MOUNTAIN VIEWS

The Newsletter of the Consortium for Integrated Climate Research in Western Mountains
CIRMOUNT

Sunrise on Indian Peaks from Niwot Ridge, Colorado Front Range. Photo: Bill Bowman

Informing the Mountain Research Community

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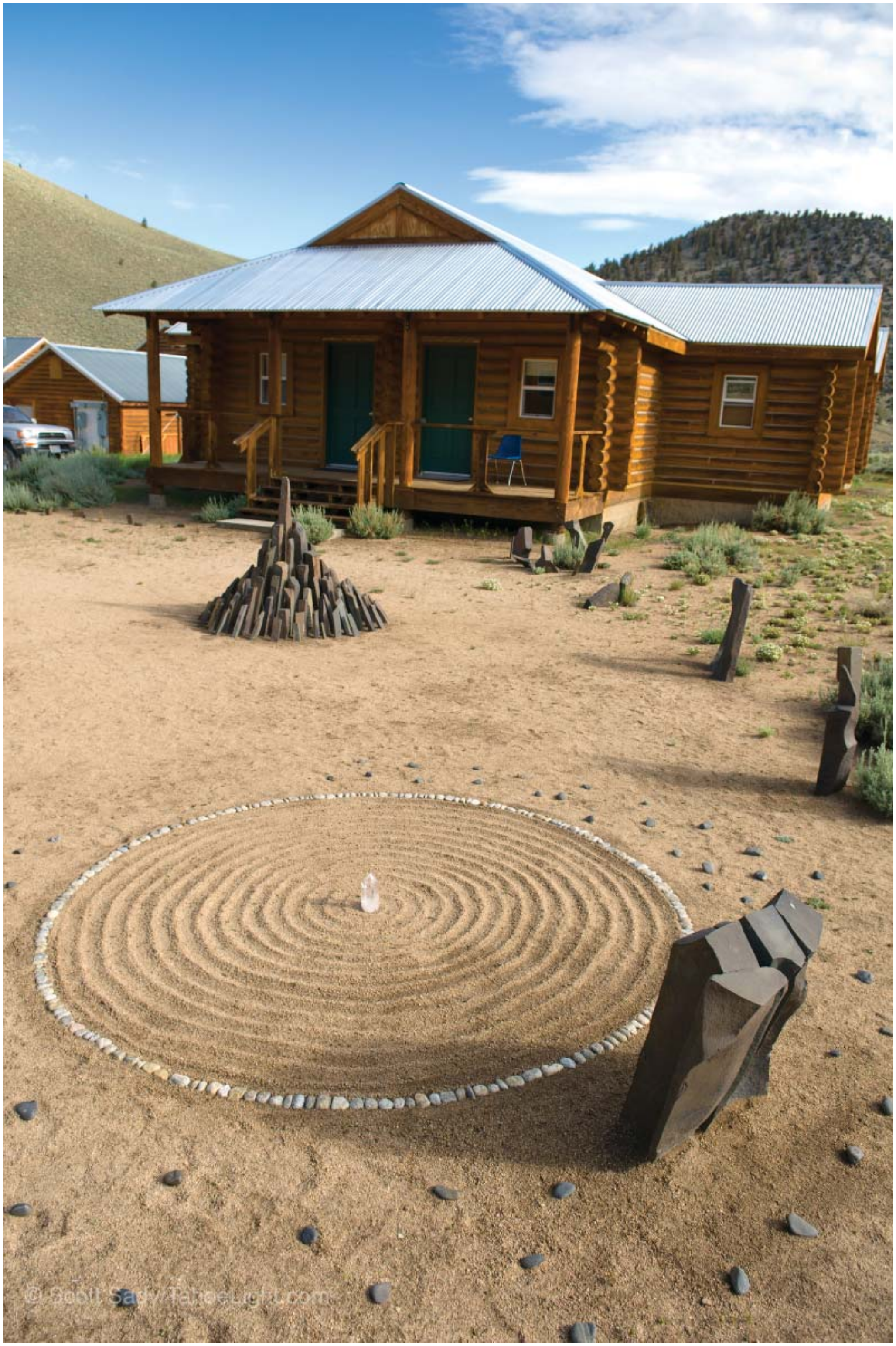

Rock and sand art by Tim Forsell, University of California, White Mountain Research Center, at the high-elevation Crooked Creek Field Station, White Mtns, CA. Photo: Adelia Barber

Read about contributing artists on page 59

Mountain Views

The Newsletter of the Consortium for Integrated Climate Research in Western Mountains

CIRMOUNT

Volume 6, No 2, November 2012

www.fs.fed.us/psw/cirmount/

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The Mountain Views Newsletter (*MVN*)

Connie Millar, *Editor*

Welcome to Mountain Views, the biannual newsletter of the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT, www.fs.fed.us/psw/cirmount/). Our big event this season was to convene *MtnClim 2012*, the sixth mountain climate conference CIRMOUNT has sponsored, this year held in Estes Park, Colorado in early October. The *MtnClim* conferences aim to advance sciences related to climate and its interaction with physical, ecological, and social systems of western North American mountains. As importantly, we strive to encourage serious scientific interaction in informal mountain settings. The backdrop of the Rocky Mountain Front Range provided just that context, with fresh snow glimmering on the peaks, elk bugling in the evenings, and patches of forest mortality on the slopes reminding us of the climatic-hydrologic-ecologic complexities we were discussing inside. Sherri Eng, communications specialist from my USFS office, traveled with us to Estes Park, and provided a summary overview of the meeting (pg 3).

