Conference Purpose

MTNCLIM aims to advance the sciences related to climate and its interaction with physical, ecological, and social systems of western North American mountains. Within this arena, MTNCLIM goals are to:

- Provide a biennial forum for presenting and encouraging current, interdisciplinary research through invited and contributed oral and poster sessions.
- Promote active integration of science into resource-management application through focused sessions, panels, and ongoing problem-oriented working groups.
- Advance other goals of CIRMOUNT through ad hoc committees, networking opportunities, co-hosting meetings, and targeted fund-raising efforts.

In 2014 a pre-conference field trip to the Uinta Mountains, a post-conference workshop for resource managers, and several work group meetings are also scheduled.

Conference Sponsors

MTNCLIM is sponsored by the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT), with coordination and support from the following agencies and institutions:

- USDA Forest Service, Pacific Southwest and Pacific Northwest Stations
- DOI USGS, John Wesley Powell Center for Earth System Analysis and Synthesis, and Southwest Climate Science Center
- University of Arizona, Institute of the Environment and School of Natural Resources and the Environment
- NOAA, Earth Systems Research Lab
- University of California, Scripps Institution of Oceanography
- Desert Research Institute, Western Regional Climate Center
- Western Washington University, Department of Environmental Sciences
- University of Idaho, Department of Geography
- University of Utah, Department of Geography
- Mountain Research Initiative, Bern, Switzerland

Steering Committee

Connie Millar, USDA Forest Service, Pacific Southwest Research Station (chair)
Jill Baron, US Geological Survey
Andy Bunn, Western Washington University, Department of Environmental Sciences
Henry Diaz, NOAA, Earth Systems Research Laboratory
Mike Dettinger, USGS Water Resources Division, and University of California, Scripps Institute of Oceanography
Gregg Garfin, University of Arizona, School of Natural Resources and the Environment, and the Institute of the Environment
Greg Greenwood, Mountain Research Initiative, Bern, Switzerland
Jeff Hicke, University of Idaho, Department of Geography
Jeremy Littell, USGS, Alaska Climate Science Center
Dave Peterson, USDA Forest Service, Pacific Northwest Research Station
Kelly Redmond, Desert Research Institute, Western Regional Climate Center

Logistics Coordinator: Diane Delany, USDA Forest Service, Pacific Southwest Research Station

CIRMOUNT website: www.fs.fed.us/psw/cirmount
Tenth Anniversary Conference

MtnClim 2014

www.fs.fed.us/psw/mtnclim

September 15-18, 2014
Homestead Resort
Midway, Utah

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Autumn near Cascade Springs in eastern foothills of the Wasatch Range, Utah;
Cascade Mountain rises in the background
AGENDA
MTNCLIM 2014
Homestead Resort, Midway, Utah
September 15-18, 2014
www.fs.fed.us/psw/mtnclim

Speakers’ names are given for oral presentations; additional authors are included with abstracts

Sunday, September 14, 2014
8:00am-5:30pm Field Trip to Uinta Mtns, Mirror Lake Highway (lunch and vehicles provided). Forest Health, Biodiversity, Climate Change and Climate Adaptation Issues
Trip Leader: John Shaw (US Forest Service)
Meet in front of the Conference Center at the fountain with lawn, ready to depart by 8am.

Monday, September 15, 2014
4:00pm Check-in opens for Homestead Resort (rooms)
4:00-6:00pm MtnClim Registration, Garden Meeting Room, Homestead Resort
6:00-7:30pm Welcome Dinner, Pavilion Dining Room, Homestead Resort
7:30-9:00pm MtnClim 2014 Convenes, Garden Meeting Room
Invited Talk: Round-up of MtnClim Weather Since 2012
Kelly Redmond, Regional Climatologist and Deputy Director
Western Regional Climate Center, Desert Research Institute, Reno, NV

Tuesday, September 16, 2014
8:00-9:00am Keynote Address. Moderator: Henry Diaz, NOAA ESL, Tucson, AZ
Opportunities for Climate Adaptation Science and Solutions in Western Mountains
Kathy Jacobs, Director, Center for Climate Adaptation Science and Solutions
University of Arizona, Tucson, AZ
9am–noon Mountain Refugia, How They Work, and Options for Climate Adaptation
Conveners: Connie Millar, US Forest Service, PSW Research Station, Albany, CA, and Mike Dettinger, USGS, La Jolla, CA
9:00-9:25am Steve Jackson, DOI, SW Climate Science Center, Tucson, AZ
The Roles of Mountain Refugia in Past and Future Climate Changes
9:25-9:50am David Whiteman, Dept of Atmospheric Sciences, University of Utah, Salt Lake City, UT
Topoclimatic Variations in Temperature and Winds as the Basis for Mountain Refugia
9:50–10:20am Break
10:20-10:45am Solomon Dobrowski, University of Montana, Missoula, MT
Mountain Refugia and the Velocity of Climate Change
10:45-11:10am  Toni Lyn Morelli, Northeast Climate Science Center, U Mass, Amherst, MA  
*Climate Change Refugia as a Tool for Climate Adaptation*

11:10-11:35am  Deanna Dulen, Devils Postpile National Monument, Mammoth Lakes, CA  
*NPS Climate Change Response Leadership: Service Wide, Regional, and at Devils Postpile. National Monument Climate Change Refugia as a Tool for Climate Adaptation*

11:35-11:55am  Contributed Session  
Ian Billick, Rocky Mountain Biological Lab, Crested Butte, CO  
*The Role of Field Stations in Fostering Research on Mountain Ecosystems*

Noon–2:00pm  Lunch and free time

2:00–5:30pm  Contributed Session. Moderators: Lara Kueppers, Lawrence Berkeley National Laboratory, Berkeley, CA, and Phil van Mantgem, USGS Redwood Field Station, Arcata, CA

2:00-2:20pm  Andy Bunn, Dept of Environmental Science, Western Washington University, Bellingham, WA  
*Thresholds in Growth of Bristlecone Pine with Small Changes in Elevation in the White Mountains of California, USA*

2:20-2:40pm  Matthew Bekker, Department of Geography, Brigham Young University, Provo, UT  
*Lessons from Centennial- and Millennial-length Reconstructions of Northern Utah’s Hydroclimate from Tree Rings*

2:40-3:00pm  Daniel Barandiaran, Dept of Plants, Soils, and Climate, Utah State University, Logan, UT  
*Snow Water Equivalent Reconstruction Using FIA Tree Ring Data*

3:00-3:20pm  Erin Conlisk, University of California, Berkeley, CA  
*Modeling Subalpine Conifer Response to Climate Change with Data from a Warming Experiment*

3:20-3:40pm  Steve Kroiss, University of Washington, Department of Biology, Seattle, WA  
*Population Dynamics Across Tree Elevational Ranges: Implications for Climate Change Responses*

3:40–4:00pm  Break

4:00-4:20pm  Charles Truettner, NatureTrends, LLC, Crested Butte, CO  
*An Upward Shift of Engelmann Spruce on the Pinaleño Mountains, AZ, USA*

4:20-4:40pm  Katherine Renwick, Dept. of Ecosystem Science and Sustainability and the Graduate Degree Program in Ecology, CO  
*Climate Change Impacts at the Range Margins of Rocky Mountain Tree Species: Interactions with Disturbance and Implications for Future Forests*

4:40-5:00pm  Kaitlin Lubetkin, University of California, Merced, CA  
*Responses of Conifers Encroaching into Subalpine Meadows in the Central Sierra Nevada to Climate Variability*

5:00-5:20pm  Stu Weiss, Creekside Center for Earth Observation, Menlo Park, CA  
*Up, Down, and Sideways: Species Range Shifts in the White Mountains under Climate Change*

6:30pm  Dinner, Pavilion Dining Room, Homestead Resort

Evening:  Poster Session
Wednesday, September 17, 2014

8:00-9:00am  Ten Year CIRMOUNT-MtnClim Anniversary
Moderator: Connie Millar, USFS PSW, Albany, CA

Henry Diaz, NOAA, Earth Systems Lab, Tucson, AZ
*Climate Science and Adaptation in Western Mtns: Where We’ve Been, and Where We Need to Go*

Julio Betancourt, USGS, National Research Program, Reston, VA
*Patterns and Sources of Seasonal Timing Variability in Hydroclimate and Phenology Across the American West and U.S.*

9:00-10:00am  Panel Discussion
*Accelerated Warming at High Elevations and Implications for Climate Adaptation*
Moderator: Greg Greenwood, Mountain Research Initiative, Bern Switzerland

Panelists:
Imtiaz Rangwala, Earth Systems Lab, NOAA, Boulder, CO
Nick Pepin, Department of Geography, University of Portsmouth, Portsmouth, UK
Justin Minder, Dept of Atmospheric and Environmental Sciences, SUNY, Albany, NY:
Chris Daly, PRISM Group, Oregon State University, Corvallis, OR

10:00–10:30am  Break

10:30–12:10pm  Contributed Session. Moderator: Jill Baron, USGS, Boulder, CO

10:30-10:50am  Mike Dettinger, U.S. Geological Survey, Scripps Institution of Oceanography, La Jolla, CA
*Regional-Pattern Scaling in Mountainous Terrains—Where and When Will Downscaling Perform Well in the Southwest?*

10:50-11:10am  Jared Oyler, College of Forestry and Conservation, University of Montana, Missoula, MT
*Artificial Amplification of Elevation-Dependent Warming in the Western U.S.*

11:10-11:30am  Christopher Crawford, Oak Ridge Associated Universities, Oak Ridge, TN
*Snowmelt Runoff Modeling in the Upper Colorado River Basin Using Modis Fractional Snow Cover*

11:30-11:50am  David Inouye, Dept. of Biology, University of Maryland, College Park, MD, and Rocky Mtn. Biological Laboratory, Crested Butte, CO
*Varying Temporal Scale of Climate Control of Flowering at High Elevation in the Colorado Rocky Mountains*

11:50-12:10pm  Karen Pope, USDA Forest Service, PSW Research Station, Arcata, CA
*A Deadly Disease in a Changing Climate Causes Tough Times for Montane Frogs*

12:10–1:30pm  Lunch

Contributed Session continued

1:30-1:50pm  Chris Daly, PRISM Climate Group, Oregon State University, Corvallis, OR
*PRISM Update: What’s New and What’s Next?*
1:50–5:15pm  **Machida Session: Coupled Human-Natural Systems**  
Conveners: Greg Greenwood, Mountain Research Initiative, Bern Switzerland, and Gregg Garfin, Institute of the Environment, University of Arizona, Tucson, AZ

1:50-2:30pm  **Part 1: Understanding Human-Environment Interactions Through the Institutional Analysis and the SES Framework Lens**

Catherine Tucker, Indiana University, Bloomington, IN, and Marty Anderies, Arizona State University, Tempe, AZ

2:30–3:00pm  **Break**

3:00-4:25pm  **Part 2: Reality, How Theory Relates to It, and What Are the Next Steps for Research?**

Tim Duane, UC Santa Cruz, CA and USD School of Law (visiting), La Jolla, CA

*Sandra Lee Pinel, MtnSEON NSF Research Collaborative, Universidad Técnica Particular de Loja, Ecuador*

*Understanding Multi-Jurisdictional and Collaborative Governance as Legal Pluralism*

Derek Kauneckis, Political Science Department, University of Nevada, Reno, NV


Marty Anderies, Arizona State University, Tempe, AZ

*Institutions, Biophysical Context, and the Robustness of Small-Scale Mountain Irrigation Systems*

Barbara Cosens, University of Idaho, College of Law, Waters of the West, Moscow, ID

*Adaptive Governance in the Headwaters: The Resilience and Law Project*

4:25-5:15pm  **Part 3 (Panel): (How) Is This Kind of Science Helpful?**

Moderator: Gregg Garfin, University of Arizona, Tucson, AZ

**Panelists:**

Eric Lindquist, Public Policy Research Center, Boise State University, Boise, ID

Maura Olivos, Alta Ski Area, Alta, UT

Marcie Demmy Bidwell, Mountain Studies Institute, Silverton, CO

6:30pm  **Dinner**, Pavilion Dining Room, Homestead Resort

8:00pm  **Evening Session.** Moderator: Deanna Dulen, NPS Devils Postpile NM, Mammoth Lks, CA

John All, American Climber Science Program and Department of Geography and Geology, Western Kentucky University, Bowling Green, KY

*Mountain Climate Science and the American Climber Science Program*

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**Thursday, September 18, 2014 (morning)**

