MtnClim 2024 Abstracts

September 16-19 2024, Granlibakken, Tahoe

Kelly Redmond Lecture,

Monday, September 16

The Evolving Nature of Western Wildfires and Their Societal Implications

Mojtaba Sadegh, Boise State University

This presentation will first delve into the changing characteristics of wildfires across the Western United States (WUS). Increases in burned area and large fire occurrence are widely documented over the WUS over the past half century. The observed trend, however, is heterogenous across the elevational gradient. While there have been widespread increases in fire danger across the mountainous WUS from 1979 to 2020, trends were most acute at high-elevation regions. Several physical mechanisms underpinned the observed trends, including elevationally disparate impacts of earlier snowmelt, intensified land-atmosphere feedbacks, irrigation, and aerosols, in addition to widespread warming/drying. These processes culminated in the largest increase rates in burned area occurring above 2,500 m. WUS high-elevation fires advanced upslope with a median cumulative change of 252 m in 34 years across studied ecoregions, scorching territories that were too wet to burn frequently before. Next, this presentation will focus on the societal impacts of wildfires. Cumulative primary human exposure – population residing within large wildfires' perimeters – was 487,780 people from 2000-2019 across WUS. Primary population exposure increased by 185% in WUS in the past two decades. Population dynamics – e.g., migration and population growth – from 2000-2019 alone accounted for 24% of the observed increase rate in human exposure, whereas increased wildfire extent drove a majority of the observed trends. Certain vulnerable populations such as older adults and those with a disability observed a large rate of increasing exposure to wildfire in the past two decades.

Hydroclimate Extremes and Their Impacts,

Tuesday, September 17

Advancing global snow observations through the NASA SnowEx campaign

Carrie Vuyovich, NASA Goddard Space Flight Center

Global snow data are required for understanding the role of snow in the Earth's water, energy and carbon cycles, and critical for informing water resource and snow-related hazard management. Numerous satellite observations exist or are planned that are sensitive to the presence of snow and may provide value towards global snow observations. However, there are currently no global observations of snow water equivalent (SWE), or the equivalent amount of liquid water contained in the snowpack – a critical variable for hydrology – at the required frequency, resolution and accuracy to address scientific and operational requirements. NASA SnowEx is a multi-year field campaign, sponsored by NASA's Terrestrial Hydrology Program (THP), to assess the ability of different remote sensing techniques to measure snow characteristics across the range of snow climates and topographic and vegetation gradients. This community-wide effort has included hundreds of national and international participants and partners from multiple agencies, organizations and universities. SnowEx includes extensive surface-based and airborne observations, as well as modeling efforts to address the most important gaps in our snow remote sensing knowledge. SnowEx campaigns have focused on mountain ranges and temperate forests of the western United States, and tundra and boreal forest landscapes of Alaska. Through SnowEx, research and validation have aimed to address challenges unique to each region needed for global satellite-based snow observations to be successful. Here we summarize some key SnowEx findings to date and discuss expected future work, remaining gaps, and critical observations needed from future satellite missions to meet global data needs.

Forecast Informed Reservoir Operations: Adapting to Hydroclimate Extremes

Ava Cooper, Center for Western Weather and Water Extremes

California has one of the most variable climates in the United States, and it's getting more extreme, marked by long periods of warm, dry conditions punctuated by stronger and wetter atmospheric river (AR) storms. ARs provide half of the state's annual precipitation but cause more than 90 percent of the floods in Northern California. Forecast Informed Reservoir Operations (FIRO) is a flexible water management strategy that uses improved weather and runoff forecasts to help water managers retain or release water from reservoirs to increase resilience to droughts and floods. In the Yuba and Feather River watersheds, Yuba Water Agency and the California Department of Water

Resources are working with Scripps Institution of Oceanography's Center for Western Weather and Water Extremes at UC San Diego, the U.S. Army Corps of Engineers, the National Weather Service, and other members of the Yuba- Feather Steering Committee to implement FIRO at New Bullards Bar and Lake Oroville. The Yuba-Feather FIRO research and operations partnership, has two primary elements: improving precipitation and runoff forecasts, especially for large AR events, and integrating improved forecasts into new reservoir operations to improve operational flexibility. Data driving FIRO include weather data collected from reconnaissance flights over the Pacific Ocean, weather balloons launched during AR storms, and a growing network of weather stations that collect continuous real-time data to ground-truth conditions, including soil moisture, which is critical for accurate runoff predictions. This presentation summarizes how FIRO efforts in the Sierra Nevada aid in adapting to hydroclimate extremes.

Weathering Drought: The Forest Beneath Our Feet and the Hydrological Underpinnings of Tree and Stream Response

David Dralle, USDA Forest Service Pacific Southwest Research Station

As droughts intensify across the American West, our understanding of forest mortality and streamflow reduction in seasonally dry forests remains incomplete. This study investigates the critical role of subsurface water storage in regulating tree survival and stream behavior during drought, focusing on California's seasonally dry forests as test beds for improving process understanding these regions, strong seasonality forces plants to extend roots beyond soils into fractured bedrock for moisture. We address two key questions: How do weathering profiles and subsurface water storage capacity influence forest drought resilience and mortality risk? What is the relationship between subsurface water dynamics and low flow generation in drought-affected watersheds? We synthesize insights from multi-year field monitoring across diverse California sites, exploring interactions between weathering processes, bedrock characteristics, and water storage capacity. Our study examines how these subsurface factors influence vegetation response to water stress and streamflow generation during dry periods, leveraging remote sensing and hydrological modeling, we extend site-specific findings to less-instrumented forest areas across the American West. This approach offers a broader understanding of subsurface hydrological processes across varied landscapes. Our findings provide new perspectives on the relationships between subsurface water dynamics, weathering profiles, and forest ecosystems, with implications for mitigating forest mortality and managing low flows. This research aims to inform effective drought management strategies in vulnerable regions.

Insight into extreme events and their impacts in snowy regions

Laurie Huning, California State University, Long Beach

Seasonal snowmelt is critically important worldwide given its wide variety of uses (e.g., drinking water, agricultural irrigation, hydropower). Snow also plays a vital role in climate, ecosystem, and biogeochemical processes from local to regional and global scales. Despite significant advancements in observing and modeling snow, estimating how much water is stored in the snowpack, how and where it is distributed throughout the landscape, and how it changes across montane terrain remain significant challenges for managing water, energy, and food systems. Using a variety of multi-decadal atmospheric and snow reanalyses, I explore both extreme events (e.g., droughts, heatwaves, extreme storms) across snow-dominated regions and the hydroclimatology of such areas. I also provide insight into the snowpack response to various levels of atmospheric warming as well as other drivers of snowpack change contributing to accumulation and loss. Insight into the complex interactions of the drivers of snowpack change and the spatiotemporal variability of extreme events will help us improve streamflow forecasts, manage our natural resources, and develop disaster risk reduction strategies across the globe. Lastly, I will discuss future directions for better characterizing and quantifying hydrometeorological processes, extreme events, and their impacts in snow-dominated regions and beyond.

Precipitation, Snow, and Runoff,

Tuesday, September 17

Understanding changes in western-US precipitation predicted by high-resolution climate models

Nick Siler, Oregon State University

High-resolution regional climate model (RCM) simulations of global warming consistently predict larger percentage increases in precipitation in the lee of the Cascades and Sierra Nevada, indicating a weakening of the orographic rain shadow. This redistribution of precipitation could have profound consequences for water resources and ecosystems, but its underlying mechanisms are unknown. Here we show that rain-shadow weakening is just one manifestation of a more general decrease in the influence of orography on precipitation under global warming. We introduce a simple model of precipitation change based on this principle, and find that it agrees well with an ensemble of high-resolution simulations performed over the western United States. The decrease in orographic influence also modulates the change in precipitation "flashiness"—i.e., the fraction of precipitation that falls during extreme events—with flashiness increasing over windward slopes and decreasing in the lee. We discuss possible implications of this work for water resources, drought, and flooding.

The "Four Horsemen of the Snowpack Apocalypse" Limit Modeling Future Seasonal Mountain Snowmelt

Adrian Harpold, University of Nevada, Reno

Seasonal snowmelt provides water for billions of people and generates trillions of dollars in economic productivity. While simple snowmelt models tend to bracket future snow losses from a warming climate, they become problematic when diagnosing interactions between different components of the land-surface energy budget. This talk will summarize important snowpack and streamflow modeling challenges, groupings these problems under four multi-faceted and inter-related problems termed the "Four Horsemen of the Snowpack Apocalypse". The "Rain or Snow Problem" refers to the complex interaction between atmospheric vapor transport, topography, and microclimatic conditions that control the phase of precipitation at the land surface. The "Latent Heat Problem" refers to the impacts of condensation and evapo-sublimation on snowpack energy budgets that are strongly controlled by poorly vapor pressure gradients and near-surface turbulence. The "Radiation Tradeoff Problem" refers to the tradeoffs between incoming longwave and shortwave radiation and its sensitivity to snow albedo and snow impurities, vegetation shading and longwave radiation, and changes in clouds and atmospheric humidity. Finally, the "Landscape Heterogeneity Problem" encompasses issues associated with heterogenous topography, vegetation structure and disturbance, and wind fields that result in small-scale differences in snowpack mass and energy budgets. This talk will argue that to refine snowmelt forecasts to meet the current challenges of water management will require including new model physics and information into snowmelt models.

A Climatology and Future Projections of Rain on Snow to Improve Structural Snow Load Estimates

Sean O’Neil, Desert Research Institute

While snow fractions are decreasing in a warming environment, the geospatial characteristics of rain on snow (ROS) remain uncertain. ROS poses a threat to structural infrastructure due to the increased load from snow’s ability to retain liquid precipitation. Most research on ROS focuses on hydrologic impacts rather than the potential for structure collapse. This research aims to provide climate aware guidance of the risks of ROS to the American Society of Civil Engineers (ASCE), which informs structural codes in the United States. To better understand spatial patterns of ROS, a 40-year high resolution climatology has been produced for CONUS. The climatology spans 1982 to 2022 and utilizes daily temperature and precipitation from PRISM and snow water equivalent (SWE) from the UA SWE product. Spatially varying rain-snow temperature thresholds were applied due to differences in climatological drivers of evaporative cooling. The climatology shows a more uniform pattern of ROS frequencies in the upper Midwest and northeast United States but is more variable over the maritime mountains of the western United States. The observation-based ROS climatology was used as a benchmark dataset to compare against an ensemble of downscaled global climate model projections (CMIP5 LOCA-1) over the historical period and then examine future changes in ROS frequency. The next phase of this project will incorporate the ROS frequencies described in this presentation into non-stationary probability distributions to create climate-change-aware design snow load and ROS recommendations suitable for inclusion in ASCE 7.