The MtnClim 2012 conference began with a field trip hosted by Bill Bowman (UC, Boulder) to the Niwot Ridge Long-Term Ecological Research site. Photo: Bill Bowman

One goal for *MtnClim 2012* was to promote discussion on potential future opportunities to move our field forward, both within the CIRMOUNT community specifically and toward international collaboration generally. To that end we held several panels and invited speakers to address these issues, including a keynote by Harald Bugmann (Swiss Federal Institute of Technology, Zürich). For *MVN* we include a range of articles intended to continue this conversation, and to stimulate action toward bringing the voice of the mountain climate community to attention on societally pivotal issues. This includes Henry Diaz (NOAA) and Ray Bradley's (UM Amherst) framework for a proposed initiative on climate research in the American cordillera (pg 8) and Greg Greenwood's (MRI, Bern) discussion on "What Next?" for the international Mountain Research Initiative (pg 18). Fred Swanson (USFS) invites the CIRMOUNT community to stretch farther, and to embrace opportunities for science collaboration with arts and humanities, as he outlines for LTER and other programs in which he is a key leader (pg. 24). Finally, adopting shamelessly from SCIENCE magazine, I am adding a new section to *MVN*, "Voices in the Wind", which includes answers to a question of interest (hopefully) to our readers. For this issue of *MVN*, we posed the following question, and then cornered nine of our younger colleagues attending *MtnClim 2012* for their answer: **What burning climate-change research question would you like to have answered in coming decades?** Sherri Eng kindly interviewed these scientists and captured their thoughts (pg. 49).

An important component of CIRMOUNT is to promote the use of best available science in natural-resource management and policy. We have committed to organize a post-*MtnClim* workshop at each conference that includes regional managers and targets applications and management action. This year Linda Joyce, Sarah Hines (both USFS), Jill Baron (USGS), and Gregg Garfin (UA Tucson) organized and hosted such a workshop, entitled "Bridging Boundaries: Climate Change Adaptation" and attended by over 40 practitioners, which convened following the main conference (pg 7).

The *MtnClim 2012* program, abstracts, pdf copies of the poster and oral presentations (main conference and managers' workshop), and links to video-tapes of oral presentations, are available on the CIRMOUNT meeting archive website: www.fs.fed.us/psw/cirmount/meetings/archives.

The *MtnClim* Conferences alternate annually with our sister event, the Pacific Climate Workshop (PACLIM), which last convened in Pacific Grove, CA in March 2011. The next PACLIM Workshop will be March 3-6, 2013 at the Asilomar Conference Center, Pacific Grove, CA. Contact Scott Starratt, USGS, for information: sstarrat@usgs.gov.

CIRMOUNT also sponsors mountain-climate sessions at the annual Fall Meeting of the American Geophysical Union (AGU) in San Francisco. At the December 2012 AGU meeting, we will convene a session entitled, "Geomorphology, Ecology, and Climate-Coupling in Mountain Environments" (Dec 3 and 4), CIRMOUNT's ninth year contributing to AGU. Abstracts and copies of oral and poster presentations will be posted on the CIRMOUNT meeting archive web page noted above.

On behalf of the CIRMOUNT coordinators, we send our best wishes for the coming winter and the likely weather and climate surprises it will bring.

— Connie

Aspen leaf on a pond near Estes Park, CO. Photo: Kelly Redmond

Highlights from the *MtnClim 2012* Conference

Sherri Eng
USDA Forest Service
Pacific Southwest Reseach Station
Albany, California

The majestic Rocky Mountains looming in the distance provided a fitting backdrop for the 120 scientists, students, land managers, policymakers and natural resource specialists who gathered for this year's *MtnClim 2012* conference on climate research in the western North American mountains. Conference-goers from the U.S., Canada, and Europe participated in panel discussions, visited poster sessions and attended focused talks during the four-day event, held Oct. 1-4, at the YMCA of the Rockies in Estes Park, Colorado.

Figure 1. YMCA of the Rockies, Epsilon Peak.

Topics of discussion focused on the following themes: mountain lakes; humans and mountains of the West; ecosystem services; emerging mountain-climate institutions; and the future of mountain climate research. A special session offered an opportunity to highlight the work of early-career scientists. A pre-meeting field trip to the Niwot Ridge Long-Term Ecological Research site near Boulder, Colorado, a post-conference workshop entitled "Bridging Boundaries: Climate Change Adaptation," (see pg 7) and a planning meeting for the North American Treeline Network (see pg 51) were also held. The *MtnClim* conferences are sponsored by CIRMOUNT and rotate to different mountain locations in western North America biennially.

Highlights from the Conference

Western Climate 2011-2012 in Perspective

Climatologist Kelly Redmond from the Desert Research Institute (Reno, NV) kicked off the conference with a perspective on recent climate in the western U.S. The winter of 2010-11 extended through all of spring and into early climatological summer. Snowpack in some locations reached its maximum extent or depth in June, especially in the Sierra Nevada and in the Colorado River headwaters. Record volume and lateness of runoff were experienced in Utah and Colorado. In Arizona and New Mexico severe drought continued from winter and intensified the subsequent spring.

Except for a cool strip along the coast, the rest of the country was warm and dry during spring 2011. Summer precipitation was lighter than usual including the monsoon region. Summer was cool in the Pacific Northwest and California, shading to extremely warm in eastern New Mexico. The entire region was deficient in precipitation during autumn, with temperatures near to somewhat above average. Winter continued the extreme dryness, a major turnaround from a year earlier, with warm conditions mostly confined to Montana and part of Wyoming.

