW work by examining the synoptic patterns and spatial variability of the surface weather and hydrology during historical SEHW events. Atmospheric reanalysis data (ERA5) are used to first develop circulation regimes associated with SEHWs by performing a cluster analysis on 500 mb geopotential heights (GPH) using self-organizing maps (SOMs). We then analyze composites of other atmospheric variables (200 mb GPH and integrated water vapor) and surface variables (2 m temperature, precipitation, snow water equivalent, and solar radiation) based on SOM clusters. We hypothesize that 1) atmospheric ridging will be present for most SEHWs but variations in the strength and location of the ridge will be found in SOM clusters that will produce spatially varying surface responses and 2) not all SEHWs are sunny heatwaves with cloud cover and atmospheric moisture playing a role in persistent warm overnight temperatures. Findings from this work have the potential to provide guidance on predicting SEHWs and the associated surface impacts.

## Thin Spots: Mapping Persistent Slab Trigger Zones with Airborne LiDAR

### Joe Ammatelli, Desert Research Institute

Persistent slab avalanches—those in which a cohesive layer of snow releases when an enduring, underlying weak layer of snow collapses—are among the most dangerous avalanche types given the challenge of predicting when and where the weak layer will fail. When persistent weak layers are present, recreationists are advised to avoid areas with shallow snow where triggering a slide is more likely. However, in practice, this is difficult since snow depth can vary substantially over short distances, even when the surface appears uniform. Now, with the rise of watershed-scale, LiDAR-based snowpack monitoring from Airborne Snow Observatories (ASO), multiple years of high-spatial-resolution snow depth maps are available for basins across the Western U.S., providing an opportunity to identify these persistent-slab "trigger zones." Here, we exploit patterns in the spatial distribution of snow depth to identify areas that are shallow relative to surrounding terrain. For three watersheds with ASO data available (Tuolumne, California; Truckee, California; East River, Colorado), we compile all accumulation-season snow depth data (21/11, 5/4, and 4/4 flights/years, respectively) and evaluate three statistical

approaches for identifying shallow areas: sliding-window percentile analysis, Local Moran's I, and residual analysis using low-rank singular value decomposition. We validate the methods using withheld flights and leave-one-out-cross-validation, quantifying the influence of record length and flight timing. The resulting maps reveal recurring pockets of shallow snow that persist across years and observation dates. Combined with topographic mapping tools, these shallow snow maps provide a new layer of spatial context for avalanche forecasting, education, and decision making.

# Hydrology, Part 2,

Thursday, September 17

## Connecting Soil Moisture Observations to Streamflow Response in the Upper Yampa Basin

### Mari Webb, Center for Western Weather and Water Extremes

The Upper Yampa is an important snowmelt-dominated headwater basin of the Colorado River. Locally, the watershed supplies water for municipal, agricultural, ecological, and recreational use in Northwest Colorado. More broadly, the Yampa River contributes approximately 10% of Colorado River streamflow at Lees Ferry and supports habitat for four endangered fish species. However, it is becoming increasingly challenging to predict how snowmelt and precipitation will translate into streamflow in watersheds like the Upper Yampa. Warming temperatures, changes in snowpack accumulation and melt, drought, and variable soil moisture conditions all affect runoff generation. These changes contribute to uncertainty in seasonal water supply forecasting and water management. The Y-BASIN observational network was developed through a multi-agency collaboration to expand observations of soil, snow, and surface meteorological conditions in the Upper Yampa basin. The network currently includes nine stations, with additional stations planned. Each station measures soil moisture and soil temperature at six depths in the soil column, along with precipitation, snow depth, air temperature, humidity, wind, pressure, and solar radiation. These data are publicly available in near-real time. This observational network provides an opportunity to better understand how soil moisture conditions influence streamflow response across timescales. This work aims to improve our understanding of runoff generation in the Upper Yampa and inform how soil moisture data can be used to support both short-term water management decisions and long-term water resource planning.

## Declining Streamflow Resilience in Mountain Systems

### Rosemary Carroll, Desert Research Institute (DRI)

Mountain snow is a globally important source of water for downstream users and ecosystems, but it is uncertain if snow metrics alone provide reliable indicators of water supply. Here, we combine a large-sample regional analysis with a high-resolution integrated hydrologic model of a Colorado River headwater basin (East River, Colorado, 750 $km^2$) to examine the coupling of surface and subsurface processes in mountain streamflow generation. Analysis of nearly 4,700 western U.S. mountain watersheds shows that streamflow predictability depends not only on snow accumulation magnitude, but also on whether snow is the dominant water reservoir. Snow storage-dominated basins exhibit a tight coupling between peak snow water equivalent and runoff, whereas mixed-storage systems, such as the East River, depend on interactions among snow, rainfall, and groundwater. Recent declines in runoff efficiency and degradation of low-flow conditions in the East River coincide with persistent subsurface storage deficits associated with overlapping climate extremes. Simulations of persistent warming indicate that enhanced vegetation water use reduces recharge, drives groundwater storage loss, disproportionately affects dry years, and limits recovery during wet periods, ultimately reducing annual flows and increasing stream intermittency. Sensitivity experiments further show that the depth and porosity of active bedrock circulation strongly modulate drought response. Deeper, higher-porosity groundwater systems buffer low flows during multi-year droughts but experience prolonged recovery. Collectively, these findings highlight the coupling among climate, vegetation, snow, and groundwater, and demonstrate that explicit representation of subsurface storage dynamics is essential for forecasting mountain water supply, ecosystem vulnerability, and drought response under climate change.