Anticipating How Rain-on-Snow Events Will Change through the 21st Century: Lessons from the 1997 New Year’s Flood Event

Alan Rhoades, Lawrence Berkeley National Laboratory

Atmospheric rivers (ARs) account for many of the costliest flood events in western U.S. maritime mountains. The flood potential of ARs is amplified when an antecedent snowpack is present. The New Year’s flood event of 1997 was representative of an AR-induced rain-on-snow event and remains the costliest in California’s history. The compounding influence of saturated soils, widespread rainfall, and abrupt snowmelt led to widespread inundation. AR-induced rain-on-snow events are projected to occur more frequently in a warmer world. Yet, the sensitivity of the rain-on-snow flood drivers to warming remains understudied, particularly at the spatiotemporal scales needed by water managers. Here, we leverage the regionally refined mesh capabilities of the Energy Exascale Earth System Model (RRM-E3SM) to recreate the New Year's flood event of 1997. We simulate the 1997 flood event at grid spacings of 14km, 7km, and 3.5km, with forecast lead times of up to 4 days, and across six different warming levels. We then identify the sensitivity of various aspects of the 1997 flood event hydrometeorology to resolution, forecast lead time, and warming level. Specifically, we describe precipitation intensity, efficiency, rain-snow partitioning, and cold content sensitivities and how runoff characteristics respond to these factors. We also show how certain aspects of the flood event change when viewed from a storm total versus sub-hourly perspective. We aim to provide water managers with insights on how warming-induced changes to AR precipitation characteristics and snowpack dynamics could interact to amplify or diminish runoff potentials and guide preemptive, rather than reactive, climate adaptation.

People in the Mountains,

Tuesday, September 17

The effect of climatic conditions on changing patterns of recreational use at Yosemite National Park

Jeffrey Jenkins, University of California, Merced

In the recent history of NPS-era management, visitation to national parks in the Sierra Nevada has been shaped by shifts in socially acceptable practices around resource impact and user capacity, and changing climatic conditions that limit or enable access. Law, policy, and science have evolved from an earlier era, when annual snowpack volume and seasonal timing were more certain, and when fire suppression predominated, supported by fire lookouts and a network of response roads beginning in the 1930s. Wilderness camping and stock use grew in popularity during the post-war years, and backcountry fire permits were introduced in the early 1970s, followed later in the decade by overnight wilderness permits. In 1990 the Park experienced its first full closure due to the A Rock fire. For this talk, I share findings on the effect that hard closures and long-term influences, including drought or wet conditions, snowpack, floods, fires, and wildfire smoke have on recreational use patterns at the Park. These conditions can displace users; to different times of the day or season, a different location, a different activity, or by forgoing their trip altogether. Changing climatic conditions and associated environmental hazards compromise the reliability of access that may no longer exist but that visitors have come to expect be managed for in practice. This has implications for visitor management systems originally design without consideration for the scale and severity of disturbances or the displaced use, thus management actions like day use reservations should consider flexible parameters that allow for equitable access.

Modeling Day and Overnight Visitor Travel at Lake Tahoe

Scott Kelley, University of Nevada, Reno

The Lake Tahoe Basin has long been a popular destination for visitors, but how to manage ever-increasing visitation there represents one of the region's primary challenges. Increased visitation contributes to greater vehicle miles of travel (VMT), congestion, crashes, emissions, and deteriorating travel experiences at Tahoe, while frustrating residents and visitors alike. Policymakers are exploring ways to mitigate these problems, but data on visitation and how visitors travel at Tahoe have been challenging to collect. This study therefore seeks to: 1) review and analyze existing data that can help inform visitation studies at Tahoe, and then: 2) using a combination of these data, estimate the number of day and overnight visitors at Tahoe on a typical summer day, and compare these volumes to year-round and seasonal resident populations, and 3) estimate VMT attributable to each group within the basin, along with common trip purposes. As a case study for how to employ these data to address visitation issues, a model is specified that analyzes the relationship between hot conditions in nearby Sacramento and increased vehicle flow through two of the basin's primary entry points, estimating how hotter temperatures in the region influence visitation to Tahoe. Through different ways of defining "hot" conditions in Sacramento, this study finds that between 500-1,200 additional vehicles enter the basin at these two points on hot days alone, generating an additional in-basin daily VMT between 12,000-33,000. These data and analyses can help managers design and scale interventions related to increased visitation.

Building drought early warning systems for fisheries, water management, and public resource use in the Northern Rocky Mountains

Justin Martin, USGS

The mountain rivers and streams of the Northern Rockies region help draw millions of visitors each year to Montana, Idaho, and Wyoming while also helping fuel rapid population growth in the region. While often a boon to local economies, greater use of the region's water resources comes with challenges including recreational crowding and increased demands for water that impact river ecosystems, especially during drought. In collaboration with state and federal partners, USGS scientists are building new tools to meet these challenges through the development of a drought risk forecasting framework capable of providing long-lead outlooks on the expected impacts of low streamflows on fish populations as well as outlooks for resulting management actions that impact public recreation. This two-pronged approach utilizes long-term fisheries monitoring, streamflow, and climate data to understand drought risks and relationships to production and resilience of ecologically, culturally, and economically important cold-water trout populations. Using the same datasets, future management actions that impact public recreation are forecasted to help engage the public in the resource management process and to aid in planning of both commercial and private recreation. Early results show that low streamflow during drought negatively effects trout production by exerting strong controls over recruitment and survival of juvenile fishes. However, management actions meant to mitigate those negative effects can be predicted with substantial lead times and with high accuracy, giving managers important tools for engaging the public in local resource management, mitigating impacts to recreational opportunities, and improving long-term drought resilience for freshwater ecosystems.

Northern Rocky Mountain ice patch perspectives on Holocene climate, ecosystem change, and human activity

Nathan Chellman, Desert Research Institute

Permanent ice patches around the globe—including from the Northern Rocky Mountains, Alaska and the Canadian Yukon, Mongolia, and Europe—preserve an unparalleled record of environmental conditions, ecosystem change, and human activity in alpine regions. Here, we present research focusing on the intersection of humans, climate, and the environment as preserved in the long-term records from ice patches in the Northern Rocky Mountains and Greater Yellowstone Area. Frozen within these enigmatic ice features are fragile organic artifacts documenting past human and animal activity, geochemical records indicating past climate conditions, as well as pollen grains, macrofossils, and charcoal fragments preserving regional ecological changes. Together, these records provide a detailed picture of rapidly changing wintertime climate throughout the Holocene and the response of treeline and vegetation cover to changing seasonal climate conditions. High-resolution snapshots from five-thousand-year-old subfossil wood from established forests further illustrate changing temperature conditions affecting ice patch growth and disappearance. These indicators can be interpreted in parallel with the archaeological record and traditional worldviews from the region to better reflect linkages between paleoclimate and human use of these alpine environments.

Entrepreneurship resilience and vulnerability reduction in the Afromontane region: Analysing the livelihood strategies of female entrepreneurs in QwaQwa

Jerit Dube, University of the Free State

Resilience in female entrepreneurship appears as a significant component that critically influences the achievement and capacity to overcome vulnerabilities in the Afromontane communities. Up to now, various scholars in the field entrepreneurship have understood resilience as a response to adversity or extreme events or disasters. However, this study understands resilience as the ability to bounce back after exposure to vulnerabilities. It also understands entrepreneurship resilience as the ability of female entrepreneurs to bounce back and reduce their vulnerabilities. This study conducted a systematic literature review which indicated that there is an existing gap in literature of entrepreneurship resilience and vulnerability reduction of female entrepreneurs in the marginalised regions like the Afromontane. Thus, due to this existing literature gap, less is known about the vulnerabilities encountered by the female entrepreneurs in the Afromontane regions. To address the issue of vulnerability and resilience of female entrepreneurs and close this existing gap in literature and knowledge, this study explored entrepreneurship resilience and vulnerability reduction of female entrepreneurs in the Afromontane. It particularly analysed the livelihood strategies of female entrepreneurs in QwaQwa to understand the vulnerabilities they are exposed to, their vulnerability reduction and entrepreneurship resilience capacity. This study followed a multitheoretical framework in a qualitative approach understand the experiences and perceptions of female entrepreneurs in QwaQwa. Data was collected through in-depth interviews, focus group discussions, life history narratives, transect walks and entrepreneurship hotspot analysis. Data was thematically analysed using ATLAS ti 22 version. The findings of the study indicate that female entrepreneurs in QwaQwa are exposed to multidimensional vulnerabilities. : Entrepreneurship, female entrepreneurs, entrepreneurship resilience, vulnerability, vulnerability reduction and QwaQwa.

Posters,

Tuesday, September 17

Future climate and water balance projections for Alaska: regional variation in decision-relevant climate futures

Spencer Vieira, Alaska Climate Adaptation Science Center

Alaska land and resource managers often require future climate projections for climate change vulnerability assessments, adaptation planning, or impacts modeling. Accessing and interpreting such climate information has historically been challenging for many users, and the available products often only address basic changes in temperature and precipitation. Moreover, guidelines for best-available climate science increasingly require careful selection of future scenarios that address uncertainties in future climate projections and frame impacts risks appropriately. The Alaska Climate Adaptation Science Center (AKCASC) has developed tools to provide access to a wide range of place- and community-specific climate projections, including extremes, wildfire and vegetation, as well as other indicators of potential change. Here we describe a new set of physically-consistent climate futures, derived from downscaled climate models and hydrologic modeling, that allow comparison of changes in water balance, including soil moisture, runoff, snowpack, and evapotranspiration. Analysis of these projections yields some surprising results. For example, annual precipitation is projected to increase almost everywhere in the state. But in some regions, despite the increased precipitation, the combination of earlier snowmelt and temperature-related increases in evapotranspiration results in lower summer soil moisture, creating a drier environment for plants. In others, the increase in precipitation results in increased snowpack because winter temperatures are still cold enough for the increased precipitation to arrive primarily as snow. We provide analysis of these changes across Alaska for federal land management units and are available to facilitate summarization and translation for collaborators requiring other summaries.