2012 was a warm and dry year. During the October 2011 to September 2012 water year, precipitation was lower than normal and temperatures were higher than normal in much of the country. These conditions drove fire potential in 2012 to August levels by April in the Great Basin. 2012 brought extremely large fires to New Mexico and Oregon, and destructive fires to Colorado, though the year lagged or just barely exceeded long term averages for acreage by mid-summer, perhaps indicative of a lack of very large grass fires until July 2012. Globally, temperatures were also higher than normal. Sea ice extent in the Arctic shrank in August, compared to the same period in previous years.

Figure 2. YMCA of the Rockies, assembly hall.

Climate data of mountain regions have also shown a warming trend. Over the past decade, the elevation of freezing level in the Rocky Mountains has been higher than previous long-term averages. During that same time, the Rockies have had more rain than snow. These dry conditions have contributed to increased mountain pine beetle infestations in central Colorado, according to Redmond. Low precipitation has led to falling water levels at Lake Powell, which is at only 58 percent at capacity.

Figure 3. Lara Kueppers, Ben Bobowski, Greg Pederson, and Stewart-Frey discuss future of mountain-climate research.

Weather forecasters are predicting mostly dry conditions for the western U.S. next year. Assuming a wetter El Niño year, official outlooks predict a wetter than usual conditions in the South and drier than usual conditions in the Pacific Northwest.

Future of Mountain Climate Research

Scientists, land managers and policymakers agree that they must continue to find new and innovative ways to mitigate human effects on the climate system. A panel of scientists shared their thoughts on the future of mountain climate research.

Developing a sustainable water strategy is crucial to protecting our ecosystem, encouraged Iris Stewart-Frey, hydrologist from Santa Clara University. Citing that mountains are the main driver of our freshwater supply, we should place more focus on hydrological research and how human interactions are impacting our freshwater resources. Stewart-Fry suggested that scientists need to synthesize and analyze the hydrologic system as a holistic entity and should have more cross-disciplinary interaction with colleagues in the biological, atmospheric, and geologic sciences.

Greg Pederson, paleoclimatologist with the U.S. Geological Survey, suggested that there need to be better linkages to biological and ecological systems by integrating networks and network design. He challenged climate scientists to conduct integrative research that addresses stakeholder needs, particularly in the face of decreasing federal funding.

Ben Bobowski, Chief of Resource Stewardship with Rocky Mountain National Park, talked about how the park approaches the issue of climate change. Bobowski said that park management recognizes the impact of climate change and is looking for ways to making it relevant and tangible to the 3 million people who visit the park each year. The two greatest impacts of climate change on the park are the infestation of beetles and the expansion of exotic plants, such as cheatgrass. In seeking ways to address climate change, National Park Service scientists try to embrace three priorities: sound science that is rigorous and repeatable; adaptive management that integrates new information with new policy; and resiliency and relevancy in trying to understand climate change at landscape scale.

Lara Kueppers, ecosystem ecologist at the University of California, Merced's School of Natural Sciences, emphasized the importance of examining how the ecosystem can provide feedback to the climate system. Kueppers suggested that scientists look at how biophysical interactions between the land and atmosphere can have significant impacts on the climate and on hydrological and biological systems.

Proglacial Lake-Sediment Records: Searching for Climatic Significance in a Split-Personality System

Glacial movement and changes in snow pack and alpine ecosystem biodiversity can tell us a lot about the effects of climate change on high-elevation lakes. Mountain glaciers are sensitive barometers of climate, explained Western Washington University geologist Doug Clark. As glaciers melt and move downstream, they carry with them sediment, or rock flour, which collects in proglacial lakes.

Coring the lakes provides a long-term and continuous record of the expansion and contraction of glaciers above them. The basic concept behind coring proglacial lakes is attractively simple: as glaciers expand (as a result of cooling or increased snowfall), they flow across greater amounts of bedrock and produce

Figure 4. Park Williams and Jeff Hicke discuss results from their latest research.

progressively greater amounts of fine glacial rock flour; as they retreat, less rock flour is produced.

However, interpreting these data is often difficult and ambiguous, and there's debate about whether large or small glaciers provide the best information. Clark compared the larger Canadian glaciers to the smaller cirque glaciers found on the continental U.S. He found that big glaciers tend to be less well-behaved—one needs more information on lake sediment records to interpret them.

Figure 5. Andy Bunn, Harald Bugmann, and Phil van Mantgem enjoy a sunny break between sessions.

Small glaciers can produce very sensitive records of glacier climate change. Based on his findings, Clark suggested that the ideal study site would contain small, existing glaciers with small bouldery moraines located in stripped crystalline bedrock basins, and have nearby proglacial lakes that are fed by outwash and exhibit mineral varves.

Does Climate Trump Fish or Do Fish Trump Climate?

Citing Rita Adrian's paper in Limnology and Oceanography, University of Nevada, Reno limnologist Sudeep Chandra noted, "Lakes are effective sentinels of climate change because they are sensitive to climate, respond rapidly to change, and integrate information about changes in the catchment." Working under the premise that a lake's heat content drives its algal productivity — a primary food source food source for zooplankton and other organisms—Chandra collected a variety of climatic and limnological data at Castle Lake in California's Klamath Mountain region, including water and air temperatures, snow depth, snow-ice-water content, solar radiation, nitrogen and phosphorous content, zooplankton composition and biomass, and fish stock records. He then created a hypothesized model to determine the influence of climate and fish manipulation on the productivity of zooplankton. He divided the data into three periods reflecting whether or not the lake was stocked with fish and drought conditions.