8:30-9:30am  **Keynote Talk.** Moderator: Connie Millar

Barbara Bentz, USDA Forest Service, Rocky Mtn Research Station, Ogden, UT

*Bark Beetles and Climate Change: Implications for Mountainous Regions of the Western US*

9:30–10:00am  **Break**
10:00–11:40am Early Career Scientists Session
Conveners: Andy Bunn, Western Washington University, Bellingham, WA, and Sudeep Chandra, University of Nevada, Reno

10:00-10:25am Brenna Forester, Nicholas School of the Environment, Duke University, Durham, NC
*Evaluating the Implications of Local Adaptation, Habitat Connectivity, and Gene Flow for an Endemic, Montane Salamander under Global Change*

10:25-10:50am Sarah Null, Department of Watershed Sciences, Utah State University, Logan, UT
*Adaptations for Hydroclimate Variability: Revisiting Water Year Classification in Nonstationary Climates*

10:50-11:15am Valerie Trouet, Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ
*A Tree-Ring Based Reconstruction of North Pacific Jet Variability and its Influence on Sierra Nevada Fire Regimes*

11:15-11:40am Justin Minder, Department of Atmospheric and Environmental Sciences, University of Albany, Albany, NY
*The Role of the Snow-Albedo Feedback in Simulated Regional Climate Change Over the Rocky Mountains*

11:40am Final Announcements

Noon *Mtnclim 2014 Adjourns*

**Thursday, September 18, 2014 (afternoon)**

Post-Mtnclim Concurrent Workshops and Group Meetings

1:00–5:00pm **Workshop for Natural Resource Managers**
This workshop is open to all interested, with no fees. Goals of this half-day workshop are to provide state-of-science updates on the effects of climate change on:
- vegetation and water
- Identify management concerns and priorities
- Focus on sensitive resources and locations
- Discuss options for adapting to changing resource conditions

Organizers: Dave Peterson, USDA Forest Service, PNW Research Station, Seattle, WA
Natalie Little, USDA Forest Service, Region 4, Ogden, UT
Steve Jackson, DOI SW Climate Science Center, Tucson, AZ

1:30–5:00pm **Alpine and Arctic Treeline Ecotone Work Group Meeting**
This work group meeting is open to all interested in treeline-ecotone dynamics. We will start with 5-minute “speed talks” from those who would like to share their current work on treeline ecotones. We will also discuss the value of treeline studies for illuminating current ecological theories related to stress gradients, climate change, and disturbance.

Coordinators: Dave Cairns, Texas A&M, College Station, TX
Lara Kueppers, Lawrence Berkeley National Lab, Berkeley, CA
Connie Millar, USDA Forest Service, Pacific Southwest Research Station, Albany, CA

1:30–5:00pm **Mountain Research Initiative, Social Science Work Group Meeting**
Coordinator: Greg Greenwood, Mountain Research Initiative, Bern, Switzerland
Abstracts MtnClim 2014
Alphabetic by Senior Author

Talk, invited
RECENT ENVIRONMENTAL CHANGES AND EFFECTIVE MOUNTAIN COMMUNITY RESPONSES

All, John; Arnott, Pat; Schmitt, Carl; Cole, Rebecca; Sofield, Ruth; Lapham, Ellen
American Climber Science Program, United States of America
John All: Department of Geography and Geology, University of Eastern Kentucky, Bowling Green, KY

The American Climber Science Program (ACSP) is an integrated environmental initiative to study mountains of the world, such as the Himalaya of Nepal and the Cordillera Blanca range in Peru. The ACSP collects a variety of integrated data to support the development of sustainable environmental management and sustainable livelihoods in mountain regions (http://www.climberscience.com; http://www.mountainscience.org). In Peru, the ACSP has been working with Huascaran National Park, the Ministry of Environment, the National Water Authority, the American Alpine Club, numerous Peruvian universities, and diverse groups of stakeholders to demonstrate the potential value of a long-term integrated research program. The need for such a program is created by the paucity of coordinated, long-term monitoring data in this critical region. Greater coordination across disciplines, research groups, and stakeholders and inclusion of missing important environmental issues, such as air quality, would greatly improve sustainability science efforts in the region. Key themes that have emerged from our interactions with land managers, researchers, and policy makers is the need to assess the impacts and production of ecosystem services including grazing, fire, water quality, and biodiversity; climate mitigation approaches; predictions of changes in land cover; impacts of climate change and anthropogenic disturbance on native ecosystems; drivers and modeling of glacier cover change; and a need for better local and regional weather and climate modeling. Our experience indicates the value of cohesive efforts among researchers and a broad community of stakeholders and practitioners to understand and address the rapid environmental changes in this region and at a larger scale through the tropical Andes.

Talk, contributed
SNOW WATER EQUIVALENT RECONSTRUCTION USING FIA TREE RING DATA

Barandiaran, Daniel(1); Wang, Shih-Yu(1); DeRose, Justin(2)
(1) Department of Plants, Soils, and Climate, Utah State University, Logan, UT, (2) Forest Inventory and Analysis, Rocky Mountain Research Station, Ogden, UT

Tree ring widths have been used as a proxy for climate variables for several decades. Temperature, precipitation, and less commonly, snow water equivalent have been modeled in numerous locations throughout the world. Typical studies use carefully selected trees to maximize length of record and sensitivity to the variable of interest, and result in a reconstruction for a specific location. Here we use tree ring data collected by the Forest Inventory and Analysis (FIA) program, conducted by the U.S. Forest Service to reconstruct snow water equivalent for the state of Utah. This program collects increment cores on a geographically unbiased grid at horizontal resolution of 5-km across the U.S., resulting in an unprecedented sample density of tree ring data, and therefore enabling a reconstruction that covers a large geographic area at a resolution not possible using traditional dendroclimatology methods. Prior work (DeRose et al. 2013) has shown FIA to have coherence with previously published chronologies and with water-year precipitation. Snowpack is a major source of water in the Intermountain West, and yet few tree ring studies have reconstructed SWE and the instrumental record is limited in length, so this reconstruction represents a novel and useful dataset for water users and resource managers alike. Here we present initial results and a preliminary analysis of this unique dataset.
LESSONS FROM CENTENNIAL- AND MILLENNIAL-LENGTH RECONSTRUCTIONS OF NORTHERN UTAH’S HYDROCLIMATE FROM TREE RINGS

Bekker, Matthew F. (1); DeRose, R. Justin (2); Wang, Shi-Yu (3)
(1) Department of Geography, Brigham Young University, Provo, UT 84602, (2) USDA Forest Service, Forest Inventory and Analysis, Rocky Mountain Research Station, Ogden, UT, (3) Department of Plants, Soils, and Climate, Utah State University, Logan, UT 84322

The Wasatch Front in northern Utah is one of the largest and fastest-growing metropolitan areas in the semi-arid Intermountain West, and is largely dependent on snowmelt-fed streams to provide critical water resources. Our understanding of hydroclimatic variability in this region is hampered, however, by short instrumental records and complex interactions among climate drivers at different spatial and temporal scales, making long-term forecasts difficult. Over the past four years, the Wasatch Dendroclimatology Research (WADR) Group has developed an extensive network of tree-ring chronologies covering the entire Great Salt Lake (GSL) watershed. These chronologies have been used to successfully develop centennial- to millennial-scale reconstructions of major Wasatch Front rivers (Bear, Weber and Logan) as well as GSL Levels. The reconstructions indicate that many extreme dry and wet periods affected all of the Wasatch and western Uinta Mountains, but suggest some watershed-scale events as well. As is commonly the case in the western US, they also indicate extreme dry and wet events that were much greater in magnitude than anything during the post-1900 record. In particular, a 1,200-year reconstruction of the Bear River developed from Utah juniper shows a period of reduced streamflow during the Medieval Warm Period (ca. mid-1200s CE) that persisted for approximately 70 years. Recent research indicates a close association between the GSL elevation and a peculiar climate mode called the Pacific Quasi-Decadal Oscillation (QDO), and a statistical model based on this relationship was able to replicate and forecast turnarounds in the GSL elevation. A forecast of the GSL elevation out to 6 years based on this model also verified well with post-2005 observations. These efforts to combine extensive tree-ring records, climate dynamics, and empirical forecasting are providing new insights into drivers of northern Utah’s hydroclimate, and improving risk assessment of extreme events.

Keynote talk
BARK BEETLES AND CLIMATE CHANGE: IMPLICATIONS FOR MOUNTAINOUS REGIONS OF THE WESTERN US

Bentz, Barbara J.
USDA Forest Service, Rocky Mountain Research Station, Logan UT

Bark beetles are major contributors to tree mortality globally, with more than 8.5 million forested ha impacted in western North America in recent decades. Historically, periods of warm temperatures were associated with increased bark beetle activity, and recent warming and drought events associated with climate change continue to influence population outbreaks. Warming winters can increase brood survival, and at high elevations warming summers allow some species to shift from one generation every two years to one generation every year. Focusing on the mountain pine beetle (Dendroctonus ponderosae), it is clear that evolved, thermally-dependent traits that serve to maintain seasonality will constrain population response in some areas as temperatures continue to warm. Genetic differences among populations across latitudes, however, will allow for differential response. Moreover, not all high elevation pine species are equally susceptible to mountain pine beetle attack. Models developed to describe the relationship between temperature and bark beetle population success can be used in forest planning and other efforts aimed at facilitating adaptation to the effects of a changing climate in western US forests.
Talk, invited
PATTERNS AND SOURCES OF SEASONAL TIMING VARIABILITY IN HYDROCLIMATE AND PHENOLOGY ACROSS THE AMERICAN WEST AND U.S.

Betancourt, Julio L. (1); McCabe, Gregory J. (2); Ault, Toby R. (3); Pederson, Gregory T. (4); Schwartz, Mark D. (5); Feng, Song (6)
(1) USGS, Reston, VA 20194, (2) USGS-Denver, CO 80225, (3) Cornell University, Ithaca, NY 14853, (4) USGS-Bozeman, MT 59715, (5) UW-Milwaukee, Milwaukee, WI 53201, (6) University of Arkansas, Fayetteville, AR 72701

Seasonal timing has myriad impacts on plants and animals, biospheric processes, and human systems, and is critical for formulating adaptive responses to both climate variability and change. In the U.S., and especially in the American West, the timing of seasonal transitions varies widely from year to year and is also changing directionally, yet the climatic drivers, patterns and consequences of these variations are poorly understood. Influenced by the seminal work of Cayan et al. (2001, BAMS), we will synthesize recent research that map and explore day-of-year (DOY) metrics that define the growing season and shape the water cycle in the West and elsewhere in the U.S. All DOY metrics exhibit secular trends consistent with both natural variability and greenhouse warming, with abrupt advances spring for most regions clustered in the mid-1980’s and abrupt delays in fall clustered in the mid-1990. Exceptions include “warming holes,” with delayed spring onset abruptly ~1958 and advanced autumn onset in the High Plains gradually since the 1950’s. In the West, both snowmelt and accumulated heat needed to bring plants out of winter dormancy in the West covary and track Pacific Ocean variability. In the atmosphere, spring onset variations also appear linked to the Pacific North American (PNA) pattern and the Northern Annular Mode (NAM). By contrast, last spring frost, first fall frost, and the duration of the growing season in the coterminous U.S. follows Indian and North Atlantic Ocean variability. Our presentation will reconcile different interpretations of large-scale drivers, discuss opportunities for long-range forecasting, and consider constraints for DOY metrics in general circulation models.

Talk, contributed
THE ROLE OF FIELD STATIONS IN FOSTERING RESEARCH ON MOUNTAIN ECOSYSTEMS

Billick, Ian
Rocky Mountain Biological Lab, Crested Butte, CO 81224

To understand and manage mountain ecosystems we need a science strategy that effectively uses all available resources to understand how these ecosystems will respond to a changing climate. A recent planning effort conducted by the Organization of Biological Field Stations and National Association of Marine Laboratories has helped define the role field stations can play. In addition to their historical roles of providing access to research sites along with logistical support, field stations are important to the organization of communities of scholars and the accumulation of place-based knowledge that serve as powerful research platforms. Field stations can provide the institutional support and longevity needed to foster long-term field research. Because they attract multiple research groups for which place is an organizing theme, they create opportunities for synthesis.

Using RMBL as example, the field station has been critical to the maintenance of long-term datasets, including the marmot study (50+ yrs), stream ecology (40+ yrs), plant phenology (40+ yrs), climate warming (20+ yrs), butterflies (20+ hrs), ground squirrels(20+ yrs), and burying beetles (20+ hrs). Extending studies significantly beyond 40+ years requires the transfer of the studies across generations, which is facilitated by a field station. Experience with the climate warming experiment suggests that field stations have an important role to play in long-term experiments that require logistical support.