Wildfire and vulnerability assessment in Alaska: Regional variation in climate-fire futures and implications for adaptation

Jeremy Littell, USGS Alaska Climate Adaptation Science Center

Boreal fire regimes in Alaska are and northwestern Canada are expected to change as climate changes. In recent decades, higher fire activity increased deciduous dominance at the expense of spruce, potentially presaging landscape transformations that will in turn affect regional habitat, ecohydrologic function, and ecosystem services. Where boral forest is currently underlain by permafrost, the combined changes in fire regimes and climate may accelerate permafrost thaw, increasing methane and carbon dioxide emissions. Future ecosystem trajectories are contingent on climatic changes and ecological responses to fire and are thus difficult to predict, but plausible ranges of future climate-fire scenarios could allow land management entities to conduct more specific vulnerability assessments and more effective adaptation strategies. Here, we present projections of future fire size, area burned, and vegetation responses for boreal Alaska from the landscape fire model ALFRESCO. We used five downscaled CMIP5 climate models for three emissions scenarios to simulate historical and future fire simulations based on changes in summer temperature, precipitation, and vegetation. We summarize these futures for different regions (arctic, interior, and western Alaska). Area burned triples in interior Alaska, but increases much more (up to 8-fold) in Arctic and western Alaska, assuming historical fuel feedbacks. White spruce dominate forests are characteristic of upland and mountain systems in interior Alaska. Under future climates warming > +3 C, spruce forests are largely replaced by deciduous boreal forest, but < +3 C, spruce forests and deciduous forests retain roughly similar prevalence to historical, although with projected increases in annual area burned.

How does observation uncertainty affect parameter selection in hydrologic models? A case study in the Upper Colorado River Basin

Lucas North, Colorado School of Mines

Data available for hydrologic model evaluation is always limited in spatiotemporal resolution, extent, and/or accuracy. Forested montane watersheds present further limitations, as climate, snow, and soil observations are often located in canopy gaps and necessarily accessible elevations – potentially misrepresenting the broader landscape. These challenges introduce epistemic uncertainties that affect hydrologic model parameterization in ways that are poorly understood. However, advances in remote sensing data provide new avenues for evaluating hydrologic models and understanding the limitations of point observations. We present a data-driven approach to quantify observational uncertainties and their impact to parameters and predictions in the United States Geologic Survey (USGS) pywatershed model. Remotely sensed and in-situ observations for snow and soil moisture are statistically compared to quantify biases. The suite of datasets is applied in a multi-objective Bayesian uncertainty framework to identify the impact of data selection to parameter and prediction probabilities. The workflow is carried out over three data-rich, climatologically distinct watersheds in the Upper Colorado River Basin to assess the spatial transferability of the findings. These efforts inform modeling decisions and data selection in complex terrain, with potential implications for operational modeling practices or observation network design.

Using OGC SensorThings API for a Socio-Environmental Observation Network

Luke Todd, Wyoming Geographic Information Science Center

The University of Wyoming has received a new National Science Foundation award named WyACT (Wyoming Anticipating Climate Transitions), aimed at facilitating the co-production of knowledge to enable cutting-edge science that helps Wyoming communities anticipate and adapt to these potential climate change impacts on water. One component of this work is to measure aspects of the environment using sensor networks, which we have named the Socio-Environmental Observatory Network, or SEaSON. Long-term observation networks maintain measurements across many different sensor types and sources. These sensors and sources produce observations in different formats, making storing and accessing that information difficult. To reduce these barriers and assist in normalizing disparate formats into a standard form, we chose to use SensorThings API (STA) to organize, store, and provide access to our sensor data. STA is an open-source, RESTful Web service that adapts the OASIS OData standard for simple data navigation, filtering, and the ability to customize requested results. SEaSON will house observations from lake buoys, soil sensors, eddy covariance towers, and much more. We use custom middleware to translate sensor-specific data formats into a standardized form. Thus, despite observations from highly variable sensors, STA enables easier access and reusability of all data, regardless of observation type. This poster will outline our current STA cyberinfrastructure while also diagraming future expansion plans. We believe SEaSON will provide trusted, high quality, freely available data, and information on coupled human-environment systems and their responses to changing water availability.

Are mountains triangles? Using high-resolution mountain topography to inform global snow loss estimates

Adrienne Marshall, Colorado School of Mines

Mountains are sometimes conceptualized as triangles, with diminishing area as a linear function of elevation. However, real mountains and mountain ranges have complex and nonlinear area-elevation relationships. Widely-available high resolution global digital elevation models (DEMs) can allow us to characterize these area-elevation relationships, and can provide much higher-resolution insight to snowpack changes than the resolutions available with relatively coarse climate and Earth System models - with information available at tens to hundreds of meters, rather than tens to hundreds of kilometers. Here, we ask: (1) to what extent are global mountain ranges triangles? (2) How can mountain area-elevation relationships be used to estimate the loss of land area receiving snowfall? (3) How much snow-dominated area is lost by global mountain ranges when snow lines increase, and how do these areal changes vary along warming trajectories? We use DEMs to develop empirical area-elevation relationships for global mountain ranges. Using the Sierra Nevada as a case study, we then use historical freezing line data to estimate the fraction of precipitation falling as snow in recent decades. We then evaluate the potential area receiving snow lost as snowlines rise. While this analysis has important simplifying assumptions, it nonetheless provides novel insight to global snowpack sensitivity by adopting a bottom-up, rather than top-down approach to estimating snow loss.

Evaluating the Relationship Between Snow and Streamflow Distribution Width in the Western United States

Kyla Bazlen, Colorado School of Mines

Snowpack characteristics, including volume and timing of peak snow water equivalent (SWE), influence the quantity and timing of runoff in snow-dominated watersheds. Despite water availability implications, the width of the streamflow distribution is rarely considered and can be described by the standard deviation of timing (SDoT). Recently submitted research shows that in the eastern U.S., SDoT is wider during cold years, while in the mountainous western U.S., SDoT is narrower during cold years, suggesting that snow is a controlling factor of SDoT in these basins. However, the relationship between snowpack and SDoT has not been directly evaluated, leaving uncertainties about the extent of the impacts of declining snow on streamflow distribution. To better understand the drivers of SDoT, we evaluated the relationship between SDoT and the day and volume of peak SWE using spatially distributed SWE from the Western United States UCLA Daily Snow Reanalysis dataset and USGS GAGES-II streamflow data. Here, we show that the volume of peak SWE is closely tied to SDoT, with greater peak SWE resulting in narrower SDoT across the western U.S. Meanwhile, the relationship between the day of peak SWE and SDoT is spatially variable, with later peak SWE resulting in narrower SDoT in the Rocky Mountains. These results suggest that declining snowfall and earlier snowmelt could yield wider streamflow distributions in the Rocky Mountains, while there is greater uncertainty about the effects in other regions. Wider streamflow distributions could alter the availability of water impacting water rights holders, ecosystems, and water management.

Impact of avalanches and rain-on-snow events on the under-ice environment of Sierra Nevada lakes

Riley Hacker, University of California, Davis

Winter conditions in high elevation mountain regions are changing in response to climate warming; as air temperatures rise more winter precipitation falls as rain rather than snow, leading to more frequent rain-on-snow events. Rain-on-snow events cause increased runoff and a higher likelihood of avalanches that can impact ice-covered mountain lakes, potentially causing water column mixing and changes in dissolved oxygen. However, effects of avalanches and rain-on-snow events

on mountain lakes are almost unknown–these systems are typically considered static during the ice-covered period. We identified four high-elevation mountain lakes in the Sierra Nevada, CA, that are likely to experience impacts from avalanches and rain-on-snow events based on their catchment morphology and size. We examined high frequency sensor data (water temperature, conductivity, and dissolved oxygen) for 3-6 winters at each lake to identify avalanche/rain-on-snow events and subsequent impacts on the under-ice environment. We found that these events can cause water column mixing, temperature changes, and increases in oxygen concentrations, with potential implications for biogeochemistry and ecology of lakes both under ice and for the following summer.

Distributed Sensor Networks for Decision Support in Lake Tahoe

Jehren Boehm, Department of Geography, University of Nevada, Reno

Resource managers in the Lake Tahoe region require accurate and reliable data to make sustainable decisions. Recent seasonal volatility in this popular vacation destination has brought calls to better understand natural hazards pertaining to snow, drought, and fire. Rapid growth in outdoor recreation coupled with large spatiotemporal fluctuations in visitation often leave land managers, business owners, and community organizations at odds with policies that benefit all user groups. Current data sources do not offer the flexibility to explore ecohydrologic science questions across sub-watersheds in Tahoe, nor study the flux of recreationists and the patterns they follow. Modern technology creates opportunities to improve quality, accuracy, and timely delivery of data products for environmental and transportation geographic sciences. Particularly, low-cost sensor systems connected by real-time data networks (e.g., the Internet of Things - IoT) is rapidly changing the research and management landscape. In the Intermountain West, the adoption of IoT so far has been grassroots and piecemeal. Our work is focused on development of science-ready IoT solutions, standardizing deployment models and associated data workflows to serve decision makers in water, fire, snow, recreation, and conservation communities. Initially, we are testing sensor deployments that use Long Range Wide-Area Network (LoRaWAN) edge communications technology, Starlink internet terminals, terrestrial wireless research network backhaul, and refined solar power designs. Our early results show that low-cost (<$100) soil and air sensors can be deployed in the Lake Tahoe region with minimal disturbance and reliable network communications to hub sites across mountain terrain separated by many kilometers.