Using a structural equation modeling (SEM), multivariate approach, Chandra looked at a network of variables to understand how climatic changes affect the drivers of planktonic biomass. While noting that water and air temperatures are indeed changing, Chandra found no trends in classic climate characteristics—ice-out, snow-water content. He discovered that the planktonic biomass has not decreased over the past two decades, but the composition of it has, with the cyclopoid community dominating copepods. Fish stocking, combined with drought conditions, can be attributed to this change in zooplankton community structure, according to Chandra. Furthermore, the altered lake composition may take two decades to recover. "I think that's an important consideration for climate folks. We often try to interpret things in terms of changes to climate, but it's actually the human perturbation of adding and removing fish that can cause these changes," explained Chandra.

National Climate Assessment

Gregg Garfin, policy analyst with the School of Natural Resources and the Environment, University of Arizona, talked about the National Climate Assessment (NCA), which evaluates, synthesizes and interprets the findings of the U.S. Global Change Research Program; analyzes the effects of global change on various key sectors (such as forestry, water resources, ecosystems); analyzes current trends in global change, both human and natural; and projects major trends for the subsequent 25 to 100 years. Previous NCAs have presented concise reports on the state of knowledge with respect to climate science, climate impacts on society, adaptation challenges, and research needs. The current NCA, which will formally report to the nation in late 2013, has expanded goals that are highly compatible with the CIRMOUNT initiative. These include enhancing the ability of the nation to anticipate, mitigate, and adapt to changes in the global environment, and advancing an inclusive, broad-based and sustained process for assessing and communicating scientific knowledge of the impacts, risks, and vulnerabilities associated with a changing global climate.

Figure 6. Imtiaz Rangwala explains his poster to David Inouye.

The NCA's main thrust is support of decision-making across the nation. The following innovations in the current NCA are relevant to mountain climate researchers and institutions: focus

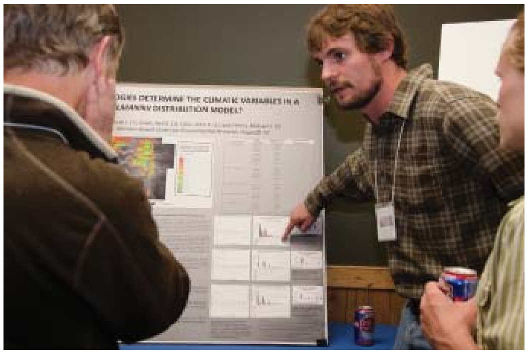


Figure 7. Charlie Truettner points out results in his poster.

on international aspects of global change, assessment of cross-cutting issues (such as water, energy and land use; impacts on biogeochemical cycles), and the development of national climate change indicators. Mountain-focused scientists can contribute to the current NCA through review of the National Climate Assessment report, participation in working groups, and participation in ongoing assessment, through the NCAnet. NCAnet (http://ncanet.usgcrp.gov) is a network of volunteer organizations that contribute to interim NCA reports, build capacity for sustained and ongoing assessment, and cultivate partnerships with other research organizations and stakeholders. Benefits to participants include organized access to the NCA process, and enhanced ability to convey research results to stakeholders.

Role of Human Intervention in Climate Adaptation

Steve Running, Regents Professor, College of Forestry & Conservation of the University of Montana presented a provocative talk about global limits to biological productivity and planetary resource limits. With global population rising at an alarming rate, Running examined whether our current biospheric consumption of global primary production is sustainable. If global population rises 40 percent from 2011-2050, then one would expect that resources must increase by a corresponding amount to sustain it. To achieve this, we would need to find more land to grow more plants, enhance current production with more irrigation and fertilization, or find genetic improvements to enhance plant growth.

However, the planet simply cannot sustain this increase in production, according to Running. Arable and irrigated land is not increasing, and is, in fact, decreasing. Nitrogen loading is already damaging the biosphere, so increasing fertilization is not a viable option. Running notes that there are already "dead zones" in areas – such as the mouth of the Mississippi River - that are depleted of oxygen due to run-off from fertilized land. Genetic improvements in plants are an unlikely source, said Running. "The gene jockeys may be coming up with incredible things in the medical field, but they aren't coming up with any breakthroughs that double or triple photosynthetic capacity in plants." More troubling, global agricultural production is expected to decrease by 14 percent by 2030. The demand for bioenergy will place even further pressure on our land resources.

Running noted that we are currently using about 40 percent of net primary production (NPP), which should leave 60 percent left. However, about half of NPP is unavailable, such as below ground and areas that are inaccessible (wilderness areas, preserves and mountainous areas), leaving just 10 percent available globally.

All photos: Sherri Eng

Figure 8. Sculpture at YMCA of the Rockies.

"Building Bridges", the Post-*MtnClim 2012* Workshop for Natural-Resource Managers

Linda Joyce
USDA Forest Service
Rocky Mountain Research Station
Ft Collins, Colorado

Betsy Neely,
Senior Conservation Planner,
The Nature Conservancy

Louise Misztal,
Conservation Biologist,
Sky Island Alliance

On Thursday, Oct 4, 2012 more than 40 scientists, land managers, and academics representing the US Forest Service, National Park Service, Bureau of Land Management, Colorado State Forest Service, and a suite of academic and non-profit institutions participated in the "Bridging Boundaries: Climate Change Adaptation Workshop", in Estes Park, CO. This workshop focused on opportunities to bridge boundaries and to enhance climate change adaptation in natural resource management. Speakers brought real world examples where individuals and groups worked together to bring understanding and action to the ground to adapt resource management to climate change. The workshop was co-organized by Linda Joyce, US Forest Service, Gregg Garfin, University of Arizona, Jill Baron, US Geological Survey, and Sarah Hines, US Forest Service.