RMBL also provides examples of the value of co-locating studies and research teams. Dr. David Inouye and Dr. Carol Boggs combining long-term plant phenology and butterfly data to understand the impact of increasing frost events on butterfly population dynamics.
**Poster**

UNDERSTANDING THE DYNAMICS OF COLD AIR POOLING INFORM CLIMATE CHANGE ADAPTATION STRATEGIES IN DEVILS POSTPILE NATIONAL MONUMENT, CALIFORNIA

Buhler, Monica (1); Dulen, Deanna (1); Cayan, Daniel (2); Tyree, Mary (2)

(1) Devils Postpile National Monument, CA 93546, (2) Scripps Institution of Oceanography, University of California Santa Barbara, La Jolla, CA

We present preliminary results of a five year study of the physical dynamics of cold air pooling and the potential role as climate change refugia in Devils Postpile National Monument (DEPO). Cold air pools (CAPs) are temperature inversions that occur in regions of confined terrain where cold, dense air becomes trapped and concentrated resulting in cooler and moister conditions as compared to the surrounding, often higher elevation, area. Over one hundred temperature sensors placed along five, east-west transects in and around DEPO provide information about the temperature along an elevational gradient and the frequency, duration, timing and magnitude of the CAP. Temperature sensors are placed in live trees singularly or at different heights (e.g. 1m, 5m, 10m, 20m and 30m) in a single tree to determine both coarse and fine scale temperature variation. Preliminary results of the DEPO study indicate that the temperature gradient is strong - with temperatures in the CAP as much as 12 C degrees cooler than 300 meters (1000 feet) higher in elevation (Cayan et al. 2012). Observations also indicate that temperature could be up to 8 C cooler at one meter as compared to 30 meters above the ground in a single tree (Cayan per. comm). In addition, there are strong correlations between weather patterns (e.g., high pressure) and the formation, magnitude and persistence of the CAP.

Refugia can provide conditions for species to survive climate shifts and allow for the ‘retreat & re-radiation’ process that has maintained a significant portion of Sierra Nevada biodiversity. Several physical components can create conditions for a refugia that may include CAPs. Other conditions could include a wet riparian corridor, spatial heterogeneity of the surrounding topography, shading in north/south canyons, and/or ecological components. However, the effect of climate change on potential refugia sites, including the role of CAPs, is uncertain and a better understanding of CAP dynamics may help predict whether these areas could provide refugia or if refugia components will be compromised. This research will be a vital part of development of climate change adaptation strategies and management at DEPO.

**Talk, contributed**

THRESHOLDS IN GROWTH OF BRISTLECONE PINE WITH SMALL CHANGES IN ELEVATION IN THE WHITE MOUNTAINS OF CALIFORNIA, USA

Bunn, Andrew G. (1); Salzer, Matthew W. (2); Larson, Evan R. (3); Weiss, Stuart B. (4); Hughes, Malcolm K. (2)

(1) Department of Environmental Science, Western Washington University, Bellingham, WA, (2) Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ, (3) Department of Geography, University of Wisconsin-Platteville, Platteville, WI, (4) Creekside Center for Earth Observation, Menlo Park, CA

We developed a set of bristlecone pine (*Pinus longaeva*) tree-ring chronologies at and just below upper treeline along a north-facing and a south-facing elevational transect in the White Mountains of California. Trees growing at treeline show positive trends in growth in the 20th century concomitant with temperature limitation. However, there is evidence for a climate-response threshold just below treeline where chronologies from just 80 m or more below treeline show an abrupt change in climate response and do not correlate strongly with the treeline chronologies. Intriguingly, trees on south-facing slopes grow faster than trees on north-facing slopes and high growth rates in the treeline south-facing trees have somewhat abated since the mid-1980s. This hints that the climate-response of the highest south-facing trees might have shifted from being positively to negatively associated with temperature due to modern warmth. An ongoing field campaign seeks to map temperature anomalies at the scale of meters in order to isolate individual trees that might be undergoing changes in climate-response as function of microtopography and better understand these threshold responses.
**Poster**

**CURRENT, HISTORICAL, AND FUTURE WEATHER SUITABILITY FOR MOUNTAIN PINE BEETLE OUTBREAKS IN LODGEPOLE PINE FORESTS**

Buotte, Polly C. (1); Hicke, Jeffrey A. (1); Preisler, Haiganoush K. (2)

(1) Department of Geography, University of Idaho, Moscow, ID 83844, (2) USDA Forest Service PSW Research Station, Albany, CA 94701

Mountain pine beetles (*Dendroctonus ponderosae* Hopkins) are a native disturbance agent in lodgepole pine forests of western North America. When weather conditions are suitable, mountain pine beetle populations increase and cause widespread tree mortality. Weather conditions affect beetle development and survival as well as the ability of trees to defend themselves against attacks. Our goals are to understand the influence of weather on the recent mountain pine beetle outbreaks in lodgepole pine forests, evaluate changes in weather suitability over the past century, and estimate future weather suitability. We use an empirical approach to develop generalized additive models of the probability of tree mortality from mountain pine beetles. We determine the presence of lodgepole pine mortality due to mountain pine beetles using observations from USDA Forest Service aerial surveys. Our explanatory variables represent processes affecting mountain pine beetle development, host tree susceptibility, the number of attacking beetles, and stand structure. Once model selection and evaluation is complete, we will apply the best models to historical weather data and to downscaled future climate projections from ten global climate models for three 30-year time periods given three emissions scenarios. Our results will show trends in weather suitability for mountain pine beetle outbreaks over the past century and estimates of future weather suitability. This work is part of the Forest Mortality, Economics, and Climate (FMEC) project being conducted by an interdisciplinary team of scientists from Oregon State University, the University of Idaho, the University of Oxford, and the UK Met Office Hadley Centre to study the causes of severe forest die-offs in western North America, then learn to predict and avoid these events. The FMEC project goals are to enhance existing earth system models and economic models, then couple them to elucidate the interactions and feedbacks among climate, tree mortality, and economic factors.

**Poster**

**IMPACTS of the 2013 “ASPEN” and “RIM” FIRES on AIR QUALITY in DEVILS POSTPILE NATIONAL MONUMENT, SIERRA NEVADA**

Andrzej Bytnerowicz (1), Buhler, Monica (2), Burley, Joel (3), Chapman Varela, Jennifer (3), Cisneros, Ricardo (4), Dullen, Deanna (2), Horn, Michelle (5), McDaniel, Mark (6), Schweizer, Donald (4), and Zielinska, Barbara (6)

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Air pollutants with potential effects on human and ecosystem health were monitored in summer 2013 at Devils Postpile National Monument (DEPO), eastern Sierra Nevada. Measured species included ozone (O<sub>3</sub>), ammonia (NH<sub>3</sub>), nitrogen oxides (NO and NO<sub>2</sub>), nitric acid (HNO<sub>3</sub>), volatile organic compounds (VOCs), sulfur dioxide (SO<sub>2</sub>), and fine particulate matter (PM2.5). The original objective of the study was to develop a better understanding of how air quality at DEPO is affected by locally produced air pollutants compared with those transported from remote pollution source areas, such as the California Central Valley and the San Francisco Bay Area. No major impacts of local emissions on air quality were detected and generally, concentrations of the monitored pollutants were low before the Aspen and Rim Fires. Emissions from these fires drastically changed the air quality status at DEPO. The highest impact of the fires was on PM2.5 which reached the “unhealthy” level of the Air Quality Index (AQI) during the Aspen Fire (3-h rolling averages >135 mg m<sup>-3</sup>) and the “unhealthy for sensitive people” level during the Rim Fire (3-h averages >85 mg m<sup>-3</sup>). Concentrations of NH<sub>3</sub>, NO and NO<sub>2</sub> became elevated, while concentrations of O<sub>3</sub>, HNO<sub>3</sub> and SO<sub>2</sub> did not noticeably change. In general, concentrations of VOCs were quite low with a-pinene as a dominating species. Concentrations of all VOCs dropped dramatically during the Aspen Fire period. This phenomenon could have been caused by high concentrations of fine particulate (PM2.5) scavenging the gas phase organic species. Results of this study indicate potential impacts of air pollution on human and ecosystem health of this eastern Sierra Nevada receptor site and the importance of continued monitoring of air quality at remote areas.
**Poster**

ARE RECENT INCREASES IN AREA BURNED IN THE PACIFIC NORTHWEST REFLECTED IN INCREASED AREA BURNED IN ALPINE TREELINE ECOTONES?

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This research provides a large-scale assessment of the extent of wildfire in alpine treeline ecotones (ATE) in the Pacific Northwest, USA, over the last three decades. ATEs are expected to be sensitive to climate change because many species are at or near the limit of their environmental tolerances. Direct effects of climate change in ATE include upward moving of treeline, infilling of meadows and snowfields by trees, and upright growth of previously prostrate trees. Increase in the extent, frequency, and severity of disturbance, such as wildfires, would immediately decrease vegetation cover, and in some ATEs the impacts of disturbance persist for decades. Even if changes in climate allow faster recover after disturbance in ATEs, the combined effects of increased establishment and growth directly due to climate change, and increased tree mortality due to climate-mediated effects on disturbance regimes, are unclear.

We use existing geospatial data to identify ATEs and to calculate the amount of area burned regional and within ATEs in the Pacific Northwest (Oregon, Washington, northern Idaho, and western Montana) for each year during the study period (1984-2012). We then test for correlations between annual area burned and annual area burned in ATE, at the scale of the Pacific Northwest (the whole study area) and for ecoregions within the study area. Initial results for the study area support that regional fire years are also years in which the majority of area burned in the ATE in the Pacific Northwest. Regional increases in annual area burned in the Pacific Northwest have been attributed to climate, and area burned is projected to increase under future climate, and thus fire may affect ATEs more frequently in the future.

**Poster**

HIGH-RESOLUTION POLLEN AS AN INDICATOR FOR FIRE SEVERITY DURING THE POPULUS PERIOD, 2000-4000 CAL YR BP

Carter, Vachel A. (1); Brunelle, Andrea (1); Brewer, Simon (1); Minckley, Thomas (2)
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This study attempts to analyze fire severity using lake sediments from southeastern Wyoming, during a unique period of time coined the 'Populus period' (Carter et al., 2013). The 'Populus period' (3,100-3,000 cal yr BP) was a time when vegetation composition and fire regimes changed from a lodgepole pine dominant system to a lodgepole pine/quaking aspen system. This study investigates fire events from 2000-4000 cal yr BP to determine the ecological response associated with fire events and to identify drivers associated with vegetation change and fire regimes. In order to determine fire severity, this study compares high-resolution charcoal and pollen data to peak magnitude data from CharAnalysis (a statistical treatment program). Linear discriminant analysis (LDA) is used to set a threshold by which pollen taxa are associated with low or high severity fires. Based on the LDA results, fire events with peak magnitudes lower than 200 particles/cm²/episode are considered low severity, while fire events with a peak magnitude greater than 200 particles/cm²/episode are considered high severity. Superposed epoch analysis (SEA) is used to model pollen behavior both pre and post fire events to determine the ecological response associated with each of the fires events. Statistical analysis using LDA and SEA can potentially be used in combination to determine fire severity, which will be beneficial to land managers and policy makers in the 21st century.

**Poster**

INTERPRETING THE SEASONALITY OF PRECIPITATION IN NORTHERN BAJA CALIFORNIA FOR THE LAST ~45,000 CAL YR BP

Chavez, Vanessa; Brunelle, Andrea
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Northern Baja California lies in an area that is significantly affected by the El Niño Southern Oscillation (ENSO), which brings winter precipitation and the North American Monsoon (NAM), which brings summer precipitation to the region. Little is known about the relationship between the seasonality of precipitation, fire, and vegetation throughout this region over time. This study examines these relationships extending into the late Pleistocene from ~7,000-45,000 cal yr BP.
years BP for two desert wetland (ciénega) sites in the Sierra de Juarez of Northern Baja California. Preliminary data suggests fire regimes and ciénega processes, as indicate by loss on ignition, magnetic susceptibility, and charcoal data, appear to be controlled by the amount of precipitation to the region and groundwater levels. Preliminary pollen analysis shows that when summer-wet taxa are more prevalent on the landscape, winter-wet taxa declines. Based on existing data, we know that the influences of both ENSO and NAM have changed in their intensities and spatial boundaries throughout time. Our study sites (Ciénegra Chimeneas, 32° 14’ N and 116° 06’ W, and Ciénegra San Faustino, 32° 12’ 30.4” N 116° 09’ 55” W) are located in a region that will help define when and where changes in the seasonality of precipitation have occurred since the late Pleistocene. Additional dating and pollen analysis will allow us to further validate the relationships between ENSO and NAM-like activity and ecosystem processes for this site.