Snowfield Plants, Temperature, and Snowfield Retreat in the Anaconda-Pintler Wilderness of Montana

Martha Apple, Department of Biological Sciences, Montana Technological University

Snowfields and their edges present a water-rich habitat for alpine plants, but snowfields can retreat with higher temperatures and reduced snowfall. Snowfields that formerly persisted throughout the year sometimes no longer last throughout the summer, and specifically at an intermittently persistent snowfield on the alpine tundra of Goat Flat (2837 m, 46° 3' 17" N, 113° 15' 43" W) in the Pintler Mountains of the Anaconda Pintler Wilderness of Montana. To investigate possible effects of temperature on snowfield habitats as represented by alpine plant species and their qualitative functional traits, we installed an array of in-situ HOBO Tidbit V2 Temperature Sensors 5-10 cm beneath the soil surface with hourly measurements. The sensors were installed in August, 2019 after the snowfield had melted away, and at geospatially referenced and photographed 5 m intervals from the sloping snowfield's center to beyond its lateral sides and upper and lower edges. Plant species were recorded and photographed at each point along the transects. In summer 2024, we plan to revisit the site to locate and collect the sensors and plant data, but have been delayed by hot, windy weather, and forest fire smoke. Once retrieved, the sensor data can shed light on the temperature regime of the snowfield, which may influence the distribution of plant species and their qualitative functional traits. Since many alpine plants are long-lived perennials, five years may not be enough time to effect change. Therefore, a longer term study is likely.

Effects of Large Wildfires on Water Yield: Improving the Empirical Basis

Charles Luce, USDA Forest Service

The extent of wildfires over large mountain watersheds (>100 km2) has increased in recent decades. Most historical studies on effects of wildfire or other canopy loss on streamflow have been conducted in small watersheds (<10 km2), and questions regarding scaling results to large watersheds remain. We examined the response of annual water yield after wildfire in large watersheds in the western US using a paired-watershed approach. This before-after, control-impact analysis, favored in many preceding studies in small basins, has seen limited application to the large basin wildfire effect question. A substantial model-based body of work in recent years has produced a large range of estimates for wildfire effects, and a grounding in simpler observation-based analyses is useful for evaluating model-based estimates. We used streamflow records from large watersheds in protected areas along with remote sensing data to assess burned area in watersheds and recovery of forest cover after fire. Out of 15 events analyzed, 13 showed increased flow (10 significant), and 2 showed a significant decrease. Fractional changes in flow ranged from -18% to +27%. By and large, flow increases in large basins were smaller those in smaller basins, and large basins showed little dependence of flow change on fractional burned area. Statistically significant flow changes were seen in events that burned less than 15% of the basin, and increases occurred in basins with less than 5% burned. Some estimates differ considerably from model-based estimates of flow change on the same rivers.

Direct and Indirect Impacts of Fires on Rocky Mountain Lake Ecosystems

Mollie Hendry, Natural Resource Ecology Laboratory, Colorado State University

Decades of fire suppression and shifting climate regimes have increased wildfire occurrence frequency and size across the globe. The effects of wildfires on mountain lake ecosystems has been previously researched, but studies comparatively assessing the direct and indirect impacts of fires in the Rocky Mountain region have yet to be conducted. We propose an analysis of two mountain lake ecosystems, The Loch and Fern Lake, Rocky Mountain National Park, to understand the direct effects of the East Troublesome fire on Fern Lake and to understand the indirect effects of fires over a 23-year period on The Loch. Previous studies have found erosion-driven increases in sedimentation and turbidity, as well as increases in nutrients and changes to dissolved oxygen and temperature in burned watersheds. However, far more Rocky Mountain lakes are influenced by the indirect effects of regional or continental-scale fires that alter air quality and solar radiation. Using long-term meteorological data from the Loch Vale Meteorological Station, historical data pertaining to large high-severity regional fires, water chemistry data from The Loch and Fern Lake, and sediment data retrieved from the Loch, fire effects on the lakes will be evaluated in the context of ash deposition, reduced solar radiation, and novel temperatures. We will analyze observational data to find responses in lake biogeochemistry, temperature, oxygen, and algal primary productivity. We expect to see short-term increases in total nitrogen, short-term increases in net primary productivity for The Loch and Fern Lake, short-term decreases in temperature for The Loch during fire periods, and short-term decreases in dissolved oxygen for The Loch and Fern Lake through analyses of trends over seasons and years. In recent years, harmful algae blooms in mountain ecosystems similar to the Rockies (High Sierras, Wind Rivers, Uintas) driven by anthropogenic nutrient inputs have made headlines for posing risks to wildlife and human health. There is concern that similar anthropogenic nutrient inputs from wildfires in Rocky Mountain lakes may lead to the occurrence of similar phenomena. Increases in primary photosynthetic activity and shifts in algal community structure toward blue-green algae, the phytoplankton group often responsible for harmful blooms, have already been observed in the Loch. This analysis may provide ecosystem managers the tools to understand the small-scale and broad-scale effects of fire on lake ecosystems across the Rocky Mountain region.

Tree growth responses to forest health treatments across Sierra Nevada mixed-conifer forests

Jessica Katz, University of California Berkeley

To enhance the resilience of Sierra Nevada mixed conifer (SNMC) forests and their associated carbon stocks to wildfire, drought, and other disturbances, the state of California is dramatically increasing the scale of density-reducing forest health treatments, including mechanical thinning and prescribed burning. Understanding where, when, and how to apply these treatments across a geographically diverse montane region remains challenging, in part due to uncertainties about how forests will respond to treatment in a changing climate. To explore the role of climate in moderating the effects of treatment, we synthesize post-treatment forest inventory data collectively spanning seven sites, 22,500 trees, and 30 years to model individual tree growth across the SNMC. We then apply meta-regression to evaluate differences in growth response across plant functional types, treatment designs, and climate conditions. Our results suggest that mechanical thinning consistently increases growth rate relative to the control; however, the average effect of prescribed burning is neutral, with some sites experiencing a negative and others a positive growth response 1-20 years following treatment. We find that growth increases with treatment intensity (measured as the reduction in stand basal area resulting from treatment). For yellow pine, we also find that growth decreases as both winter precipitation and maximum summer temperature increase. While additional biophysical factors such as soil quality complicate these correlations, our results suggest that the effectiveness of forest health treatments in increasing tree vigor and sustaining carbon stocks in montane ecosystems may depend both on treatment design and on climate conditions.

The past as prelude: The importance of long-term monitoring in mountain ecosystems,

Wednesday, September 18

Changes in the Cryosphere

Hotaling Scott, Utah State University

Climate change is dramatically altering mountain ecosystems around the world. A salient impact of these changes is the decline of the region's cryosphere—the portion of the landscape where water exists in frozen form. This includes recession of glaciers and perennial snowfield as well as losses of seasonal snowpack. However, another component of the mountain cryosphere—rock glaciers—has received considerably less scientific attention. Rock glaciers are larges masses of debris-covered ice that move and flow down the landscape similarly to the widely known "surface" glaciers. Due to their debris cover, rock glaciers are predicted to exist on the landscape longer than surface ice. In 2015, we began the Teton Alpine Stream Research (TASR) project to understand how climate-induced alterations will impact alpine stream biodiversity. Our 12 study streams equally represent the three major stream sources: glaciers, rock glaciers, and snowfields. In our first decade, we've observed a host of changes to the physical and biological structure of alpine streams in the Teton Range. For instance, snowmelt-fed streams are warming sharply, and intermittency appears to be on the rise with preliminary evidence suggesting links to loss of ice volume. Collectively, our results highlight the power of simple long-term monitoring for quantifying the impacts of climate change on mountain ecosystems and the potential value for rock glaciers to act as key climate refugia.

The value of uninterrupted, seasonally complete, long-term glacier mass balance data

Caitlyn Florentine, U.S. Geological Survey, Northern Rocky Mountain Science Center

The U.S. Geological Survey has conducted glaciological research on key glaciers in North America since as early as the International Geophysical Year in 1958. The backbone of this research has involved direct field-based measurements of glacier mass balance, to produce uninterrupted, seasonally complete records of winter, summer, and annual changes to frozen water storage on targeted glaciers. These long-term data provide valuable insight into the climatic conditions of high-elevation alpine ecosystems. However, collecting glaciological data and maintaining long-term records is difficult due to harsh field work conditions and complex field work logistics that require snow avalanche and crevasse hazard mitigation. It is therefore worth asking, how important is it that the data are collected every year? Can the same results be achieved by reducing the frequency of data collection to alternating years? Here the hypothesis that data collected every other year yield comparable results to uninterrupted data is tested. A simulation excluding every other year reveals the magnitude error introduced by interrupting the record. Questions regarding the resilience and vulnerability of glaciers in different climate settings cannot be tackled without uninterrupted, seasonally complete glacier mass balance data.

The evolution of mountain snowpack and alpine ecosystem shifts in the Teton Range, Wyoming as recorded by lake sediments in Grand Teton National Park, WY

Darren Larsen, Occidental College

The western United States relies heavily on water resources derived from seasonal mountain snowpack to sustain human and ecological systems. Thus, the substantial variations in mountain snowpack observed over recent decades, including declines in snowpack thickness and duration across the region, raise serious concerns. Geologic archives of past winter precipitation trends and associated environmental responses provide valuable context for modern and future hydroclimate changes and their potential impacts to sensitive alpine ecosystems. This talk will highlight results from more than a decade of lake sediment studies in the Teton Mountain Range, WY with an emphasis on past hydroclimate evolution operating on multiple timescales (from decadal to millennial) and the responses of alpine catchments, glaciers, and ecosystems over the past ~15,000 years. We use traditional sedimentary parameters, including sediment accumulation rate, grain size distributions, and clastic sediment flux, to infer changes in snowpack-derived runoff in multiple high- and low- elevation sites from both glacial and non-glacial catchments, and assess alpine ecological changes by integrating biological sedimentary analyses with novel biomolecular techniques. We will discuss our results within the context of previous work in the region with the goal of providing an improved framework for understanding contemporary snowpack trends in Grand Teton National Park and the broader western US.

Limited directional change in mountaintop plant communities over 19 years in the Sierra Nevada and Great Basin, U.S.A.