The workshop featured five presentations by practitioners who are successfully "bridging boundaries" in their everyday work:

- Fire management under a changing climate across the Southern Sierra Nevada Ecoregion landscape, Koren Nydick, Science Coordinator/Ecologist, Sequoia & Kings Canyon National Parks
- Lessons learned from bridging boundaries: 50 years of the Greater Yellowstone Coordinating Committee, Virginia Kelly, Executive Coordinator, Greater Yellowstone Coordinating Committee, USFS
- Managing for climate change in the Gunnison Basin: Building resilience, Betsy Neely, Senior Conservation Planner, The Nature Conservancy
- Bringing resilience from theory to practice, Dennis Ojima, Senior Research Scientist and Professor, Colorado State University
- Spring and seep assessments in the Sky Island region: A process of engaging NGOs, resource managers, and academics, Louise Misztal, Conservation Biologist, Sky Island Alliance

The workshop also included a panel presentation and interactive discussion about lessons learned from the bark beetle outbreak in Colorado, featuring John Mack (Rocky Mountain National Park, NPS), Mart Martin (Arapaho-Roosevelt National Forest, USFS), and Ron Cousineau (Colorado State Forest Service).

The five talks that preceded the panel session are available on the Rocky Mountain Research Station website at: http://www.fs.fed.us/rmrs/presentations/bridging-boundaries/.

A Framework for a Proposed U.S. Initiative on "Climate and Environmental Change in the American Cordillera"

Henry F. Diaz[1] and Raymond S. Bradley[2]
[1] NOAA & University of Colorado/CIRES, Boulder, Colorado
[2] Department of Geosciences, University of Massachusetts, Amherst, Massachusetts

Overview

The climate of the Americas—and the western Cordillera in particular—is changing, and the impacts of those changes are rapidly emerging in the form of modified streamflow patterns, plant phenology, terrestrial and aquatic ecosystem structure, wildfire regimes, and many other phenomena (IPCC 2007a,b). The mountain regions that stretch from Alaska to southern Argentina and Chile, home to nearly 200 million people, are especially vulnerable to changes in climate and to the ensuing changes in snowpack, streamflow, and ecosystem functioning that support these societies.

In simple terms, the globe is warming because of a shifting balance between energy received from the Sun and the energy the Earth emits to space. The Earth must warm to relieve a growing imbalance caused principally by trace gas increases, particularly carbon dioxide, that result from human activity. The effect of elevation on temperature and precipitation induces a vertical compression of the typical latitudinal climatic gradients, causing changes in life zones—geographic regions or areas defined by their characteristic life forms, e.g., alpine, subalpine, coniferous forests, drylands, etc.—over relatively short distances. In mountain regions, relatively small perturbations in global processes can operate through the system to produce large local changes. Mountains provide life-sustaining water for people living there and, probably more significantly, for populations living in adjacent lowland regions. Therefore climatic and other environmental changes in the American Cordillera will have a large impact on the future well being of an area far larger than the mountain region itself (Beniston et al. 1997; Barnett et al. 2004, 2008; Bradley et al. 2004, 2006; Decker and Bugmann 1999; Stewart et al. 2005; Diaz et al. 2003, 2006; Westerling et al. 2006).

Accelerated warming at higher elevations in most of the world's mountain zones has been documented by a number of investigators. For the western U.S. climatic changes and subsidiary effects documented to date include changes in phenology (Inouye et al. 2000; Cayan et al. 2001; Westerling et al. 2006), hydrology (Barnett et al. 2004, 2008; Kaser et al. 2004; Coudrain et al. 2005; Juen et al. 2007; Knowles et al. 2006; Mote et al. 2005; Regonda et al., 2005; Stewart et al. 2005), and ecosystem changes (Pounds et al. 1999; 2006; Still et al. 1999; Breshears et al. 2005, 2008; Diaz and Eischeid 2007). In fact documented changes, including increases in elevation of the freezing level along the full length of the American Cordillera have been noted in a number of studies (Diaz and Graham 1995; Vuille and Bradley 2000; Vuille et al. 2003; Diaz et al. 2003; Bradley et al. 2006; Karmalkar et al. 2008, 2011); such changes have also been noted in mountains elsewhere (Diaz and Bradley 1997; Diaz et al. 2003; Giambelluca et al., 2008). All of the world's mountain regions have been warming steadily through much of the 20th century, with an apparent acceleration in the warming rate in the past several decades (Fig. 1). In the southern American Cordillera warming accelerated in the past 30 years (Fig. 2), while in the contiguous United States, temperature changes for the last few decades in the Rocky Mountains region are much greater than in the rest of the contiguous U.S. (Hoerling et al. 2006; 2007, Figs. 3, 4).

Persistent drought presents the countries that are part of the American Cordillera with some of their greatest challenges. Changes in hydrological variability, precipitation and snow cover will impact a broad range of socioeconomic sectors ranging from hydropower generation, ecosystem health, water resources for irrigation and civil supply to tourism-related industries (Bradley et al. 2006; IPCC 2007b; Milly et al. 2008). The challenge is to anticipate the environmental changes that can be expected under future climate scenarios, and as societal pressures on mountain ecosystems increase, in order to plan for sustainable development in these regions and the downstream areas which depend on them. This article thus proposes a framework for an integrated climate science and human dimensions program initiative to be considered by the appropriate federal, regional, and state agencies. We present some examples of ongoing research and outreach activities that could serve as models for agency-supported activities in this area. The proposed areas for future integrated climate assessment work are illustrative of activities to be highlighted in a formal call for proposals.