**Poster**

**TOWARDS A MORE BIOLOGICALLY-MEANINGFUL CLIMATE CHARACTERIZATION: HETEROGENEITY IN SPACE AND TIME AT MULTIPLE SCALES**

Christianson, Danielle S. (1); Kaufman, Cari G. (2); Kueppers, Lara M. (3); Harte, John (1)

(1) Energy and Resources Group, University of California, Berkeley 94720, (2) Statistics, University of California, Berkeley 94720, (3) Lawrence Berkeley National Laboratory, Berkeley, California 94720

Sampling limitations and current modeling capacity underpin the common use of mean temperature values in summaries of historical climate and future projections. However, a monthly mean temperature representing a 1-km² area on the landscape is often unable to capture the climate complexity driving organismal and ecological processes. Estimates of heterogeneity in addition to mean values are more biologically meaningful and are increasingly used in climate change research to explain ecological processes and to project organismal response. For example, a change in spatial heterogeneity will affect the availability of suitable habitat on the landscape and thus, will influence future species ranges. While previous research suggests increasing temporal heterogeneity at coarse scales in a warmer future, few studies have considered how spatial heterogeneity changes with warming, and comparisons across both spatial and temporal scales is lacking. In this study, we use temperature data at multiple scales to characterize spatial and temporal heterogeneity under a warmer climate, i.e., increased mean temperatures. Fine-scale observational data from the Sierra Nevada (California, USA) and Rocky Mountains (Colorado, USA), in combination with coarse-scale PRISM data (USA), allow us to compare characteristics of a mean-heterogeneity relationship across spatial scales ranging from 1-m² to 10,000 km² and across temporal scales ranging from hours to decades. Preliminary spatial analysis at fine-spatial scales (~1 m²) shows greater heterogeneity in maximum temperature with warmer mean temperatures, while minimum temperature heterogeneity remains constant. Our preliminary findings do not support an inherent assumption of species distribution models that fine-scale heterogeneity is static, implying that current projections of future ranges for species sensitive to maximum temperatures may be biased – though the direction and magnitude require further study.

**Talk, contributed**

**MODELING SUBALPINE CONIFER RESPONSE TO CLIMATE CHANGE WITH DATA FROM A WARMING EXPERIMENT**

Conlisk, Erin (1); Castanha, Cristina (2), (3); Moyes, Andrew (2); Kueppers, Lara M. (2), (3)

(1) UC Berkeley, (2) UC Merced, (3) Earth Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA

Now in its fifth year, the Alpine Tree Warming Experiment (ATWE) has gathered data on the impact of artificial warming (by suspended infrared heaters) on germination and establishment of seeds from two provenances of Engelmann spruce, lodgepole pine, and limber pine at three elevations (alpine, subalpine, and forested). Results from the first four years of the project demonstrate the importance of growing season length, temperature, and water availability to the recruitment of Engelmann spruce and limber pine. Most models of climate change impacts to species abundance and distribution do not incorporate these important biological mechanisms. Instead, models rely on correlational approaches (such as species distribution modeling), which relate species presence to environmental variables. Combining the ATWE experimental data on germination and survival with data from the literature on survival of older life stages, we have constructed population models that allow us to interpret how changes in conifer recruitment due to warming will impact populations of Engelmann spruce and limber pine. We find strong effects of heating and watering on population sizes, and these effects vary across the three elevations: alpine, treeline, and lower elevation forest. Regardless of climatic pressures, there are large lags between the onset of a climate pressure and the population response.
Talk, invited

ADAPTIVE GOVERNANCE IN THE HEADWATERS: THE RESILIENCE AND LAW PROJECT

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This abstract is based on a project made possible through support by the National Socio-Environmental Synthesis Center (SESYNC) under funding from the National Science Foundation DBI-1052875. URL: http://www.sesync.org/project/water-people-ecosystems/adaptive-water-governance

Mountain climates provide capture, natural storage, and regulate the timing of runoff for the rivers on which ecosystems and economies depend. Rivers connect the headwaters to the estuary, spanning ecological zones that range from alpine to estuarine. In many river systems, anadromous fish reverse the flow by bringing nutrients from the ocean to headwater streams. The course of a river runs through multiple jurisdictions without regard for political or cultural differences. A river basin is thus an archetypal complex social-ecological system and essential to the sustainability of mountain regions.

Changing climate poses both a challenge and an opportunity for renewal of ecosystems and a window of opportunity for modifications of institutions to improve social-ecological interaction. Resilience theory predicts that change in ecological and social systems may be dramatic, abrupt, and surprising, and along with panarchy which focuses on the interaction across nested scales of complex systems, provide bridging concepts for the linking ecological dynamics to governance, and caution our consideration of mountain social-ecological systems with an understanding that larger scales (such as that of the river basin they lie within) will influence their ability to adapt. While governance must respond to change in the ecological system, adapting to the uncertainty of climate driven change must be done in a manner perceived as legitimate by the participants in a democratic society, thus adaptive governance must include aspects of "good governance". Thus, we hypothesize that building adaptive capacity to climate change will require integrating the science of ecosystem dynamics with adaptive governance and that adaptive governance must include not only the aspects of governance that resilience scholars have observed to build adaptive capacity in management, but aspects of governance that facilitate legitimacy, equity and justice in governance in general if we are to consider the social system both sustainable and desirable. We refer to the appropriate response as “adaptive governance.”

The Adaptive Water Governance co-chaired by the authors, looks at the integration of resilience and law to identify legal barriers, catalysts, and mechanisms for achieving adaptive governance and is working toward the development of a process for assessment and a package of tools that may be tailored to the circumstances of a specific basin. The project is developing and testing this approach in six North American river systems: Anacostia; Columbia River; Florida Everglades; Klamath River; Middle Rio Grande River; and Platte River. The project has identified five preliminary areas of inquiry to determine whether a particular approach to basin management can respond and adapt to change: (1) structure; (2) scale; (3) capacity; (4) legitimacy and (5) risk. We will define each of these factors and describe their application to riverine systems on which mountain regions rely.

Talk, contributed

SNOWMELT RUNOFF MODELING IN THE UPPER COLORADO RIVER BASIN USING MODIS FRACTIONAL SNOW COVER

Crawford, Christopher J. (1, 2); Hall, Dorothy K. (2); DiGirolamo, Nicolo E. (3); Riggs, George A. (3); Foster, James L. (4)
(1) Oak Ridge Associated Universities, Oak Ridge, TN, 37831, (2) Cryospheric Sciences Laboratory (Code 615), NASA Goddard Space Flight Center, Greenbelt, MD, 20771, (3) SSAI, Lanham, MD, 20706, (4) Emeritus, Hydrological Sciences Laboratory (Code 617), NASA Goddard Space Flight Center, Greenbelt, MD, 20771

A trend towards earlier snowmelt has been documented since the mid-20th century across the western United States, a pattern that is consistent with satellite-derived records of Northern Hemisphere spring snow cover. Declining mountain snowpacks translate into diminishing freshwater resources, and this has important implications for streamflow and reservoir management at watershed to basin scales. This work examines historical daily streamflow records and then simulates daily stream discharge using the Snowmelt Runoff Model (SRM) in two sub-basins along the northern periphery of the Upper Colorado River Basin in western Wyoming, USA. We partitioned our analysis and SRM simulations by watersheds with and without stream diversions to control for resource allocations above gauging...
stations. Using MODIS Collection 6 cloud-gap filled daily fractional snow cover, meteorological observations, and SNOTEL snow-water-equivalent measurements, we simulated daily stream discharge for 13 years (2000-2012). Our results indicate that streamflow can be described by interannual and decadal variability, and that the longer-term trend is sensitive to observed flows during the 2000s. Overall, the SRM was able to skillfully simulate stream discharge in the Upper Green River and New Fork basins, although model accuracy varied from year to year. Model accuracy was consistently lower for watersheds with diversions when compared to watersheds without diversions. While the SRM is a physically based model, its performance is contingent on in-situ data quality, as well as input parameters that characterize base flow, and rain and snow events during the snowmelt season. The use of MODIS daily fractional snow cover to simulate daily stream discharge is a notable advancement, and with efforts to identify the optimal data combination and model parameterization, can support operational streamflow monitoring in un-gauged watersheds. Coupling streamflow analysis with SRM simulations is helpful for interpreting past hydrological variability and change within a seasonal snowmelt context.

Panelist
FRACUTRED LANDSCAPES: THE ROLE OF FINE SCALE FACTORS IN COMPLICATING THE EFFECT OF ELEVATION ON WARMING

Daly, Christopher
PRISM Climate Group, Oregon State University, Corvallis, OR 97331

As we move upwards in elevation, other factors that affect the local temperature regime change as well. These include topographic position, slope and aspect, canopy cover, snow cover, presence of riparian zones, and others. These factors make it nearly impossible to cleanly isolate the effects of elevation on temperature trends and variations. I will briefly summarize a study conducted at the HJ Andrews Experimental Forest that highlights just one aspect of this complicated story. HJ Andrews is located in an area of deeply dissected terrain in the Cascade Mountains of Oregon. The project found that topographic position (one’s height relative to the surrounding terrain) can dramatically alter the temporal variations of temperature at both daily and monthly time steps. The culprit is the relationship between topographic position and exposure to cold air pools, which play an important role in how temperature responds to changes in synoptic flow patterns in the upper atmosphere. This means that the HJ Andrews temperature landscape is not just spatially complex, but temporally complex as well. If future climate changes result in changes in the frequency distribution of synoptic flow patterns, actual temperature responses could diverge widely between very closely-spaced locations. The magnitude of this divergence might equal or exceed that of the projected temperature change itself.

Talk, contributed
PRISM UPDATE: WHAT’S NEW AND WHAT’S NEXT?

Daly, Christopher
PRISM Climate Group, Oregon State University, Corvallis, OR 97331

The PRISM Climate Group has been very active since the last MTCLIM meeting, and several new spatial climate products and services have become available. New 1981-2010 monthly climatologies of precipitation and maximum, mean, and minimum temperature for the conterminous US were released in summer 2012. In summer 2013, a new version of our 120-year monthly time series of precipitation and maximum, mean, and minimum temperature for the conterminous US was released, based on the 1981-2010 climatologies. Also, the first version of a daily time series of these variables covering the period 1981-present was made available. Some of the challenges of modeling precipitation at the daily time step will be discussed, including the use of radar reflectance patterns, time of observation issues, and shaky statistics. Both time series are updated as the month or day ends, and maps are re-modeled several times, out to six months, to capture late data entries and QC edits. A list of station networks currently ingested by PRISM will be presented. In the fall of 2013, an updated PRISM website (http://prism.oregonstate.edu) was launched, providing the public with free access to 4-km versions of all of our conterminous US products. (Due to their large size, the native 800-m grids must be purchased directly from us.) PRISM dataset versions are now tracked and named, and ancillary information is provided, such as FGDC-compliant metadata, pedigree files detailing the source and processing of each grid, and lists of stations used in the modeling procedure. Upcoming products in the next one to two years include 1981-2010 normals and monthly and daily time series of mean dew point and minimum and maximum vapor pressure deficit for the conterminous US, and 1981-2010 monthly temperature and precipitation normals for Alaska. A recent project to create an operational QC system and web portal for the SNOTEL network will also be discussed.
**FEASIBILITY OF HIGH-DENSITY CLIMATE RECONSTRUCTION BASED ON FOREST INVENTORY AND ANALYSIS (FIA) COLLECTED TREE-RING DATA**

DeRose, R. Justin (1); Wang, Shih-Yu (2); John D. Shaw, John D. (1)

(1) Forest Inventory and Analysis, Rocky Mountain Research Station, Ogden, UT, (2) Department of Plants, Soils, and Climate, and Utah Climate Center, Utah State University, Logan, UT

This study introduces a novel tree-ring dataset, with unparalleled spatial density, for use as a climate proxy. Ancillary Douglas fir and piñon pine tree-ring data collected by the U.S. Forest Service Forest Inventory and Analysis Program (FIA data) were subjected to a series of tests to determine their feasibility as climate proxies. First, temporal coherence between the FIA data and previously published tree-ring chronologies was found to be significant. Second, spatial and temporal coherence between the FIA data and water year precipitation was strong. Third, the FIA data captured the El Niño-Southern Oscillation dipole and revealed considerable latitudinal fluctuation over the past three centuries. Finally, the FIA data confirmed the quadrature-phase coupling between wet/dry cycles and Pacific decadal variability known to exist for the Intermountain West. The results highlight the possibility of further developing high-spatial-resolution climate proxy datasets for the western United States.