Meagan Oldfather, USGS

Plant communities on mountain summits are thought to be particularly vulnerable to rapid climate change because plants in these communities are often long-lived, cold-adapted perennials with low dispersal ability. GLORIA (Global Observation Research Initiative in Alpine Environments) is an

international network and methodology for surveying mountain summits with the objective to assess global distributional shifts of alpine species in response to climate change. Synthesizing data across 8 GLORIA study regions in California and Nevada USA, we investigated temporal changes in plant communities on 29 arid mountain summits over 19 years. First, across all summits and regions, we found no change in species richness over time. Second, there was relatively high species turnover (22%) between the five-year survey intervals, but turnover was not significantly different from random expectation. Third, we observed a small but consistent signal of decrease in the relative abundance of cushions, graminoids and shrubs/trees over the study period. Community patterns were widely similar across regions, and suggest that climate change has not directionally impacted local colonization or extirpation of mountaintop species over this period, in contrast to observed impacts in less arid mountain systems globally. These findings highlight the potential for differing responses to climate change between temperature-limited and water-limited regions globally, as well as the lagged and variable nature of high elevation systems. Our findings fill a major gap on alpine plant community responses to climate change in the western United States and set the stage for a broader synthesis of GLORIA peaks across this region.

Data in Support of Ecological Understanding,

Wednesday, September 18

What do we know about climate change refugia in the mountains?

Toni Lyn Morelli, USGS - Northeast Climate Adaptation Science Center

Anthropogenic climate change is posing a serious risk to Earth's biodiversity. Mountains seem particularly exposed. As scientists and practitioners, we can document the erosion of our biodiversity, and can model how those changes will increase with each warming increment. However, we can also work together to identify ways to reduce those impacts. Climate adaptation focuses on conducting and translating research to minimize the impacts of climate change, including threats to biodiversity and human welfare. One adaptation strategy for montane ecosystems is to focus conservation on climate change refugia, areas that are relatively buffered from contemporary climate change over time and enable persistence of valued physical, ecological, and socio-cultural resources. Although attention to and understanding of climate change refugia has increased dramatically over the last decade, there is still limited understanding of the mechanisms that create refugia, and even less is known of how long the climate buffering can be expected to last at particular montane sites, or in the face of extreme climate events. Moreover, more research is needed on how refugia do, or don't, protect ecological and evolutionary processes. I will review the latest on this mechanistic understanding and discuss recent work focused on defining refugial capacity for management and conservation interventions.

From Weather Station to Microclimate: Modeling Strategies for Projecting Hourly Station Data Across a Virtual Temperature Network

Stu Weiss, Creekside Science

The climates near the ground in which organisms actually live are vastly different from standard weather station data, affected by insolation across terrain, cold air pooling, and wind exposure at the topoclimatic scale, and vegetation structure and fine-scale surface features at the microclimatic scale. Downscaling from weather stations to topoclimate and microclimate can combine sensor networks, environmental biophysics, terrain and canopy structure, and geostatistical projections. In this presentation, I demonstrate a proof of concept of using weather station data to drive hourly temperatures at multiple sensor microsites. I wedged iButton Thermochrons into grape clusters for one growing season in four vineyard microsites – two row sides in two vineyard blocks with different row directions. A simple neural net driven by CIMIS station inputs of air temperature, humidity, wind speed/direction, global insolation, and hour of day produced simultaneous predictions of hourly temperatures with a validation RMSE of <2°C, and accounts for non-linear interactions among the variables. Leverage of each input variable was consistent with environmental biophysics. Importantly, the effect of canopy shading was obvious from the leverage of hour as an input variable, obviating the need for detailed canopy measurements. A single season provides enough weather combinations for extrapolation to other years. The method can also be used in topoclimatic mapping, where inputs can be multiple weather stations that can capture lapse rates and temperature inversions. The method reduces the need for long-term hardware deployment once a calibrated “Virtual Temperature Network” has been established.

Climate Change as a Major Evolutionary Event With Cascading Impacts

Tom Whitham, Northern Arizona University

Plants are often locally adapted to their environment, but with rapid climate change, populations are becoming locally maladapted and dying out. Genetics is key to understanding climate change effects and identifying naturally occurring genetically appropriate stocks that can survive future conditions. Our work with cottonwoods and pinyons demonstrates five key points. First, climate change models that include genetics project that half of a tree’s current distribution will become so marginal that restoration efforts will fail. Tree genotypes from low elevation edge sites, intermittent streams and drought tolerant mycorrhizal mutualists are critical to save as they will become the source populations for higher sites that will become future edge populations. Second, because different tree genotypes differ in functional traits that are heritable, they support different communities of organisms from microbes to vertebrates such that conservation of tree genetic diversity preserves biodiversity. Third, with the ongoing megadrought, selection has changed the genetic composition of forests in as little as a single year resulting in a rapid evolution. Fourth, climate change as an evolutionary event on trees is equivalent or greater than the Black Death that killed off 30-50% of the human population that changed human genetics in the 1300s. With forests, evolutionary changes are occurring with legacy affects that will last 1000s of years. Fifth, we need a national network of experimental forests to test the genetic limits of individual tree species (see Congressional Bill HB5145). Climate scientists, geneticists, foresters, restoration biologists and politicians need to collaborate to mitigate these impacts.

Ongoing elevation-dependent warming in the northern Andes

Daniel Ruiz-Carrascal, Independent Consultant, Poleka Kasué Mountain Observatory, Colombia

The unusual upper tropospheric warming is having a negative impact on the integrity of high-altitude environments inhabiting the upper ranges of the northern Andes. In our research, we have gathered and processed regional and in-situ climate data from data-scarce Colombian páramo environments to deepen our understanding of the dynamics of the ongoing elevation-dependent warming, EDW. Our study is focused on the Ruiz-Tolima volcanic massif in the Colombian Central Cordillera, which used to be the largest glacierized extent in Colombia and one of the most extensively glacier-covered massifs in the northern Andes. The volcanic massif falls within the so-called northwestern South-America reference sub-region of the latest assessment report of the Intergovernmental Panel on Climate Change. Here we show that a rapid warming took place over the past 84 years, with the highest rates of warming occurring in the medium to upper tropospheric levels. EDW rates are consistent with the results of previous research efforts conducted in the central and southern tropical Andes, and add additional evidence of the threat being experienced by some of the world's main mountainous regions. We argue that the ongoing changes in environmental conditions are likely causing a long-term, severe, permanent dryness of the northern portion of the Andes. The consequences of this rapid destabilization are manifold and have serious implications for overall ecosystem processes, compromising the water and energy supply of tens of millions of inhabitants. Ambitious sustainable management strategies are now urgently required to protect these unique, rich, fragile, and highly endangered environments.

Subarctic Shifts: Ecosystem Change in Denali National Park

Johanne Albrigtsen, University of Nevada, Reno

Subarctic vegetation communities are changing. For example, in Denali National Park, balsam poplar trees are proliferating in landscapes where successional pathways were otherwise expected to lead to tundra ecosystems. We apply a snow-soil-vegetation interaction model to a classic chronosequence study in the subalpine zone of the Alaska Range to evaluate how water and carbon balances have changed across a set of different-aged terraces since 1958. This site was remeasured by the National Park Service in 2012, revealing a rapid increase in the distribution and abundance of balsam poplar trees over the 54-year period since the original study during which summer temperatures warmed by approximately 2°C. Summer temperature increases due to climate change likely explain much of the vegetation changes in Denali, but the non-uniformity and patchiness of these changes suggest that other processes are at play. Our work builds upon this unique historical dataset through both summer and winter field campaigns to identify how snow

accumulation and resulting insulation effects interact with soil edaphic factors and vegetation structure and function. Given that the snowpack and its 8-month duration can control soil temperature regimes and resulting vegetation growing conditions, and that snow accumulation patterns are heterogeneous due to wind-driven redistribution, we hypothesize that snow-soil-vegetation interactions are a key control over ecosystem changes in the subarctic. Our results indicate that snow depth, vegetation structure, and soil properties are indeed inter-related; snow-soil-vegetation interplay yields changes in carbon and water cycling that may eventually lead to the conversion of entire landscape mosaics.

Sounds of Change: Long-term monitoring of Lake Tahoe's bird populations in response to climate change

Shale Hunter, USDA Forest Service

Biodiversity in Lake Tahoe's ecosystems is ever changing, and understanding its status and dynamics is a critical part of sustaining the resilience of the basin's ecosystems. Climate is expected to be the primary driver of change for terrestrial and aquatic biota, accompanied by land use pressures, invasive species, and related disturbance processes such as fire. Historical datasets can serve a vital role in extending long term datasets into the past and provide context for changes observed into the future. The Tahoe Environmental Observatory Network (TEON) project is establishing a biophysical monitoring system throughout the basin as well as leveraging multiple historical monitoring datasets for terrestrial and lentic habitats from as early as 1995 in order to better understand the direction, magnitude, and location of changes we might expect to see into the future.the most readily detectible (and one of the most charismatic) class of wildlife described in our historic datasets, birds serve as an effective lens into historical change. Here we compare avian point count data from 20-year-old historical datasets (2002-2005) to contemporary data (2023-2024) at the same sites to evaluate changes in species composition and community structure across the basin. Future exploration will focus on climate- and human-driven changes to vegetation and habitat structure and their impact on Lake Tahoe bird populations.

Assessing the relative contributions and quality of long-term mountain climate monitoring stations in the Pacific Northwest

Rachel Fricke, University of Washington & National Park Service, North Coast and Cascades Network

Long-term mountain climate datasets are immensely valuable for understanding temporal climatological change and providing context to observed trends in alpine and subalpine ecosystems. However, maintaining climate data stations in dynamic environments requires significant upkeep, personnel hours, and funding. Gridded climate datasets interpolated from physical climate stations dispersed across the landscape span nationwide scales and offer an opportunity to estimate climatological conditions in remote locations. We sought to understand how similar these interpolated datasets (e.g., gridMET, PRISM, Daymet) are to local climate variable measurements recorded at climate stations across a range of locations and elevations. Here, we compare daily climatological time series (for maximum and minimum temperature, and precipitation) from 20 climate stations within the National Park Service's (NPS) North Coast and Cascades Monitoring Network (NCCN) to data at the same time frequencies from gridMET, PRISM, and Daymet. We used cross-validation analysis to assess how well paired in situ and interpolated measurements of precipitation and temperature at station locations align with one another at different temporal scales (daily, monthly, annual). Assessing the alignment of local and global datasets will help evaluate the accuracy and utility of interpolated climatological data in remote park-managed landscapes. Furthermore, our study will quantify the potential added value of incorporating NPS-operated climate stations into networks of stations informing interpolated datasets, particularly in mountainous environments where local stations are sparse.