## Warming exacerbates plant-driven subsurface storage depletion in a high elevation catchment

### Ashley DeFrates, Stanford University Department of Earth System Science; work for abstract conducted at Princeton University Department of Civil and Environmental Engineering

As temperatures increase with a changing climate, streamflow in the Upper Colorado River Basin (UCRB) is declining. Much of this downstream surface water originates as groundwater in mountainous catchments. As conditions warm, plants' demand for water increases, potentially reducing groundwater's ability to sustain streamflow. Transpiration's response to warming, however, is dependent on the extent of water limitation, which varies spatially and temporally in topographically complex catchments of the UCRB. This study examines the effects of precipitation and warming on plant-driven subsurface storage loss in the East Taylor Watershed, a high-elevation representative catchment of the UCRB. ParFlow-CLM is used to model hydrologic and land surface processes throughout a wet and dry water year – October to September of WY2017

and WY2018, respectively. To explore the effects of projected warming alongside different precipitation levels, we uniformly apply a 1.5°C increase to the baseline temperature forcing of each water year, and focus our analyses on the summer months. We find the greatest losses in subsurface storage under dry conditions, despite lower transpiration. Warming is found to amplify plant-driven subsurface storage loss regardless of precipitation input, with root zone storage losses shifting to deeper layers under higher temperatures. Water limitation dampens the effect of warming on transpiration and potential recharge, with the largest changes to subsurface storage loss occurring under wet conditions.

## From Data to Decisions: How Hydrologic Information Supports Water Management in the Upper Colorado River Basin

### Tanya Petach, Aspen Global Change Institute

Water management in the Upper Colorado River Basin is challenged by persistent drought, overallocation, and growing demands for timely, reliable hydrologic information. While an unprecedented volume of environmental data is available, it is critical to understand which datasets practitioners actually use, why these datasets are trusted, and what characteristics make scientific information actionable in decision-making. We conducted surveys and interviews across the data user community in the upper Colorado River Basin examining how hydrologic data are incorporated into management decisions within two focus areas: (1) snowpack and (2) the intersection between wildfire and water. We identify characteristics of datasets most commonly relied upon, attributes that make information usable and trusted, and explore differences in data needs across sectors and decision contexts. Our findings reveal common themes in the importance of long-term monitoring, data accessibility, transparency, and locally relevant information, while also highlighting persistent gaps between research production and operational decision-making.

## Coupling UAV-derived canopy temperatures with sap flow measurements to explore topographic and species-specific transpiration controls

### Julia Longmate, USC Berkeley

Evapotranspiration (ET) is the primary water flux from land to atmosphere, and is critical to understand in mountain watersheds, which supply freshwater to at least half the world. ET, especially transpiration, is challenging to measure and model in complex mountain terrain; standard observational approaches (such as eddy covariance) rely on assumptions of horizontal wind across a flat footprint. Topography and species composition as controls on transpiration remain poorly constrained; as climate change alters mountain forest structure and composition, there is growing need to understand

how ecosystem-scale transpiration dynamics will be impacted, and subsequently impact short-term water resource availability and long-term drought dynamics. Thermal remote sensing offers a promising approach for estimating ET through a surface energy balance approach in regions where complex terrain makes direct measurement techniques inappropriate.the East River region of the Upper Colorado River Basin, we uncrewed aerial vehical (UAV) multispectral and thermal imagery with net radiation observations, topographic data, and sap flow measurements directly measuring transpiration to establish relationships between canopy temperatures and transpiration rates, across landscape position, radiation environments, and species. We hypothesize that topography largely drives in convergent landscape positions, topography will drive transpiration more than will species or forest structure effects, whereas species and forest structure will exert stronger controls in neutral and divergent landscape positions, particularly during drought. Through this approach, we hope to better characterize spatial variability in ET in this region.

## Mount Lemmon Lecture,

Monday, September 14

### Anticipating Effects of Climate Change in Rocky Mountain Subalpine Forests

#### Lara Kueppers, UC Berkeley, [Keynote Speaker]

Subalpine forests have been important features of Rocky Mountain landscapes for many millennia, providing habitat, storing carbon, and regulating watershed function. How will anthropogenic climate change alter their distribution, structure, and function? Based on a complement of observational, experimental and numerical modeling approaches, I'll summarize what we're learning about how climate has shaped subalpine conifer forests, in particular, and how the signal of climate change is emerging. I'll also share our understanding of the drivers and constraints on subalpine forest range shifts, and whether forest migration can keep pace with the changing climate. Consistent with its pronounced role in the rhythms of life at high elevations, but perhaps less well appreciated for its influence on tree and forest dynamics, snow is an important part of the story. Finally, since fire and forest management may catalyze change on large portions of the landscape, with consequences for forests, carbon and water resources, I'll touch on our ongoing work to incorporate these factors into projections of the future. Climate and forest change are underway and the trajectory of change is emerging – how far will we go?