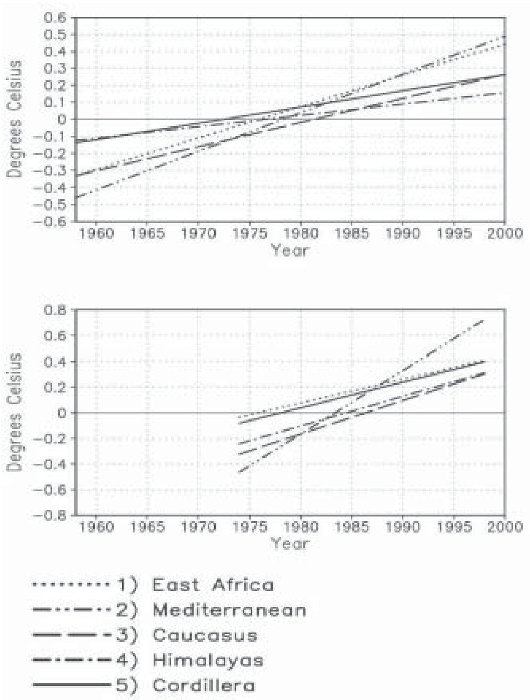


Figure 1. Linear trends in near surface air temperature for 5 different mountainous regions, based on the NCEP/NCAR Reanalysis data set. Top panel is for 1958–2000, lower panel for the period 1974–1998. Source: Diaz et al. (2003).

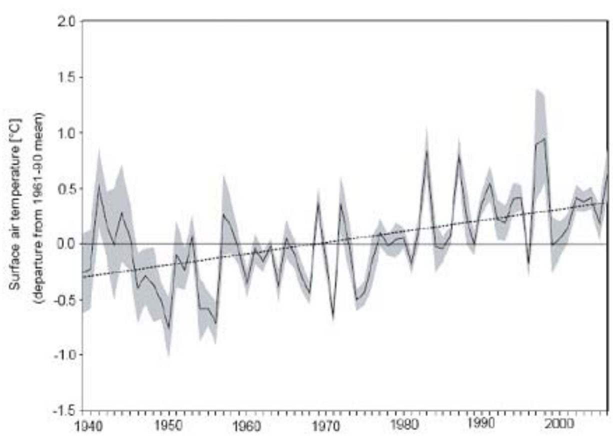


Figure 2. Annual temperature anomalies, 1939–2006, relative to 1961–1990 averages in the tropical Andes (1°N–23°S). Time series based on records from 279 stations. The increase in temperature in the Cordillera is ~0.1˚C/decade. Source: Vuille et al 2008a.

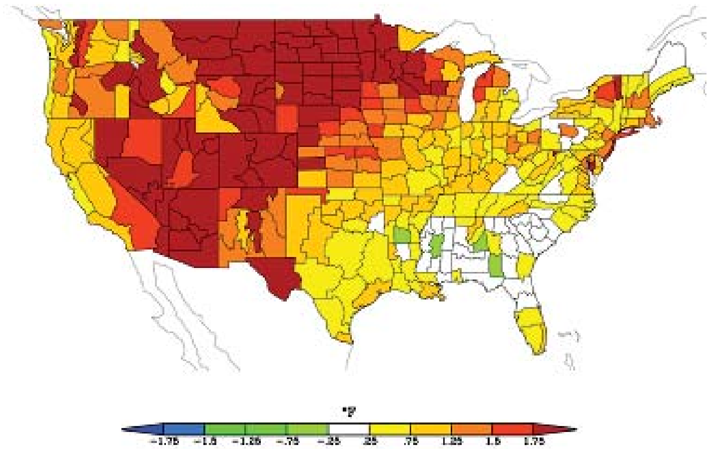


Figure 3. Observed annual temperature anomaly 2000–2006. Notice much greater warming in the mountainous Western U.S.A Source: NOAA Earth System Research Laboratory. Reference Period: 1950–1999.

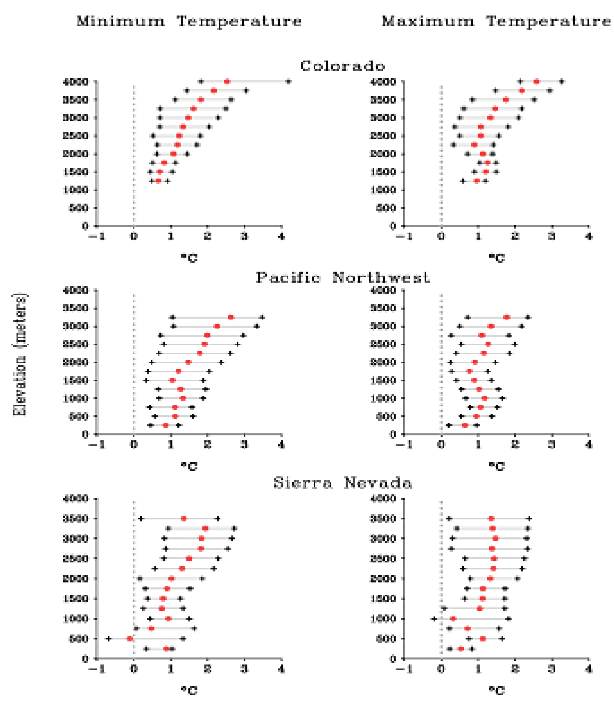


Figure 4. Post-1980 observed temperature trends vs. station elevation for western USA. From Diaz and Eischeid 2007.