Climate projection uncertainties hamper 21st Century sustainability planning in California

James Thorne, UC Davis

Regional sustainability requires informing climate-adaptive natural resource programs with accurate projections from global climate models (GCMs). However, the iterative nature of GCM publications can leave climate adaptation efforts uninformed about intensifying climate during the lag times between editions. This risk can be moderated by identifying effective climate dates, the comparison of current climate trends to future projections. Effective climate dating can help natural-resource adaptation programs anticipate potential impacts from intensifying climate change that are not identified in a given GCM edition. We compared mean decadal climate trends in California for nighttime temperatures (Tmin) and climatic water deficit (CWD) to 10 projected future scenarios developed by the California's Fourth Climate Change Vulnerability Assessment, and calculated effective climate dates. The GCM ensemble projections underestimate the Tmin warming rate since 2006 by 50%, overestimate annual precipitation, and project California's recent decadal averages for annual Tmin and CWD only by 2049 and 2080. Lack of tracking ongoing climate at ecoregional scales has resulted in missing annual Tmin warming since 1980 of 2.1^{o}C in the Sierra Nevada, 2.2 ^{o}C in the Cascade Ranges, and 2.6 ^{o}C in the ecoregion east of the Sierra Nevada. Over the same time, the three coastal ecoregions show decadal mean Tmin increases of 1.3 ^{o}C (northwestern CA), 1.5 ^{o}C (Central Western CA), and 1.8 ^{o}C (southwestern CA). The analysis process also revealed a 0.89 ^{o}C cold bias in the historical climate data that was used to bias correct the state-published GCMs. While ecological tipping points in terrestrial ecosystems are still being quantified, the use of effective climate dates can help to identify the speed with which California's climate is approaching them, and potentially to better anticipate climate impacts by calibrating published studies of disturbance intensities with updateable assessments of climate change intensification.

Early Career Research in the Mountains,

Wednesday, September 18

Monitoring the Mountains: A call to move beyond daily data and unlock new research opportunities

Anne Heggli, Desert Research Institute

Hydrometeorological monitoring networks in mountain environments provide essential data that have built the foundation of our collective understanding of mountain systems. From managing water resources to monitoring climate change and the associated ecological impacts, these observational networks allow us to improve models, calibrate remote sensing products, and examine interactions between the atmosphere, vegetation, soils, and streamflow. However, the majority of research today still uses daily data despite the prevalence of sub-daily data, underutilizing the investments made to advance monitoring networks. The transition from daily to sub-daily data to research mountain systems is not just a methodological enhancement; it represents a paradigm shift with significant implications for scientific research and resource management. In this presentation I will examine the research potential of ten years of ten minute data at the Nevada Climate-ecohydrological Assessment Network (NevCAN) in the Great Basin and show how embracing this untapped potential, we can maximize the investments in monitoring networks and achieve a more comprehensive understanding of the dynamic and vital mountain environments. This call to action encourages researchers to move beyond daily data and maximize the value of existing monitoring networks, unlocking new opportunities for research and practical applications in water resource management, ecological conservation, and climate adaptation.

Climate change impacts to hydrologic and biogeochemical function of glacierized costal watersheds in Southcentral Alaska

Anna Bergstrom, Boise State University

Glaciers can dominate the hydrologic and biogeochemical signatures (streamflow timing and chemistry) of the watersheds in which they reside. However, as climate change causes rapid glacier mass loss and altered precipitation patterns, our ability to predict changes to water and biogeochemical export signatures is dependent on our understanding of water source, flow paths, and land cover change across the entire watershed. We used remote sensing, source water characterization, and high frequency water chemistry monitoring to characterize the current hydrologic and biogeochemical function of a series of watersheds representative of different landscape types within the 340 km2 Nellie Juan Watershed on the Kenai Peninsula in southcentral

Alaska. Across all sub watersheds, groundwater is an important source of streamflow, particularly early and late in the snow-free season. Rain events produce high flow events that flush dissolved organic carbon. These events are dominant in the fall and through the winter at low elevation. We found that this region has been greening since the start of the Landsat 5 record in 1985; sparse tundra vegetation is establishing in areas previously covered by ice, particularly on south facing aspects. Increasing vegetation cover coupled with predicted increased rain for this region means we can expect more high flow events flushing solutes from the landscape with a carbon signature moving toward less labile humic carbon rather than more labile microbial carbon typical of glacier-dominated watersheds. Combined, this research helps us envision the future hydrologic and biogeochemical function of this region in a warmer, wetter, less icy future.

Precipitation Regime Shifts in High Elevations: Amplifying Flood Risks in a Warming Climate

Mohammed Ombadi, University of Michigan

Extreme precipitation events are increasing in frequency and intensity due to anthropogenic warming, posing significant challenges to water sustainability in mountainous regions. This study examines the impact of global warming on precipitation patterns in high-elevation areas of the Northern Hemisphere, focusing on the transition from snow to rain. Using climate reanalysis data and future model projections, it is shown that warming amplifies rainfall extremes by an average of 15% per degree Celsius—twice the increase expected from atmospheric water vapor alone. This amplification is driven by a shift from snow to rain, significantly heightening the exposure of high-altitude regions to hazards like floods, landslides, and erosion.the context of the Contiguous United States, this research explores the factors that influence flooding risk in mountainous hydroclimates, emphasizing the complex interactions among precipitation phase, topography, land cover, and hydrological processes. The findings identify high-elevation areas as critical “hotspots” for future flood risk, necessitating robust climate adaptation strategies to mitigate potential impacts. This study not only enhances our understanding of how extreme precipitation events evolve in mountainous settings but also contributes insights to reducing uncertainty in future climate projections related to rainfall extremes.

Lakes in Mountains,

Thursday, September 19

Linking mountain streamflow to near-shore metabolism in a large, oligotrophic lake

Kelly Loria, University of Nevada Reno

Upland processes like streamflow can influence nearshore lake productivity dynamics by modulating the timing and delivery of organic material and nutrients. The degree to which streamflow can influence nearshore productivity varies as a function of catchment characteristics and is largely unclear given the alternate influences of internal lake processes. In this study we monitored dissolved oxygen, streamflow, and nutrient concentrations, in the nearshore (i.e., littoral zone) of Lake Tahoe (USA) across multiple watersheds with differing flow regimes for three consecutive years to model daily nearshore metabolism. Nearshore locations impacted by inflowing streams tended to be more heterotrophic while areas away from streams were more autotrophic. Using Bayesian structural equation models we found the influence of streamflow was greater on the west shore, positively influenced gross primary productivity (GPP), and also indirectly decreased lake water temperature and benthic light. Additionally, the impact of upland processes like streamflow on nearshore metabolism varied with winter precipitation, indicating drier years may lead to increased GPP. Given the anticipated climate warming in western US mountain basins, changes to upland processes (i.e. warmer temperatures, prolonged droughts, and enhanced groundwater nutrient delivery), may also facilitate enhanced GPP in oligotrophic mountain lakes.

Oxygen Under Ice: using long term monitoring to understand inter-annual variability

Katie Gannon, University of Colorado Boulder

Seasonal ice cover in Rocky Mountain alpine lakes is decreasing 50% faster than in lower elevation lakes across the northern hemisphere. Shortened ice duration impacts subsequent spring and summer water temperature and dissolved oxygen (DO) concentrations, which in turn impacts the production and release of nutrients, greenhouse gasses, and metals from the water column and sediments. Between lakes, differences in under-ice water temperature and DO concentration are mediated by lake size and morphology. However, within a given lake, the drivers of interannual variability in temperature and DO concentration under ice are still unclear because multi-year datasets are rare. Potential drivers of interannual variability include snow accumulation, timing of ice on, and lake ice thickness. Additionally, recent work in Arctic lakes indicates that changes in ice cover duration and spring ice out timing can impact temperature and DO concentration in hypolimnion waters in the subsequent summer. However, it is unclear if such carry over effects also occur in high elevation lakes at lower latitudes. In this study we use a unique, 5+ year dataset from two long term monitoring programs in high alpine Rocky Mountains lakes (Green Lake 4 in Green Lakes Valley at the Niwot Ridge LTER and a nearby long term monitoring sites in Rocky Mountain National Park) to investigate: 1) the drivers of interannual variability in under ice dissolved oxygen dynamics, and 2) the potential impact of changes in spring ice off timing on hypolimnion temperature and DO in the subsequent summer season.

Responses of high-elevation lake biogeochemistry to global change: synthesizing 30+ years of data across the southern Rocky Mountains

Isabella Oleksy, University of Colorado Boulder

Lakes and streams situated in high-elevation watersheds are sensitive indicators of climate-related and other environmental change. At the highest elevations in the southern Rocky Mountains (SRM), mountain landscapes are frozen much of the year, leading to hydrology that is tightly coupled to snowpack and the cryosphere more generally. With a warming climate altering timing and magnitude of snowfall and rapidly shrinking glaciers, it is important to understand how mountain headwater aquatic ecosystems are responding to these widespread climatic-driven changes so that we can better understand future changes in ecological function. Over the past thirty years, mean annual air temperature has increased by 0.5 to 1.0oC per decade across the mountain west and warming trends in the summer months are particularly pronounced in the SRM. While the effects of elevated temperature in snow-dominated, high-elevation catchments are well documented, those associated with changing precipitation and hydrological regimes are less certain, along with projections regarding future precipitation patterns or drought. High-elevation lakes integrate these climatic signals, as well as changes in watershed processes, in their aquatic biogeochemistry. Here, we are beginning to synthesize long-term biogeochemical data from high-elevation lakes in the SRM, including Loch Vale Watershed, Green Lakes Valley, and other lakes within the US Forest Service, Rocky Mountain Region (R2), all of which contain wilderness lake water quality records dating back to the mid- 1980s and 1990s. We leverage this unique dataset to evaluate the influence of changing precipitation, atmospheric inputs, and climate stressors on lake biogeochemistry, and ask whether lake responses are homogenous or if there are factors that make some lakes more sensitive than others to global change.