**REGIONAL-PATTERN SCALING IN MOUNTAINOUS TERRAINS—WHERE & WHEN WILL DOWNSCALING PERFORM WELL IN THE SOUTHWEST?**

Dettinger, Michael

U.S. Geological Survey, Scripps Institution of Oceanography, La Jolla, CA

Global-pattern scaling is an old and oft-forgotten trick (now seeing some renewed uses in IPCC circles) that develops simple statistical emulators of global-climate model outputs, to generate quick approximations of likely future regional climates given a projected global-mean temperature or, alternatively, a given greenhouse-gas concentration in the atmosphere. A statistical model (often as simple as a map of local multipliers that when applied to a projected global-mean temperature change “distributes” that temperature change to all regions of the globe) is fitted to members of an ensemble of climate-model projections to best reproduce the results from full climate models. The benefits are massive computational savings and an ability to explore wide ranges of possible climate changes very efficiently. An extension of this approach along the regional-to-local scale transition obtains similar cost savings and, just as importantly, better understanding of mountain climate changes. In a recent study over the southwestern US (Dettinger, Clim. Chg., 2013), daily synoptic-scale weather conditions (temperatures, precipitation, winds, solar radiations, humidity) were statistically downscaled to reproduce outputs from a high-resolution (10 km) regional-climate model. This amounted to development of a statistical stand-in for the computationally demanding regional model. Specifically, constructed-analogs (CA) statistical downscaling was used to downscale daily 2.5ºx2.5º weather-field inputs and reproduced the 1948-2005 CARD10 collection of 10-km reanalyses by the Regional Spectral Model (RSM) embedded in global NCAR/NCEP Reanalysis (Kanamitsu & Kanamaru, J. Clim. 2007). The accuracy with which the CA results reproduced CARD10 equivalents was high at key locations and thus the method was used to downscale climate-change projections for those locations.

However, place-to-place, and variable-to-variable, differences in CA-downscaling accuracy were apparent in the historical validation. The differences were not random but rather were closely associated with topographic features. For example, poor anomaly correlations between CA and CARD10 wind speeds were located over the southern Central Valley and parts of the southern Sierra Nevada, deriving specifically from errors in southerly winds. Those errors probably reflect sheltering from large-scale southerly winds by upwind mountainous terrains.

With due attention, error patterns from this kind of analysis could provide useful measures of where and when synoptic-scale atmospheric circulations and climatic conditions most strongly dictate local conditions in mountainous terrains versus where local conditions are less directly enslaved by synoptic scales. Such error patterns may also help to formulate more realistic expectations as to where and when (and even why) regional-climate models themselves will perform well (or poorly) in mountainous terrains.
A group of motivated scientists from around the world with a keen interest in climate change in mountains and its environments met in late May 2004 in North Lake Tahoe, NV. They shared a desire to bring greater attention by policy makers and other decision makers to climate change related issues in mountain regions of western North America—such as water scarcity related to intensifying drought, massive insect infestation of national forests, and increasing frequency and intensity of wildfires.

Meeting participants underscored that the following areas needed particular attention:

- **Climate system monitoring.** It was agreed that climate system monitoring—including the biosphere, hydrosphere and cryospheric components—was at the top of the priority list for sustainable management of western resources, in light of predicted future climate conditions under an enhanced greenhouse effect.

- **How are the vertically stacked ecosystems changing?** Boundaries between the various biophysical systems in mountains may experience changes due to global climate change (e.g. snow-line, tree-line, upper limit of plant life, etc.). Observations to date indicate changing snowmelt timing signals, pine beetles moving north and infecting large and new areas, massive forest dieback and increasing size and intensity of fires in western forests. Greater efforts are needed to monitor and study the effects of environmental changes in these areas. There is a need to improve our understanding of the relationship between ecosystem structure and function through process studies.

- **Linking ecosystem and human processes.** Climate variability and change, including the presence of trends and changes in climate regimes, lead to variability and changes in water resources, the carbon cycle, forest health and biodiversity. These systems provide multiple services that may be vulnerable to critical thresholds and rapid changes.

- **Insufficient integration of disciplinary research.** There is a need to develop tools for integrated assessments (projections) of global change impacts in mountain regions. Among such tools are development of quantitative models, and some initial efforts have been made toward this end. More is needed.

- **Enhance the delivery of information (communication) of important scientific findings relevant to western mountains to decision makers.** There is a need to base the information on the best available science provided by multiple disciplines, for better communication with non-scientists, and to evaluate credible future scenarios to help managers mitigate impacts of climate change.

Ten years on many of these same critical issues not only are continuing to affect the West, but in fact the impact of climatic extremes on western society has increased. While improvements in policy, management and public awareness of these issues has substantially improved, a coordinated approach to sustainability and a national recognition of the special problems facing western society in the face of rapid climate change and related extreme events are still lacking.

I will touch on some of the achievement of CIRMOUNT during the past decade and provide some personal notes on why this ad-hoc entity of committed citizen scientists has held together this long and members continue to interact with each other in various ways.
changes. Here I examine the climate change velocity (both climate displacement rate and direction) for minimum temperature, actual evapotranspiration, and climatic water deficit over the contiguous US during the 20th century (1916–2005). Climate change velocity vectors for these variables show complex patterns that vary spatially and temporally and are dependent on the spatial resolution of input climate data. Velocity estimates increase as the spatial resolution of climate data is coarsened because coarsely grained data underestimates the spatial heterogeneity of climate in areas of complex terrain. The sensitivity of climate change velocity to climate data resolution is largest at fine grain sizes highlighting the importance of topoclimatic and microclimatic variability for evaluating the capacity of organisms to keep pace with ongoing climate changes. These results suggest that we may be overestimating the rate at which species will need to move in order to keep pace with ongoing climate changes.

Poster
EVALUATION OF THE POTENTIAL VEGETATION MAP OF MC2 VERSUS KUCHLER IN THE BLUE MOUNTAINS OF OREGON USING A TOOL THAT INCORPORATES THE KAPPA STATISTIC AND RANDOM FRactal MAPS.

Drapek, Raymond J. (1); Kim, John (1, 2); Conklin, David (3); Kerns, Becky (1)
(1) USDA Forest Service, PNW Research Station, Corvallis, OR, 97331, (2) Western Wildland Environmental Threat Assessment Center (WWETAC), Prineville, OR, 97754, (3) Common Futures LLC

As a part of the Blue Mountains Adaptation Partnership, the MC2 dynamic vegetation model was run under four CMIP5 future scenarios and the results were used to develop science based adaptation strategies. Here we present more of a focus on examining how well MC2 simulated historical vegetation by comparing the potential vegetation map produced by MC2 versus Kuchler potential vegetation. The use of Kappa has become standard for making such comparisons but this approach is full of problems not least of which is interpreting what the resulting Kappa value actually means. Alternatives to Kappa are becoming more widely available, but as a start we chose to work with Kappa and to try to come up with a more robust interpretation of the results. The MC2 model results had a Kappa of 0.41 compared with Kuchler and this falls within the range of values that have subjectively been called "moderate". We created a tool which randomly generates vegetation maps and produces a histogram of the Kappa values for those maps versus Kuchler. We started with purely random maps and gradually added more realism. The second step was random maps with vegetation types proportionally the same as Kuchler. The random maps look nothing like any natural vegetation terrain so as a next step we created random fractal vegetation maps using the midpoint displacement algorithm. The fractal maps greatly expanded the range of values contained within the histogram of Kappas so that out of a thousand randomly generated maps one actually produced a Kappa that was higher than the 0.41 from the MC2 model. Comparing our MC2-generated Kappa versus the Kappa values coming from increasingly realistic but randomly generated vegetation maps gave us a better understanding of how well our simulation did relative to Kuchler than a simple subjective “moderate” designation.

Talk, invited
LEGAL CONSTRAINTS ON (AND OPPORTUNITIES FOR) ADAPTIVE GOVERNANCE IN THE USA

Duane, Tim
University of California, Santa Cruz, CA and University of San Diego School of Law (visiting), La Jolla, CA

Formal legal institutional structures play an important role in the United States as the forum and basis for resolution of many important land and resource policy and management conflicts. The American constitutional structure is built on fragmented authority, however, both vertically (between the states and the federal government) and horizontally (across the legislative, executive, and judicial branches of both state and federal governments). Identifying the relevant “law” that may affect governance is therefore complex: it lies within the complex web of relations among these different levels and branches of government. Federal law preempts state law, for example, but state law otherwise applies—and often varies from state to state. Agency regulation and management must come from legislation, moreover, but judicial review plays a critical role in determining the discretion within which agencies can interpret legislative statutes. Finally, executive enforcement is exercised with prosecutorial discretion that determines the risks of non-compliance for those subject to government regulation. The latter is determined in part by cultural norms that may differ at the local or regional scale than those that are manifest through nominally binding legislation and regulation adopted through nation-wide political processes.

This presentation explores the relationship between the formal legal structure for ecosystem management (highlighting both how it may promote it and constrain it) and the informal cultural systems in which that system is implemented (highlighting how those systems are highly heterogeneous in the complex west). In particular, I will discuss how the
state’s presumed monopoly on the use of force—a critical element in establishing the legitimacy of law as a means for resolving conflict—is not recognized as legitimate by some actors (including some states and those charged with enforcing state and federal law). The result is an uneasy standoff between formal legal structures and informal cultural systems that alter the power relations that determine substantive outcomes.

**Talk**

**NPS CLIMATE CHANGE RESPONSE LEADERSHIP: SERVICE WIDE, REGIONAL, AND AT DEVILS POSTPILE NATIONAL MONUMENT CLIMATE CHANGE REFUGIA AS A TOOL FOR CLIMATE ADAPTATION**

Dullen, Deanna

*Devils Postpile National Monument, Mammoth Lakes, CA*

Devils Postpile National Monument is articulating the scientific value of the monument and the importance of scientific partnerships in planning documents including Foundation Plans tied to the General Management and tiered to the developing Resource Stewardship Strategy. This presentation demonstrates how the desired condition of fostering state of the art science to better understand the impacts of climate change and to develop science based adaptation strategies is paramount. Several scientific partnerships have shed light on physical processes in the monument that create cooler, moister, and shadier conditions including cold air pool dynamics within a topographically rich setting contributing to a refugia. DEPO is developing a case study to implement the 12 step process for management strategies for using Climate Change Refugia as a Tool for Climate Change Adaptation.

**Talk, invited**

**EVALUATING THE IMPLICATIONS OF LOCAL ADAPTATION, HABITAT CONNECTIVITY, AND GENE FLOW FOR AN ENDEMIC, MONTANE SALAMANDER UNDER GLOBAL CHANGE**

Forester, Brenna R. (1), Urban, Dean L. (1), Schultz, Thomas F. (2), Wernegreen, Jennifer J. (3)

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Faced with environmental change, organisms either adapt in place or move -- or they go extinct. Relative to dispersal, adaptation in response to environmental change remains poorly understood. Fortunately, the recent development of molecular techniques for detecting adaptation in wild populations is making it easier (and more cost-effective) to evaluate this response.

We are assessing adaptive capacity, habitat connectivity, and levels of gene flow for *Plethodon welleri*, an endemic, montane salamander of conservation concern. Tactical landscape analysis is guiding a landscape genomics approach to infer how local adaptation and gene flow interact to affect the capacity of *P. welleri* to respond to fragmented and warming habitats. We are achieving this aim by (1) stratifying genetic and environmental sampling across temperature and space; (2) assessing genetic variation within and among salamander populations at a genome-wide scale by using RAD-sequencing to develop single nucleotide polymorphism (SNP) markers; (3) using statistical methods to partition SNPs into neutral and potentially adaptive genetic variation; and (4) integrating genetic, environmental, and spatial data in a common analytical framework using familiar Mantel correlations as well as emerging analytic methods.