The Challenge

Global warming and other global changes (e.g. in biodiversity) will have far-reaching, though as yet unknown, consequences for the mountain environments of the Americas. There are many daunting challenges that confront the region from the southern Andes to the northern Canadian Rockies and Alaskan ranges. Among the greatest of these is maintaining a sustainable water supply in the face of a growing population in a time of increasingly variable and changing climate. In the mountainous West of the United States, a consensus has been reached among a diverse group of researchers and resource managers that climate change will seriously alter the mountain snowpack—the principal source of precious water—and with it, ecosystem function, landscape integrity, and concomitant socioeconomic activity in the region (Diaz and Millar 2004; Diaz et al. 2006; Bradley et al. 2006; Rosenzweig et al. 2007). At the same time, other studies have found similar impacts emerging in other countries of the Western Hemisphere (Coudrain et al. 2005; Juen et al. 2007; Vuille et al. 2008a,b).

The need to better understand the natural and societal processes, which drive large-scale environmental change, has never been greater. Critical needs that an integrated national-scale program would be able to address include:

1) Augmenting the scientific capacity across disciplines and spatial scales;

2) Enhancing information exchange and delivery to a broad range of policy makers and stakeholders;

3) Promoting interdisciplinary research activities by supporting comparative and focused studies of scientific issues important to different regional entities.

In summary the overarching mission of a national research program focused on mountain environments in the Americas, and the United States in particular, would be to enhance our capacity for understanding the specific and cumulative impacts of present and future global change on regional and continental environments, promote collaborative research, and support informed adaptation and mitigation action throughout society.

The western cordillera of the Americas forms a unique transect that intersects the major features of the global atmospheric circulation and flank the world's largest ocean. The following are some key questions regarding the nature and impact of ongoing and future global warming in mountain regions of the American Cordillera:

Climate and other global change drivers

What are the major dynamic patterns, connections among different parts of the world, and feedback loops that determine the region's climate at both long and short time scales?

What are the characteristic regimes and timescales of natural variability in the climate of the region that help to sustain societies in this culturally diverse region?

What controls and modulates those regimes and scales? Will long-term changes also exhibit those regimes and scales?

What role have abrupt and extreme natural events played in the evolution and sustainability of Cordilleran mountain systems?

How do anthropogenic disturbance regimes interact with climate change on regional-to-local scales in the American Cordillera?

What are the physical components of the environment of the American Cordillera, which, if transformed by human actions, might, feed back upon the climate system?

How do the atmospheric, biogeochemical and biophysical dimensions of global change affect ecosystem structure and function?

Impacts on the land systems, ecosystem services, and human societies

How do changes in land cover and climate affect biogeochemistry, biodiversity, biophysical properties, natural hazards and disturbance regimes of terrestrial and freshwater ecosystems?

What components must remain operational for mountain ecosystems to remain viable and sustainable?

How will the provision of ecosystem services, principally water, soil, and natural resources, be affected in the decades ahead? How will changes in ecosystem service affect societal well-being and environmental security?

What social groups are likely to be vulnerable to foreseeable scenarios of global change?

How are impacts and vulnerability distributed across the different regions of the American Cordillera?

How does the vulnerability of western mountains compare to other regions and settings?

Cordilleran institutions as adaptive mechanisms

What institutions—networks of authority, governance structures—constitute the basis for adaptation?

What are the knowledge systems that underlie different actors within the network of authority?

How do globalization and political change influence development in mountain regions?

How are future abrupt, extreme, and/or sustained climatic events likely to be managed through the coping and adaptation mechanisms of natural and social systems and their interactions?

What factors determine the success of research in informing decisions taken within the existing network of authority?

Formulating a Climate and Environmental Change Initiative—Some Recent Steps

Several of the sponsors of this proposed integrated climate assessment initiative for the American Cordillera are climate researchers that have been involved in the development of informational and decision support tools for a variety of stakeholders and decision makers. Many of these efforts attempt to reach out to different groups in an effort to communicate the concerns of the science community regarding global warming impacts on society in the region of the American Cordillera. Several years ago, the US members of this group established an ad-hoc consortium to promote the diffusion of the latest scientific ideas and knowledge about climate change science in the western United States.

The Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT: http://www.fs.fs.fed/psw/cirmount/) was established as a collaborative, interdisciplinary enterprise dedicated to understanding climates and ecosystems of western North America's mountains. CIRMOUNT's goal is "to bring together researchers from diverse disciplines and institutions to measure and understand climate-driven changes in the unique landscapes that define western North American mountains, and to respond to the needs and challenges of western society for mountain resources imposed by climate change."

The Consortium was formed in 2004 following a conference attended by representatives from many scientific disciplines, state and federal governmental agencies and the media (Diaz and Millar 2004). In 2006, the Consortium published a widely distributed report titled *Mapping New Terrain, Climate Change and America's West*, available free of charge from the CIRMOUNT website, with the goal of promoting effective responses to climate-change-related problems facing the region. CIRMOUNT is sponsored by a diverse group of agencies, universities, and institutions, and is endorsed as a pilot project of the International Mountain Research Initiative (http://mri.scnatweb.ch/).

International efforts to improve understanding of climate change issues in South and Central America were the focus of a conference attended by more than 160 researchers, government officials, and representatives from donor institutions who met in Mendoza, Argentina in 2006. The Symposium on Climate Sciences of the North and South American Cordillera (CONCORD) built on past efforts to develop a continent-wide focus for climate and global change science, monitoring, and application activities in the mountains of the American Cordillera (Diaz et al. 2006). A key goal of that conference was to discuss the current state of climate change science and the next steps needed to promote successful adaptation to climate change in the western American Cordillera.