Sensitivity of long-term ecological data: An analysis of the effects of reduced sampling frequency on water quality trends in Loch Vale

Adeline Kelly, University of Colorado INSTAAR

Long-term ecological data are crucial for understanding how various aspects of ecosystems are changing in response to climate change and are often more powerful drivers of environmental policy and resource-based management than short-term studies. Long-term ecological data for high-elevation systems are of particularly notable value given both the amplification of warming rates at higher altitudes and the coupling between high-elevation lakes and the cryosphere. Here, we present a 25-year time series of aquatic biogeochemical data from the Loch Vale Watershed in Rocky Mountain National Park and analyze the impact of reduced sampling frequency on long-term trends. Historically, the Loch outlet has been sampled weekly and strong linear increases have been consistently observed in water temperature, ANC, pH, and conductivity, while statistically significantly linear decreases have been observed in nitrate and total dissolved nitrogen. We randomly subsampled these data to represent biweekly and monthly sampling frequencies, and found that most trends are not preserved or are weakly preserved when sampling frequency decreases. This highlights the need to not only continue to collect long-term ecological data, but to do so at a sampling frequency that accurately represents both the rate and degree of change occurring in these systems.

Seasonal chemistry and ecology of high elevation, Wyoming lakes

Casey Brucker, University of Wyoming

High-elevation watersheds are valuable freshwater resources facing increasing anthropogenic disturbances and a rapidly changing climate. These compounding impacts cascade through the ecosystem leading to increased water temperatures and nutrients, modified hydrological regimes, and ultimately altered biological processes and biotic communities. Despite their value, little is known about year-round, high-elevation, water body conditions, specifically winter and within-lake, ice-on conditions. We examined seasonal trends in water chemistry, seston stoichiometry, chlorophyll-A, and zooplankton community structure in seven high elevation lakes (2180-3280 m) in the plains and montane habitats of southeastern Wyoming. Plains and montane lakes show distinct differences in salinity, ice phenology, hydrologic controls, geology, and vegetation, despite their close proximity (53 km radius) and, for some, their hydrologic connectivity. Connected lakes showed diverging water chemistry and seston nutrient composition during phases of hydrologic isolation. The four highest lakes had much longer ice-on periods, and showed that elevation was an important factor associated with surface temperature, specific conductivity, and pH variability. Seston and zooplankton productivity was still evident in most lakes throughout the ice-on period.

The examination of seasonal changes in water, seston, and zooplankton stoichiometry has led to a better understanding of the importance of winter lake conditions, and unexpected insights into extreme events that can alter lake function.

The Effects of Climate on Thermal Stability Observed through a Decade of High-Resolution Measurements from Uinta Mountain Lakes, Utah, USA

Katrina Moser, The University of Western Ontario

Mountain regions are often characterized by many, oligotrophic lakes, which are important ecosystems and highly sensitive to environmental change, including climate change. Anthropogenic global warming has caused the average Earth temperature to increase, but in mountain regions this warming is occurring faster than other regions, making these lakes more vulnerable to climate change. The objective of our research is to show how mountain lake ecosystems are responding to future warming use negative binomial modelling. We explore the effects of air temperature, snowpack and precipitation on the thermal stability of five lakes (two subalpine lakes; two alpine lakes and one in between) in the Uinta Mountains, Utah. We deployed arrays of temperature and light data loggers in each lake to collect data every hour for 365 days a year for 10 years (2011-2021). We used rLakeAnalyzer to calculate daily Schmidt Stability (SS) from July 1-Sept. 14. Our data showed that surface temperatures of subalpine lakes are warmer than alpine lakes, but that deep water temperatures in alpine lakes are warmer than in subalpine lakes, suggesting that SS should be greater in subalpine lakes. Modelling showed lake depth was more important than elevation, but that elevation was important, in determining SS, with deep, low elevation lakes having the highest SS. The full model used to understand how climate influenced SS included weekly average air temperature (°C), total weekly precipitation (mm), total snow water equivalent (mm), the year and lake as random effects, and an interaction term between lakes and each climate variable. Our results showed that air temperature had the most influence on SS. Modelling showed that for all five lakes, warming temperatures led to higher SS. Snowpack was less influential on SS than temperature, only causing a slight decrease in SS in three of the five lakes. As air temperatures continue to rise, thermal stability will continue to increase, altering these pristine alpine lake ecosystems.

Spatial-Temporal variation of organic matter and nutrients in two mountains lakes

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Sedimentation in lakes is crucial for removing particulate organic material (POM)associated nutrients and pollutants from the water column, thus stabilizing aquatic. Various physical, chemical, and biological processes influence POM fluxescomposition, which are spatially and vertically heterogeneous. This leads toin sediment fluxes and POM composition across a lake. To understand this, we placed sediment traps at various locations (near-shore to off-shore) and(2 to 28 meters) in two mountain lakes in North California. Monthly during the, we retrieved these traps to analyze sediment dry mass accumulation rates andof C, N, P, and stable isotopes of C and N. Our findings show significantin sediment mass accumulation rates during the summer and across the lake.areas (less than 5 meters deep) contain a higher proportion of terrestrial POM,deeper samples have more autochthonous organic matter. A vertical variation inisotopic signal of δ15N could indicate changes in nitrogen sources used byor degradation processes in the water column. Phosphoruswere higher in off-shore non-vegetated areas than in near-shoreones. These observations highlight vertical and horizontal differences inrates and compositions, which have important implications for lake.

Regional Wildfires Impact the Ecological Structure of Castle Lake (CA, USA)

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As the wildfire seasons are increasing worldwide, smoke from fires can have far-reaching impacts on aquatic ecosystems located away from burned areas. After 45 consecutive days of exposure to regional wildfire smoke, we determined the ecological response in a mountain lake's nearshore and offshore (shallow and deep) habitats (Castle Lake, CA, USA). Smoke increased particle concentration in the air and the water column, which decreased underwater ultraviolet-B radiation by 65% and photosynthetically active radiation (PAR) by 44%. Lake habitats responded differently to changes in light from smoke. The shallow offshore algae productivity increased during smoke cover because of decreased UV-B radiation. Nearshore benthic algae productivity did not change, possibly reflecting adaptation to high-intensity UV-B light in these habitats. The decrease in PAR due to smoke did not reduce productivity in either of these habitats because even during the smoke periods, midday maximum PAR intensity at shallow waters reached values that saturate productivity at these habitats. However, the deep offshore productivity decreased due to reduced

PAR radiation at depth. The divergent shift in shallow offshore production led to the relative increase in the contribution of this habitat to whole-lake productivity. Remarkably, zooplankton biomass, community composition, and diel vertical migration patterns were not significantly different; however, trout were notably and uncommonly absent from the nearshore habitat. Our study indicates the varying impacts of wildfire smoke on lake-specific habitats that can alter energy flows and food web structure.

WILDFIRE SMOKE AFFECTS MOUNTAIN LAKE AND POND THERMAL AND METABOLIC REGIMES: A WATERSHED-SCALE INVESTIGATION

Mary (MJ) Farruggia, University of California Davis

Climate change is increasing the likelihood of extreme fires globally. These wildfires produce large smoke plumes that can decrease solar radiation and deposit ash particles across ecosystems. Several key physical, chemical, and biological processes in aquatic ecosystems are controlled by factors affected by smoke. However, the effects of smoke on lake and pond ecosystems are still not well known. studied effects of wildfire smoke on 2 lakes and 4 ponds in a representative high-elevation (2800-3230 m) watershed in the Sierra Nevada mountains of California. Smoke from major wildfires in 2020 and 2021 covered our study watershed for an average of 49 days between August and October. Using a network of high frequency measurements of water temperature and dissolved oxygen, we found that although lakes and ponds responded synchronously to smoke, the magnitude of effects varied. In general, thermal responses were clearest. Smoke reduced water temperature, with the magnitude of response controlled in part by waterbody size. Changes in rates of primary production associated with smoke were more varied, but also tended to scale with waterbody size. These results suggest that the impacts of smoke on small lakes and ponds are mediated by multiple factors, but that smaller waterbodies may be particularly vulnerable to the effects of smoke. Understanding the factors that mediate lake and pond sensitivity to smoke is a priority given current and projected wildfire regimes in a climate-modified world.

Snow, Forests, Fire and Management,

Thursday September 19

Before a Fire: Snow matters to Sierra Nevada Forests

Anne Nolin, University of Nevada, Reno

Sierra Nevada forests have been experiencing dramatic increases in fire in recent decades and these have been extending into the seasonal snow zone. This study used a novel remote sensing approach to map late summer photosynthetic activity in the fire-prone evergreen forests of the Sierra Nevada ecoregion. The Chlorophyll-Carotenoid Index, (CCI) shows a significant negative trend throughout the Sierra Nevada for the period 2000-2023. A similar trend towards earlier Snow Disappearance Date (SDD) is seen across the region for the same period. There is a significant correlation between SDD and CCI, indicating that SDD appears to serve as a proxy for late summer forest moisture stress. For years with early SDD, such as 2021, moisture stress prevails across Sierra Nevada montane forests and appears to be amplified by high June-August vapor pressure deficit. Conversely, in years with late SDD, such as 2023, late summer forest CCI is high, indicating continued forest photosynthetic activity through the dry season. These results suggest that SDD has predictive power for late summer forest moisture stress in this fire-prone regions.