This analysis will help us better understand the capacity of species to adapt to changing conditions and what actions will be most effective to conserve salamander biodiversity under global change. Additionally, our approach is applicable across taxa and montane systems, where the distribution of species on mountain peaks provides a naturally replicated environmental gradient (via elevation) for distinguishing local adaptation.
A PALEOECOLOGICAL RECONSTRUCTION OF FIRE ACTIVITY IN UTAH’S WEST DESERT

Howard, Kelsey; Brunelle, Andrea
University of Utah, Salt Lake City UT, 84112

A paleoecological reconstruction of wetland sediments in western Utah is being conducted to determine the fire activity associated with Paleo-Indian and recent human occupation of Callao and North Redden Springs, Utah. Both Callao and North Redden Springs are located within close proximity to each other in the Great Basin at N 39° 54’ 51.5” W 113° 42’ 03.8” and N 40° 00’ 47.1” W 113° 41’ 59.9”, respectively. Preliminary high resolution charcoal data from North Redden Springs suggests the presence of fuel on the landscape to support increased fire activity during the last ~5000 Cal Yr BP, with a spike in fire activity at ~1000 Cal Yr BP. After ~5500 Cal Yr BP, a substantial drop in fire activity occurs to indicate a shift in spring productivity as a result to changes in the climate system or a change in the fire practices performed by the occupants living within the region. Spring productivity shifts again at ~12700 Cal Yr BP when fire, as well as magnetic susceptibility values, increase. Further analyses will include a reconstruction of the local vegetation based on a palynological analysis of the sediment at a ~500 year resolution, as well as productivity assessments and high resolution erosional analyses to better understand these fluctuations in fire activity in connection to Paleo-Indian and human occupation within the area.

VARYING TEMPORAL SCALE OF CLIMATE CONTROL OF FLOWERING AT HIGH ELEVATION IN THE COLORADO ROCKY MOUNTAINS

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The phenology and abundance of flowering by sub-alpine wildflowers are strongly affected by climate, and in particular by the amount of winter snowpack and the date of snowmelt. The phenology of 120 species I have studied since 1973 at the Rocky Mountain Biological Laboratory (2,900m), and the abundance of some of them, are closely tied to when the snow melts. The sequence of species flowering is relatively invariant among years even though the first date of flowering can differ by seven weeks. The preformation of leaves and buds for up to four years in advance of their appearance above ground requires incorporation of time lags into models of flowering abundance based on climate variables. For example, this year’s significant mast flowering by the long-lived perennial monocarp Frasera speciosa (monument plant or green gentian; Gentianaceae) was successfully predicted by a model that uses July and August precipitation four years previously as the environmental trigger for flowering. Mast flowering years are infrequent enough that it took data from 1979 – 2010 (8 mast flowering years) to generate the model that successfully predicted this year’s flowering, highlighting the importance of long-term studies. Flowering by another mast-flowering species in the same meadows (Veratrum tenuipetalum, Helleboraceae) is predicted by a model that relies on climate data from two years prior to flowering. Within-season climatic events such as late frosts following early snowmelt can also have significant impacts, resulting in almost total loss of flower buds in sensitive species (e.g., Helianthella quinquenervis, Asteraceae). Summer precipitation can also affect flower abundance and phenology of some species, but temperature effects other than late frosts seem to be minimal in comparison to the timing of snowmelt.

THE ROLES OF MOUNTAIN REFUGIA IN PAST AND FUTURE CLIMATE CHANGES

Jackson, Stephen T.
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The biogeographic refugium concept has 19th Century origins in the dual recognition of distributional disjunctions and of past climatic changes, particularly the last glacial period. Mountainous regions have long been part of the discussion; Darwin and contemporaries specifically noted the existence of high-elevation populations of arctic species at temperate latitudes. Paleoecological records developed during the past several decades have enriched understanding of the role of refugia in times of climate change. Species populations can adapt to climate change by tolerance in situ, by habitat shifts within a region, and by large-scale migration to colonize newly suitable territory.
Mountain refugia play important roles in all of these responses. Local microhabitats provide sites for toleration of climate change, and may also foster local evolutionary adaptation. The high habitat heterogeneity and elevational range of mountains confer a potentially wide array of sites for habitat shift. Finally, mountain regions can provide sources, way-stations, and destinations for large-scale migration. Examples are amply documented in mountains of both eastern and western North America. However, some species and species populations have undergone late Quaternary extinction or near-extinction in mountainous regions, suggesting that adaptive capacity and opportunities may be finite even in highly heterogeneous terrain. The extent to which such events represent disappearance of suitable habitats, disruption of dispersal (via geographic barriers or disconnectivity), or both, remains unclear. Looking to the future, mountains will undoubtedly play important roles across a range of temporal scales for persistence and migration of species. We face at least two critical science challenges relevant to management under climate change. First, can we develop sufficient capacity to provide not only precise but accurate projections of future environmental states within complex terrains? Second, to what extent can we account for or forecast the diverse array of contingent events (dispersal, disturbance, recruitment, antecedent ecological states) that will likely govern distribution and abundance of species in a changing climate? Successful management may not require unilaterally positive answers to these questions.

**Keynote talk**

**ASSESSMENT, ADAPTATION, AND COPRODUCTION OF KNOWLEDGE**

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Historically, the focus for U.S. National Climate Assessments has been on writing the congressionally-required global change assessment reports that represent the current state of knowledge. In developing the Third National Climate Assessment (NCA3), released in May of 2014, there was a deliberate attempt to shift the focus from producing products to establishing credible processes and building assessment teams that would continue past the development of this report. Building networks that include scientists, managers, and stakeholders has a number of benefits, because those relationships, initially formed around assessment processes, can evolve into support systems for adaptation and resilience. The processes used in the NCA3 benefitted greatly from previous work in studying and developing boundary organizations, knowledge systems, and co-production. The assessment process and the electronic delivery system (http://nca2014.globalchange.gov) were built to maximize adaptive learning and decision support at multiple scales and sectors. Some of the lessons learned in the NCA3 have broader implications for knowledge systems and enhancing resilience. There are multiple ways that the mountain science community might contribute to a sustained climate assessment process, and help to focus its own research priorities as a benefit of engaging in ongoing NCA activities.

** Poster**

**CONTROLS ON GEOGRAPHIC DISTRIBUTION OF ROCK GLACIERS IN THE WESTERN UNITED STATES**

Johnson, Gunnar F.; Fountain, Andrew G.  
*Portland State University, Portland, OR 97207*

We present an analysis of topographic, geologic and atmospheric controls on rock glacier distribution in the western US, and compare these controls with those governing alpine glacier and perennial snowfield distribution. A geospatial database of ~10,000 active and relict rock glaciers has been compiled from aerial and satellite imagery and is compared to an existing database of ~8,500 alpine glaciers and perennial snowfields. Preliminary analysis suggests ~50% more rock glaciers than alpine glaciers and perennial snowfields across the study area. Topographic variables exert similar influence on the distribution of both rock glaciers and alpine glaciers, while geologic variables (more important to rock glacier distribution) and atmospheric variables (more important to alpine glacier distribution) exert disparate influences. The geospatial database of rock glaciers in the western US is critical for extrapolating the landscape-scale influences rock glaciers may have on alpine hydrology from ongoing field sampling of rock glacier meltwater chemistry. Additionally, it will serve as a training data set for development of automated rock glacier identification methods in other regions, particularly those in South America and Central Asia that do not presently enjoy such a wealth of publicly available geospatial data as the western US.
LANDSCAPE GENETICS AND GENE-FLOW IN COASTAL DOUGLAS-FIR (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*)

Johnson, Jeremy S. (1); Cairns, David M. (1); Krutovsky, Konstantin V. (2)

(1) Department of Geography Texas A&M University, College Station Texas USA, (2) Department of Forest Genetics and Forest Tree Breeding Büsgen-Institute, Georg-August-University of Göttingen Germany

Genetic variation, structured spatially, is the result of interacting environment and genotype. Dispersal mechanism, landscape composition and connectivity contribute to population level genetic structure in plants. To improve our understanding of how landscape features influence gene-flow in a long-lived tree species, Coastal Douglas-Fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) in the Pacific Northwest, we used genetic visualization, and landscape genetics analysis. Six microsatellite and 25 allozyme loci genotyped in 1363 *P. menziesii* samples were used to quantify levels of gene-flow. We assigned ancestry probabilities, generated in STRUCTURE, to individual samples and population genetic structure was inferred. *F*<sub>st</sub> values were used to assess pairwise relatedness and a Mantel’s test was used to test Isolation by Distance (IBD). We tested the hypothesis that geographic features limit gene-flow across a large geographic area.

11 subpopulations of *P. menziesii* were identified across a geographically wide and diverse ecosystem. Isolation by Distance was identified as only a small factor (\( r = 0.05984 \ p < 0.001 \)) in structuring population genetic variation. Barriers to gene-flow were identified as additional factors contributing to the observed genetic variation. Pairwise Euclidean kinship values suggest that gene-flow is restricted (\( F_{st} > 0.035 \)) along the Coastal Mountain Range and across the high peaks of the Cascade Mountain Range. Additionally, gene-flow is restricted between the Siskiyou Mountains and the southern Cascades, which are geographically close. Moderate levels of genetic differentiation (\( F_{st} = 0.025-0.035 \)) were observed across Puget Sound and latitudinally along the east side of the Coastal Mountain Range. Low levels of differentiation (\( F_{st} < 0.025 \)) were observed across the Willamette Valley and along the Cascades. We found that gene-flow occurs at sufficiently high rates over most of the study area explaining the very low population genetic differentiation.

**Talk, invited**

ASSESSING THE INSTITUTIONAL RESILIENCE OF NATURAL RESOURCE MANAGEMENT SYSTEMS: A METHOD FOR EMPIRICAL EVALUATION

Kauneckis, Derek

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The concept of resilience has captured the imagination of managers, planners and researchers in a variety of public policy arenas. However while resiliency plans proliferate, the concept remains vague and difficult to operationalize, with little empirical work beyond individual case studies, and much of the research in theoretical isolation from broader understandings of how policy systems evolve and change. This presentation discusses the current literature on resilience in natural resource management systems, provides working definitions and operationalization of the concept, and presents an application that attempts to measure the relative level of resilience of two urban water systems to potential hydrological changes. Based on theories of institutional change derived from the IAD framework and policy sub-system change in punctuated equilibrium theory, it presents a method for measuring multiple properties of resilience within a policy sub-system. The approach offers a tool for understanding how specific decision making structures within complex institutional settings can influence resilience, permits tracing institutional change and learning, and offers a means for comparative analysis of the resilience of a range of natural resource management systems.
Talk, contributed
POPULATION DYNAMICS ACROSS TREE ELEVATIONAL RANGES: IMPLICATIONS FOR CLIMATE CHANGE RESPONSES

Kroiss, Steve J.; Anderegg, Leander D.L.; Breckheimer, Ian; Busby, Posy; Chang, Cynthia; Ford, Kevin; Fricke, Evan; Harsch, Melanie; Theobald, Elli; HilleRisLambers, Janneke
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Predicting how, and how quickly, species geographic ranges may respond to climate change is a current focus in ecology and conservation. Accurate predictions of range shifts will require an explicit consideration of how population growth rates depend on individual vital rates (i.e., growth, survival, and reproduction) that may vary across ranges, as range shifts are fundamentally the result of increasing population growth rates at leading range edges and decreasing population growth at trailing range edges. Thus, to assess which demographic processes (if any) will constrain or facilitate range shifts, we examined the population dynamics of a dominant conifer species (Abies amabilis) across its elevational range on Mt. Rainier, Washington (USA). Specifically, we assessed 1) how range position influences tree growth, survival, reproduction, and ultimately, population growth rates; 2) the sensitivity of population growth rates to individual vital rates; and 3) how projected shifts in vital rates due to climate change may influence future range dynamics. We found that tree growth declined towards upper range edges, but survival and reproduction were not correlated with range position. Population growth rates were also not correlated with elevation (mean lambda 1.02). This consistency in population growth rates across elevation probably results from the low sensitivity of population dynamics to growth (elasticity range 0.003 – 0.02) and reproduction (elasticity range 0.003 – 0.01), compared to the high sensitivity to survival (elasticity range 0.08-0.43). Overall, these results suggest that the geographic range of this species will be slow to respond to climate change, unless climate change significantly affects survival rates.