Snow refugia: Exploring snow dynamics across a gradient of dormant season canopy cover

Alexej Siren, University of New Hampshire

Climate change is diminishing seasonal snow cover in temperate regions with negative consequences for human, natural, and physical systems. Conserving and creating snow refugia is crucial to mitigate these impacts. Montane forests host a range of structural characteristics that can influence snow, yet most studies in North America exploring the effects of forest canopies on snow have focused on western coniferous forests and compare open versus closed canopy conditions. However, most coniferous canopies, which have leaves present year-round, likely affect snow dynamics in fundamentally different ways than deciduous or mixed canopies that lose all or some of their leaves during the dormant season. We propose that along a gradient of dormant season canopy cover (DSCC), peak snowpack depth will be greatest when canopy-mediated effects of snowfall interception are balanced against snowpack sheltering. As an initial test of our hypothesis, we use three northeastern US case studies spanning the DSCC gradient (low, medium, and high-density canopy cover). Medium DSCC forests (25-50% DSCC; mixedwood forests), exhibited the deepest peak snowpacks, likely due to reduced snowfall interception and reduced snowpack loss. By investigating snow dynamics in forests along the DSCC gradient, we reveal important patterns that may be missed in studies limited to low versus high DSCC contrasts and emphasize the potential of medium DSCC forests as snow refugia. Measurements of snowpack depth and timing across a wider range of forest canopies would advance understanding of canopy-snow interactions and support management of northeastern forests and snow-dependent species in the face of climate change.

Landscape-Scale Forest Restoration Can Provide a Long-Term Drought Hedge in the Central Sierra Mountains

Eli Boardman, University of Nevada, Reno

Forest restoration in the central Sierra mountains of California and Nevada can provide a long-term hedge against future droughts with limited risk from higher peak flows. Forest thinning and managed fire are widely expected to improve forest resilience and water security, but few studies have directly simulated the multi-decadal landscape-scale hydrological outcomes of actionable forest restoration scenarios subject to climate change. By updating a distributed process-based hydrological model (DHSVM) with vegetation states from a distributed forest ecosystem model (LANDIS-II), we simulate the water resource impacts of alternative forest management scenarios targeting partial or full restoration of the historic disturbance return interval. In a thinner restored forest, our results show 4-9% more total reservoir inflow through the end of the century and 8-14% more inflow in dry years. Sub-watershed heterogeneity can result in greater than 20% increases in local streamflow generation from densely forested catchments. The volume of additional water yield attributable to forest restoration is about 5x less sensitive to uncertainty in the future climate compared to total water yield, indicating a partial decoupling of restoration-induced streamflow gains from yearly precipitation. As a result, forest restoration would be especially valuable for water supply during dry years or in a drier future climate. Since compensation between overstory and understory limits net changes in transpiration, our results show that 73% of streamflow gains from forest restoration are attributable to decreased canopy interception loss. Our study can help incentive forest restoration by increasing confidence in the potential water resource benefits.

Future of Fire: Science, Resilience, and Action in a Burning World,

Thursday, September 19

Reimagining science, management, and culture: catalyzing innovation for accelerated fire-climate adaptation

Carolyn Enquist, U.S. Geological Survey

Climate-driven changes in fire regimes, coupled with decades of fire exclusion, interacting disturbances, and an expanding wildland-urban interface, have urgent implications for ecosystems and society. Land and cultural resource managers are increasingly challenged to develop and adopt strategies that facilitate fire-climate adaptation and societal resilience at an accelerated pace and scale. Historical reference conditions are becoming less relevant, underscoring the need for refined and/or novel management interventions and prioritization approaches. Examples include applying Rx fire outside of typical burning windows, providing more initial attack resources in high-risk areas, planting drought-adapted varieties or species after wildfire using risk-based prioritization (e.g., climate-adapted refugia, etc.) and decision frameworks (e.g., RTT, RAD, etc.). Moreover, holistic risk framing has further evolved conventional approaches to managing fire in the WUI and beyond, opening new opportunities for cultivating connections within an expanding community of practice. Accordingly, new and emerging agency policies require broadening the partnership space to include marginalized communities in both rural and urban areas, in addition to engaging Indigenous leaders who employ traditional methods of tending, gathering, and low-intensity cultural burning, further enabling co-management of ancestral lands. Yet, widespread adoption of these approaches is often difficult due to balancing societal expectations with uncertainty in outcomes, particularly in the context of long-held, risk-averse cultural norms within most management agencies. Embracing risk tolerance through adoption of safe-to-fail policies and learning to “fail forward” are becoming increasingly critical to catalyzing innovative adaptation actions at a pace required to meet the challenge.

Deciding the fires of the future: an early career perspective on wildfire socio-environmental research

Aaron Russell, US Geological Survey Southwest Biological Science Center

Mountainous landscapes in the western United States will experience more significant effects from climate change related to aridification, rising temperatures, and incidence of extreme events like droughts than many other lands. Additionally, more complex terrain, expanding human communities in the wildland urban interface, and an accumulated 'fire-debt' in burnable fuels continue to make wildfire risk a high priority area of interdisciplinary research and practice. Wildfire risk analysis combines innovative data collection, modelling, and spatial analysis with the input of stakeholders, resource managers, and other experts on the exposure and susceptibility of values at risk. Within the overall topic of wildfire science, risk analysis presents a wicked problem that combines the urgency of crisis decision making and emergency management with the more long-term effort of improving the science through better integration of bio-physical and socio-cultural elements. Recent efforts have proposed novel communication frameworks to work towards goals related to beneficial uses of fires, including managed wildfires. However, unique cases demonstrate where more creative collaboration is needed and possible. Here, we discuss the applicability of such a fire-use decision model and then discuss ongoing efforts by the US Geological Survey to better define values at risk to wildfire for sensitive areas or specific land-management missions.

Synthesizing fire regime departure with open accessible science for resilient forest management

Michael Koontz, Vibrant Planet, PBC

Reducing wildfire risk is a top priority in mountain communities throughout the western United States. Proactive action is often constrained by a lack of interoperable data, challenges to consensus building, limited resources, and incomplete accounting of direct and indirect benefits. Vibrant Planet offers a cloud-based, collaborative decision support tool to help managers prioritize the right actions in the right places to reduce wildfire risk and increase socioecological resilience. Here, we report a west-wide synthesis of fire regime departure to identify opportunities for restoring degraded ecosystems as a co-benefit to management for fire risk. We show how quantitative evaluation of resources using departure can shift targets away from simple "acres treated" metrics to better align with state-of-the-science management goals and recent Federal legislation.

Advancing Wildfire Resilience with Planscape

Rob Lawson, University of San Francisco and Spatial Informatics group

The increasing frequency and intensity of wildfires present significant challenges to both ecological systems and communities, particularly in mountain regions like the Sierra Nevada. Planscape, a web-based tool stewarded by Spatial Informatics Group (SIG), offers a comprehensive solution to these challenges by empowering regional planners to prioritize landscape treatments that mitigate fire risk, enhance ecological benefits, and adapt to climate change.this presentation, I will provide an overview of the future of Planscape, highlighting its innovative features and substantial progress in the Sierra Nevada region. By leveraging best-in-class modeling, primarily developed by USFS R&D, Planscape enables users to explore, plan, and evaluate various land management scenarios. The tool integrates extensive datasets —including fire risk, carbon sequestration, biodiversity, and more—facilitating data-driven decision-making. The in-development modules add the ability to measure impacts of specific treatments and incorporate climate change impact evaluations.success stories from the Sierra Nevada will be showcased, including the use of the workflow by UMWRA in the Stanislaus and Eldorado National Forests, demonstrating how the free tool fosters wildfire resilience and ecological health. Additionally, I will expand on our national-scale efforts, illustrating how the tool is being adapted and deployed across diverse U.S. landscapes, including collaborations with state and federal agencies, as well as indigenous communities.us to explore how Planscape is transforming wildfire management and paving the way for resilient and sustainable landscapes, ensuring that our communities and ecosystems are better prepared for the future.

Forests, Climate, Management, and Fire,

Thursday, September 19

Multi-attribute Evaluation of Sierra Nevada Mixed Conifer Forest Simulations Under Historical Environment, Management and Fire Regimes

Lara Kueppers, UC Berkeley, Berkeley Lab

Projecting future Sierra Nevada Mixed Conifer (SNMC) forest structure, carbon and fire regimes under scenarios of climate and management changes has taken on both scientific and societal importance. To have confidence in projections of the future, it's critical that models be evaluated against a suite of observations not just of present day forest conditions, but also historical conditions and response to change in space and time. We have assembled benchmarks of SNMC forest structure and fire regimes representing forest conditions prior to the 20th c. period of active fire suppression, recent forest conditions, and changes over the 20th c. and in response to forest management for evaluation of the Functionally Assembled Terrestrial Ecosystem Simulator (FATES). We established a suite of FATES parameterizations that are consistent with benchmarks under pre-industrial CO2 concentrations, climate and ignition frequency, both with and without resprouting oak and shrub plant functional types. We found that multiple alternative parameterizations can simulate pre-20th c. forest biomass, basal area, composition, density and fire return interval. Simulations through the 20th c. yield changes consistent with present day forest structure, and allowed us to disentangle effects of fire exclusion, increasing CO2, harvest and climate change. Ongoing work involves benchmarking a new prescribed fire module using a synthesis of field experiments across the SNMC domain.

Initializing a process-based vegetation model, FATES, with airborne-derived forest structure and composition in a fire-mediated landscape

Anna Spiers, Lawrence Berkeley National Lab

Climate and land use change are modifying fire regimes and subsequent forest response. Terrestrial biosphere models allow us to study conditions for fire ignition, the subsequent changes in canopy structure and composition, and recovery trajectories. The Functionally Assembled Terrestrial Ecosystem Simulator (FATES) simulates structurally and functionally diverse forests and the impacts of fire in these ecosystems. However, it is challenging to obtain initial conditions for FATES that span the observed variation across the landscape. Therefore, we developed a workflow to initialize FATES using airborne hyperspectral and lidar remote sensing data, calibrated with

species and tree size from forest inventories. analyzed the performance of FATES in a fire case study when initialized with plot-level forest inventory data compared to landscape-scale remote sensing data. Data were from the National Ecological Observatory Network across three sites in California's southern Sierra Nevada. We evaluate how well FATES is able to capture the impacts of fire under these different initializations for the 2020 Creek Fire, which burned partly through one of the three sites. We extract forest structure properties from lidar with machine learning models with R2 ranging from 0.76 (aboveground biomass) to 0.88 (stem number density). Next, we classify functional diversity in mixed conifer forests with >85% out-of-bounds accuracy using imaging spectrometer data and lidar-derived topographic data in a random forest model. Combining the large-scale coverage of remote sensing and the mechanistic focus of FATES provides a unique opportunity to understand how structure and function mediate forest response to fire.