Talk, contributed
RESPONSES OF CONIFERS ENCROACHING INTO SUBALPINE MEADOWS IN THE CENTRAL SIERRA NEVADA TO CLIMATE VARIABILITY

Lubetkin, Kaitlin C. (1); Westerling, Anthony L. (1); Kueppers, Lara M. (2)
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High elevation meadows provide important ecosystem services, such as maintenance of biodiversity, carbon sequestration, flood mitigation, and water storage, as well as aesthetic value. However, meadows in the Sierra Nevada mountain range in California have a long history of conifer encroachment, and continued encroachment may diminish their ability to provide critical ecosystem services. To predict the persistence of these meadows into the future, we need to understand drivers of encroachment. Here, we evaluate the responses to climate of conifer seedlings and adults encroaching into subalpine meadows in the central Sierra Nevada. We combined a 4-year study of repeat surveys in 30 meadows to examine seedling dynamics with data from 224 tree cores to examine adult growth patterns. Adult trees in meadows proved surprisingly sensitive to climate conditions, showing higher sensitivity than trees in the immediately surrounding forest. Response to snowpack varied by life stage, with high April 1st SWE enhancing germination and establishment but limiting adult growth. In contrast, all life stages of conifers responded positively to warm spring temperatures. New germinants and young seedlings (<10 years old) also occurred most often in locations reaching drier late-season soil moisture levels, which is consistent with our earlier findings that encroachment intensity is highest in meadows with conditions conducive to strong soil drying (such as south facing aspect and high solar radiation). Adult trees were also most abundant in locations with strong soil drying. Our results indicate that climate change may have complex effects on encroachment, at times having opposing effects on different life stages.

Poster
CLIMATE SENSITIVITY OF WESTERN U.S. SNOWPACKS FROM EMPIRICAL ANALYSIS OF WESTERN U.S. SNOTEL DATA

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Empirical sensitivity analyses are important for evaluation of the effects of a changing climate on water resources and ecosystems. Although mechanistic models are commonly applied for evaluation of climate effects for relatively simple
processes like snowmelt, empirical relationships provide a first-order validation of the relationship and provide relatively simple ways to examine potential futures and assess uncertainty in projections. We estimated the sensitivity of snowpacks from 524 Snowpack Telemetry (SNOTEL) stations across the western U.S. We examined the sensitivity of April 1 snow water equivalent (SWE), mean snow residence time, center of timing for snowmelt, and center of timing for snow accumulation to variations in Nov-Mar precipitation and average temperature using multivariate local fit regression. Models were strong, with Nash-Sutcliffe R² values ranging from 0.87 for Apr. 1 SWE to 0.77 for CT of melt. Relationships between climate and timing variables provide insights about effects of climate shifts to snow accumulation and melt. Application of the relationships to assess sensitivity to uncertain futures shows that while projections for snow at some lower elevation stations near the coast are robust to uncertainty in precipitation, even relatively minor variations in precipitation could either trump or dramatically exacerbate temperature impacts on snowpacks in more inland areas.

**Poster**

**VARIABILITY IN THE START, END, AND LENGTH OF FROST-FREE PERIODS ACROSS THE CONTERMINOUS UNITED STATES DURING THE PAST CENTURY**

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The timing of last spring frost dates (LSFDs), first fall frost dates (FFFDs), and frost-free period lengths (FFPLs) constrains freeze-thaw processes in hydrology, paces the annual life cycles of plants and animals, affects human food production, and influences land-atmosphere interactions, including the water and carbon cycles. Daily minimum temperature data for the conterminous United States (CONUS) from the Global Historical Climatology Network for the 1920 through 2012 period are used to determine LSFDs, FFFDs and changes in FFPL. Analyses of trends and variability in LSFDs, FFFDs, and FFPLs indicate a trend towards earlier LSFDs, later FFFDs, and longer FFPLs for most locations in the CONUS. A change to earlier LSFDs appears to have occurred after 1980, whereas the change to later FFDs is most noticeable after 2000. Furthermore, a comparison of time series of LSFDs and FFFDs for each site indicates that there is little temporal correlation between these variables, which indicates that the climate processes driving these variables differ considerably. Analyses indicate that changes to earlier LSFDs for most sites are highly correlated with increases in April/May temperature, whereas changes to later FFFDs for most sites are associated with increases in September/October temperature. Additionally, variability in LSFDs and April/May temperatures appear to be associated with variability in Indian Ocean sea-surface temperatures (SSTs), and variability in FFFDs and September/October temperatures are related to variability in tropical North Atlantic SSTs. These results suggest that variability in Indian Ocean and tropical North Atlantic SSTs can possibly enhance or interfere with the effects of global warming on LSFDs, FFFDs, and FFPLs.

**Talk, invited**

**THE ROLE OF THE SNOW-ALBEDO FEEDBACK IN SIMULATED REGIONAL CLIMATE CHANGE OVER THE ROCKY MOUNTAINS**

Minder, Justin R.(1); Letcher, Theodore (1); Rasmussen, Roy M. (2); Ikeda, Kyoko (2); Liu, Changhai (2)
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As climate warms over mid-latitude mountain ranges, loss of mountain snow cover exposes a darker land surface, leading to additional surface absorption of shortwave radiation and surface warming. This is an expression of the snow-albedo feedback (SAF). The SAF imparts small-scale structure and year-to-year variability on the pattern of regional warming forced by large-scale climate change. Over mountainous terrain the SAF can only be properly simulated with a model that sufficiently resolves the shape of the topography and its influence on local temperature and precipitation. Global climate models do not meet this requirement.

We have examined the SAF in a region encompassing the Colorado Rockies by analyzing regional climate model simulations conducted with the Weather Research and Forecasting Model (WRF) at 4km horizontal resolution. Seven years of historical climate (2002-2008) were simulated both using a control simulation, and a "pseudo global warming" (PGW) experiment. The PGW experiment was designed to study the regional-scale response to large-scale forcings associated with anthropogenic climate change in isolation from large-scale changes in circulation.
A strong SAF over the Colorado Rockies dominates the spatial structure of regional climate change, enhancing large-scale climate warming by several degrees Celsius in certain regions and seasons. There is a strong seasonal cycle in SAF magnitude that peaks during the spring snowmelt season, but varies greatly year-to-year. Simulations with differing horizontal resolutions (4km, 12km, and 36km) produce qualitatively similar results. However, the SAF persists longer throughout the late spring months as model resolution is increased and is substantially stronger in early spring at coarse resolution. Atmospheric circulations act to damp the SAF by exporting excess heat away from regions of snow loss. This results in an enhancement of warming in areas remote from snow cover loss.

**Talk, invited**

**CLIMATE CHANGE REFUGIA AS A TOOL FOR CLIMATE ADAPTATION**

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The concept of refugia has been discussed from theoretical and paleontological perspectives to address how populations persisted during periods of unfavorable climate. Recently, several studies have applied the idea to contemporary landscapes to identify locations that are buffered from climate change effects so as to favor greater persistence of valued resources relative to other areas. Refugia are now being discussed among natural resource agencies as a potential adaptation option in the face of anthropogenic climate change. Here I review the latest literature on definitions and identification of climate change refugia, based on a California LCC-funded collaboration involving expert researchers and natural resource managers from across the western United States. I distinguish between ecological and physical definitions and delineate how climate change refugia can fit into the existing framework of federal management practice. I will then illustrate their utility through a montane meadow example. Genetic data and surveys of Belding’s ground squirrel (*Urocitellus beldingi*) populations in California were used to conduct a rare test of whether particular habitats are acting as climate change refugia. As predicted, refugial meadows showed higher rates of occupancy and lower rates of extirpation over time. Populations found in meadows where the magnitude of climate change was small had higher genetic diversity, indicating that they had persisted longer. Moreover, I used these species data to show that connectivity among sites increased gene flow and genetic diversity. Although no panacea, climate change refugia could be important tools for prioritizing habitats for management intervention in order to conserve populations, including genetic diversity and evolutionary potential.

**Talk, invited**

**ADAPTATIONS FOR HYDROCLIMATE VARIABILITY: REVISITING WATER YEAR CLASSIFICATION IN NONSTATIONARY CLIMATES**

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Water year classifications are helpful for categorizing water years into similar types, allowing water managers to quantify years, visualize variability, and guide water operations. Estimated unimpaired runoff for a water year is categorized by year type, such as wet, dry, or normal, compared to historical averages. However, water management frameworks that were designed assuming stationary climate conditions will be increasingly difficult to implement in nonstationary climates and present a barrier to climate change adaptation. We use climate-driven hydrologic models to identify how alternative methods to adapt historical water year classification methods for nonstationary climates in the Sacramento Basin, San Joaquin Basin, and Yuba Basin in California, USA disproportionately impact economic water uses and instream flows to protect ecosystems. We show that the frequency of water year types changes significantly with climate change and different strategies to adapt water year classification indices to climate change affect water allocations as much as the impacts from changing hydroclimatic conditions. Outcomes from this study have important implications for long term climate change adaptation strategies for managed water systems, particularly in snowmelt-dominated regions expected to experience reductions in water availability.
ARTIFICIAL AMPLIFICATION OF ELEVATION-DEPENDENT WARMING IN THE WESTERN U.S.

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Although the Snowpack Telemetry (SNOTEL) high-elevation weather station network provides critical observations of mountain climate for climate analyses and data products in the western U.S., little work has focused the network’s suitability for assessing temperature trends and variability. Raw SNOTEL data display a +1.05°C decade⁻¹ increase in minimum temperature over the past two decades, whereas corresponding lower elevation stations only exhibit a statistically insignificant trend of +0.03°C decade⁻¹. This apparent difference in warming trends has led to the conclusion that the rate of warming is enhanced at higher elevations. We show that much of this apparent discrepancy in warming trends at higher elevation can be explained by inhomogeneities in the SNOTEL data due to instrumentation and siting changes. Once we account for these inhomogeneities, the SNOTEL trend in minimum temperature is statistically indistinguishable from lower elevation climate observations. Furthermore, popular gridded climate products that input raw SNOTEL data tend to amplify and/or extrapolate the trend bias leading to overestimated high-elevation minimum temperature warming across the western U.S. Therefore, the impacts of elevation-dependent warming on hydrological processes, such as changes in snowpack and river discharge, as well as ecological processes, such as vegetation mortality, distribution, and productivity, have likely been overstated/overestimated.

UNDERSTANDING MULTI-JURISDICTIONAL AND COLLABORATIVE GOVERNANCE AS LEGAL PLURALISM

Pinel, Sandra Lee
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Federal land management agencies now widely embrace adaptive, collaborative, and co-management concepts (adaptive management) to address both social conflict and ecological complexity, as illustrated by the current implementation of the 2012 National Forest Planning Rule. However, as Elinor Ostrom and many social scientists argue, appropriateness of these theories and paradigms depends on the context and the systematic and comparative analysis of multiple exogenous and interactive variables and the interaction of state and customary institutions and norms. While these variables remain understudied, adaptive management is widely recommended as the solution to even more complex large-scale governance systems, by suggesting that co-produced knowledge, mediation, networking and negotiation can overcome conflicts among multiple political local, state, and tribal jurisdictions and users that share common ecological landscapes. However, agreement depends on actors who choose strategically among overlapping cultural and legal rules and powers to pursue their values or interests at multiple scales. An Idaho case study of the Clearwater Basin Collaborative and Nez Perce Clearwater National Forest pilot planning process is used to illustrate the importance of institutional contexts and the overlapping sources of institutional legitimacy, accountability and authority in conflict management. Summarizing some of the recent meta-studies of collaborative governance variables, I then suggest how legal pluralism theory and methods from social anthropology may help us understand behavior in these multijurisdictional and multi-cultural landscape contexts. I conclude with the importance of defining terms, looking beyond federal land management boundaries, and testing paradigm assumptions when designing adaptive and collaborative governance processes.

RESPONSE OF SUB-ALPINE AND ALPINE LAKES IN THE WESTERN UNITED STATES TO RECENT CLIMATE CHANGE

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Multi-proxy analyses of well-dated sediment cores, recovered from high elevation lakes in the western United States, provide the opportunity to place observed climate change and associated ecosystem responses in a broader temporal context. Subfossil midge analysis has successfully been used to develop high-resolution reconstructions of 20th and
21st century temperature change for lakes in the Great Basin. Analyses of subfossil midge remains and C:N from new high-resolution lacustrine records recovered from Linkins Lake and Independence Lake in the White River National Forest, CO, was undertaken to improve our understanding of regional climate variability in the central Colorado Rockies. Application of a robust midge-based inference model for mean July air temperature to the midge stratigraphies developed from these lakes documents the timing and magnitude of recent warming. Expansion of the earlier work in the Great Basin to incorporate additional sites in the central Colorado Rockies reveals that sub-alpine and alpine lakes through much of the western United States have experienced elevated air temperatures during recent decades. The results of this research provide insight into the spatial and temporal patterns of recent climate change in this region and improve our understanding of the linkage between local conditions and regional and hemispheric climate forcing.

Talk, contributed

A DEADLY DISEASE IN A CHANGING CLIMATE CAUSES TOUGH TIMES FOR MONTANE FROGS

Pope, Karen L. (1); Piovia-Scott, Jonah (2); Larson, Monty D. (3); Foley, Janet E. (4)
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Populations of montane amphibians are being devastated by a global epidemic caused by the fungal pathogen Batrachochytrium dendrobatidis (Bd). Now that Bd has become established in the western mountains of the United States, understanding the effects of endemic chytridiomycosis (the disease caused by Bd) has become important for threat assessment and conservation of many at risk species of amphibians. Climatic conditions can influence disease outcomes because Bd growth and amphibian immune responses are both highly sensitive to temperature. In the lab, optimal growth in culture occurs between 17°C and 25°C; but on an amphibian host, growth of Bd is faster at 15°C than 25°C, likely due to enhanced host resistance to infection at the higher temperature. We conducted an in-depth study of Bd infection in remnant populations of the Cascades frog (Rana cascadae) in complex habitats in the southern Cascade Range of California to understand the effects of climate, habitat, and behavior on disease risk and relate them to frog population dynamics. We found that within-season weather patterns and local water temperature influenced pathogen prevalence with increased prevalence on frogs following cool weather events and on frogs found in colder water. While warm and dry weather conditions may enhance survival for post-metamorphic frogs, these same conditions decrease recruitment of new frogs into the population by reducing the proportion of eggs that survive to metamorphosis. We discuss the implications of these findings in relation to climate change.

Talk, contributed

CLIMATE CHANGE IMPACTS AT THE RANGE MARGINS OF ROCKY MOUNTAIN TREE SPECIES: INTERACTIONS WITH DISTURBANCE AND IMPLICATIONS FOR FUTURE FORESTS

Renwick, Katherine; Rocca, Monique
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Rocky Mountain forests have experienced significant changes in temperature and precipitation regimes throughout the past century, and the altitudinal ranges of many tree species are expected to shift upward as the climate continues to warm. The ecotones between forest types, where species are at the margin of their climatic and competitive tolerance, may serve as sensitive indicators of these changes. Our research utilizes long-term ecotone monitoring transects located along natural biophysical gradients to monitor ongoing climate change impacts and investigate how climate, disturbance, and the abiotic environment jointly influence the ability of common tree species to migrate in response to climate change. Transects established from 1992-1994 were resampled in 2012 following a mountain pine beetle outbreak that affected half of the transects. Our data demonstrate that while seedling distributions are in some cases shifting up in elevation and towards cooler aspects, individual species vary in their ability to take advantage of new recruitment opportunities presented by disturbance and a warming climate. Species distribution models incorporating potential competitive interactions indicate that the spatial impact of non-climatic range constraints also varies widely among species. We expect that future tree distributions will not uniformly shift upslope, as landscape context and species-specific migration constraints complicate range dynamics.
**Talk, invited**

**A TREE-RING BASED RECONSTRUCTION OF NORTH PACIFIC JET VARIABILITY AND ITS INFLUENCE ON SIERRA NEVADA FIRE REGIMES**

Trouet, Valerie (1); Babst, Flurin (1); Stahle, David (2); Betancourt, Julio (3)

(1) University of Arizona, Tucson, AZ 85721, (2) University of Arkansas, Fayetteville, AR 72701, (3) USGS, Reston, VA 20192

The Northern Hemisphere polar jet - the fast-flowing, high-altitude westerly air current that meanders over mid and northern latitudes - is an important driver of mid-latitude weather extremes and the societal, ecosystem, and economic damage related to them. Observational and modeling studies suggest that the jet has experienced an anomalously meridional (i.e., more north-south oriented) trajectory and slower progression in recent decades. In California, the position of the North Pacific Jet (NPJ) strongly modulates winter hydroclimatology and a persistent southerly (northerly) trajectory could potentially offset (reinforce) recent and projected regional snowpack reductions on inter-annual to decadal time-scales. Snowpack variability can have a fundamental impact on water resources and ecosystem disturbances. An increase in wildfire activity in the American West since the mid-1980s, for instance, has been related to decreasing snowpacks and earlier snowmelt.

To put recent NPJ variability in a historical context, we reconstructed winter NPJ variability over the last 600 years based on tree-ring data from two locations where climate is influenced by the latitudinal NPJ position. We combined Blue Oak (*Quercus douglasii*) data from central California with snowpack-sensitive tree-ring series from the northern Rockies in a model that explained up to 35% of the variance in the instrumental winter NPJ target. The resulting reconstruction (1409-1990) demonstrates interannual to decadal-scale variability in the latitudinal position of the winter NPJ. Furthermore, we found a strong relationship between reconstructed NPJ position and historical (1700-1850) fire activity in the Sierra Nevada, with increased (decreased) fire activity after winters with an anomalously northerly (southerly) NPJ position. The months-long lag of the winter NPJ-summer fire season relationship can be explained by the sensitivity of fire activity to winter snowpack and can be important in the prediction of problematic fire seasons.

**Talk, contributed**

**AN UPWARD SHIFT OF ENGELMANN SPRUCE ON THE PINALEÑO MOUNTAINS, AZ, USA**

Truettner, Charles M.(1, 2, 3); Cole, Ken L. (3); Anderson, R. Scott (3); Cobb, Neil S. (2,4); D’Andrea, Rob (1, 3); Jarrad, Zach (4); Peters, Michael J. (3)

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Spruce-fir forests in the American Southwest are located at the topmost elevation of isolated desert mountain ranges consisting of species once found at lower elevations during the Last Glacial Maximum. These species have gained less attention than other more widespread forest species in the region, even though the available climate space for these species to migrate upwards has become drastically limited. We analyzed the coexistence of Engelmann spruce (*Picea engelmannii*) and corkbark fir (*Abies lasiocarpa* var. *arizonica*) on the Pinaleño Mountains, AZ ca. 1,000 yr BP projected to 2099 through the combination of a lake sediment core, tree-ring chronologies, plot demographics, and ecological niche modeling. We particularly examined the influence of warm-season vapor pressure deficit, annual mean minimum temperature, cold-season precipitation, and monsoon-season precipitation on the growth-climate relationship for an elevational gradient (32.7 °N). Results indicate that Engelmann spruce has declined within the transitional forest (2930 – 3100 m) on the Pinaleño Mountains, while corkbark fir and quaking aspen (*Populus tremuloides*) remain present. However, ecological niche models projected to 2099 with dynamically downscaled (15 km) general circulation models indicate that Engelmann spruce, corkbark fir, and quaking aspen are threatened to exist on the Pinaleño Mountains after warming effects of 21st century abrupt climate change.
**Talk, invited**

**UNDERSTANDING HUMAN-ENVIRONMENT INTERACTIONS THROUGH THE INSTITUTIONAL ANALYSIS AND THE SES FRAMEWORK LENS: PART 1**

Tucker, Catherine M. (1); Anderies, J. Marty (2)
(1) Indiana University, Bloomington, IN, (2) Arizona State University, Tempe, AZ

Recent research on human-environment interactions and climate change increasingly has adopted the concept of complex social-ecological systems and recognized the role of governance in shaping processes and outcomes. Among the theoretical approaches to advance interdisciplinary research on complex social-ecological systems, the Institutional Analysis and Development (IAD), Social-Ecological Systems (SES) and Robustness frameworks provide a systematic basis for identifying key biophysical and social variables in complex systems with attention to governance arrangements, and examining interactions that influence system outcomes. Developed by Elinor Ostrom and her colleagues, these frameworks have been applied usefully to investigate challenges and prospects for sustainability across a range of social-ecological contexts. We present an overview of these frameworks, their contributions to advancing theory, and their applications for modeling and analyses of mountain ecosystems. We pay attention to the potential utility of these frameworks for analyzing mountain ecosystems of the western USA, where numerous institutions (defined as rules-in-use), organizations and government entities interact in sometimes confounding ways to shape resource use, management, and adaptation to change. We explore how modeling approaches based on these frameworks can help to conceptualize interactions among the biophysical, social and governance components and their outcomes.

**Poster**

**STRUCTURE, DIVERSITY, AND BIOPHYSICAL PROPERTIES OF OLD-GROWTH FORESTS IN THE KLAMATH REGION, USA**

van Mantgem, Phillip J. (1); Sarr, Daniel (2)
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The globally unique old-growth forests in Klamath region of northern California and southern Oregon provide invaluable ecosystem services, but may be vulnerable to a wide range of stressors, including invasive species, disrupted disturbance regimes and climatic change. Yet our understanding of how forest structure in the Klamath region relates to the current physical environment is limited. Here we provide present-day benchmarks for critical elements of old-growth forest structure across a climatic gradient ranging from the coast to dry interior sites. We established 16 large (1 ha) forest plots where all stems >5 cm in diameter were identified to species and mapped. Climate across these sites were highly variable, with actual evapotranspiration predicting many fundamental measures of forest structure, including plot basal area, stem size-class inequality, tree species diversity and, to a lesser extent, tree species richness. Analyses of the spatial arrangement of stems indicated a high degree of non-uniformity, with 75% of plots showing significant stem clumping at small spatial scales (0 to 10 m). Downscaled predictions of future climate for our sites suggest changes dominated by increasing climatic water deficit (CWD, a biologically meaningful index of drought), so that by the end of this century several of our sites will be beyond the range of CWD that typically support coniferous forests in temperate regions. While these plots give a picture of current conditions, continued monitoring of these stands is needed to describe forest dynamics and to detect forest responses to ongoing and future stressors.
Poster

FMH: LONG-TERM MONITORING OF FIRE EFFECTS ACROSS THE UNITED STATES

van Mantgem, Philip J. (1); Keifer, MaryBeth (2)
(1) USGS, Redwood Field Station, Arcata, CA 95521, (2) National Park Service, Fire Management Program Center, National Interagency Fire Center, Boise, ID

Beginning in the early 1990s, the National Park Service (NPS) developed standardized plot-based fire monitoring protocols, which allows direct comparisons of fire effects to be made between and within sites, regions and years. This effort, combined with a separate but similar effort by the USFS, led to the creation of the interagency FFI database (FEAT/FIREMON Integrated, http://frames.nbii.gov/ffi). While these data have been used by federal and some state agencies to describe prescribed fire effects over relatively small management units, we have now compiled these data at a regional scale to address broader questions.

Recent and ongoing work focuses on the determinants of fire-caused tree mortality (including climatic influences) and testing the long-term effectiveness of prescribed fire to reduce surface fuels and fire risks. The FFI data have great potential to be put to additional uses, informing basic forest and fire science as well as addressing management concerns.

Talk, contributed

UP, DOWN, AND SIDEWAYS: SPECIES RANGE SHIFTS IN THE WHITE MOUNTAINS UNDER CLIMATE CHANGE

Weiss, S. B.
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Species distributions are affected by underlying geology and soils, and by climate at multiple scales. Species’ range shifts in response to climate change occur on local scales across topoclimatic gradients – the effects of solar exposure and topographic position on temperatures and moisture. The White Mountains of California, with their 3000 m elevational gradient, complex topography, and diverse geology (dolomite, limestone, meta-sedimentary, and granitic), provide an excellent arena for investigating and predicting range shifts at local levels. More than 600 rapid assessment vegetation plots were analyzed using multivariate methods (Canonical Correspondence Analysis), and species distribution models on a scale of ~50 m were developed for dozens of species, including bristlecone pines. Warming scenarios were simulated by changing the effective elevation according to a lapse rate of 3°C/500m. While there is a general upward movement of species, local topoclimatic effects lead to lateral shifts across aspect (i.e. from south- to north-facing slopes) and downward movement into cold air sinks when frost limitations are relieved. Geologic limitations can prevent upward movements to track warming climate. The complex and individualistic range shifts can be seen in existing patterns of mature and recruiting plants, and the study highlights how local topoclimatic variability allows for short distance migration of plant populations to track a changing climate.

Talk, invited

TOPOCLIMATIC VARIATIONS IN TEMPERATURE AND WINDS AS THE BASIS FOR MOUNTAIN REFUGIA

Whiteman, C. David
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The floors of basins and valleys are favorable for the development of mountain refugia, as physical processes there create local microclimates that can differ significantly from the regional climate. The physical processes leading to spatio-temporal differences in temperature microclimates within topography and their resulting characteristics are the topic of this presentation, with a focus on the diurnal evolution of vertical temperature structures that develop in valleys and basins, their relationship to thermally and dynamically driven winds, and the effects of atmospheric stability on the vertical transport and diffusion of airborne contaminants. Examples of temperature microclimates observed with in situ and remote temperature sensors will be taken from field experiments in Alpine and Western US mountain valleys and basins.
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