The MRI, a co-sponsor of the 2006 CONCORD meeting, launched the American Cordillera Transect (ACT) in a workshop immediately following the CONCORD meeting. MRI launched the ACT as a specific regional instance of a GLObal CHAnge research strategy in MOuntain REegions, GLOCHAMORE, which emerged from a EU FP6 Specific Support Action in late 2005. ACT has succeeded in creating an American Cordillera Forest Dynamics network (CORFOR, http://www.corfor.com/). The ACT is a specific form of activity, a global change research network, which could contribute significantly to ACCORD.

Connections to the National and International Science Agendas

A general framework for this national initiative would support integrated research of past, present and future global change on regional to continental environments in the Americas and to promote collaborative research and informed action at all levels. It includes:

1. *Understanding Climate Change and Variability in the Americas;*

2. *Comparative Studies of Ecosystem, Biodiversity, Land Use and Cover, and Water Resources in the Americas;*

3. *Understanding Global Change Modulations of the Composition of the Atmosphere, Oceans, and Fresh Waters; and*

4. *Understanding the Human Dimensions and Policy Implications of Global Change, Climate Variability and Land Use.*

The focus of the first theme is to observe, document and predict climate change and variability in the Americas and its links to changes in natural systems and societal impacts. The goals are to understand the role of the ocean-land-atmosphere interactions in climate, to determine the key processes that cause climatic variability, from seasonal to decadal time scales, and to apply the insight gained by these findings to improve climate predictions. Topical connections to this initiative include the following research themes:

i) Variability of the American Monsoon systems;

ii) Ocean/land/atmosphere interactions and hydrology, including atmospheric mesoscale processes; global and regional changes in the water cycle;

iii) Climate change at regional scales: scenarios, impacts, vulnerability and adaptation; climate changes in the past; and

iv) Development of an "Americas component" for a Global Observing System for climate.

There are also strong connections to the second and fourth agenda items (above), namely their focus on comparative and integrated analyses of the effects of Global Environmental Change (GEC) on natural and anthropogenic systems and processes among tropical, temperate and cold latitude systems, insofar as the American Cordillera extends through tropical, subtropical, temperate and polar and subpolar environments. This should be one of two fundamental goals of this Initiative.

On the human dimensions side, the goal is to fully integrate work that increases our knowledge of the drivers and dynamics of variability, and the impacts of such variability on regional food security, biodiversity and the provision of ecological goods and services. Relevant topics under this theme include:

i) Impacts of global change on biodiversity, including species and genetic biodiversity;

ii) Comparative studies of resilience of ecosystems including vulnerabilities of key species;

iii) Comparative studies of changes in land use and mountain-based freshwater resource use; and

iv) Climate and habitat change impacts on wide-ranging species across the American Cordillera.

Another IAI Science Agenda item focuses on studies of the dynamic interaction of global change, climate variability, land use and human beings—their health, welfare and activities, which depend on the productivity, diversity and functioning of ecosystems. Its objective is to inform public policies that increase sustainability of natural systems and human welfare. Topics suggested under this initiative include:

i) Health and environmental issues with emphasis on vector-borne diseases;

ii) Increased vulnerability of human settlements in mountainous regions due to global change, climate variability, and land use and issues related to rapid urbanization and sustainability of natural and human systems in mountain regions of the American Cordillera;

iii) Global environmental and economic change drivers; and

iv) Implications for the preservation of biodiversity and conservation strategies in mountain regions.

In the context of GEC-driven changes, including the synergistic impacts related to global warming, the proposed mountain-focused initiative envisions a strong emphasis on studies related to climate change mitigation and adaptation strategies, including activities aimed at more effective climate information exchange with decision makers, participatory environmental decision-making, and the development of appropriate science-based tools for enabling community-based adaptation. The emphasis of these types of research will be on projects that address the complex interactions between natural and socio-economic systems through interdisciplinary approaches.

We recognize that there exist other areas of scientific research that connect explicitly or implicitly to the proposed American Cordillera Initiative. Such areas include research on climate variability and change related to Tropical Atlantic Variability, El Niño-Southern Oscillation (ENSO), and other forms of low-frequency climate variability, biogeochemical processes and ecosystem hydrology.

Potential Research Actions

Mitigation and adaptation to future climate and other global changes in the American Cordillera will require a better understanding of the climate, biophysical and ecological systems, and of the capacities and performance of institutions. Such information is vital in order to enable better management of mountain ecosystems, maintain their biodiversity, sustain the use of mountain resources and ecosystems, and preserve the social and economic well being of mountain communities in this region. Efforts needed to develop effective capacities in this area include (*inter alia*):

Thematic research: grant and networking programs that focus on key aspects of the climate and coupled human-earth systems, including the alpine cryosphere (snow- and ice-covered areas), and regions with permanently frozen ground, as well as land and hydrologic systems as manifested in agriculture, energy, and transportation sectors, and the institutions that govern societal responses to environmental change.

Interdisciplinary place-based research: programs that seek to build connections across thematic disciplines, both biogeophysical and socioeconomic, in order to understand the functioning of the earth system at a level congruent with national and local decision-making, per the GLOCHAMORE research strategy.

Improved climate and environmental monitoring: programs that focus on the current and the desired configuration of environmental monitoring in the American Cordillera, while building on existing efforts such as GEOSS Americas.

Improved policy relevance of research: programs that focus on the translation of research results into forms and formats relevant to regional, national and local policy formation and decision making.

Improved strategic planning of earth system science: evaluating and identifying possible long-term institutional arrangements for improving integrated Earth climate system science research and development in the American Cordillera.

Highlight of Priority Research Activities

Climate change assessment
Climate change assessment is here broadly defined to include the collection of field-based data for validation of model simulations of atmospheric, geomorphic, hydrologic, and biospheric processes. The approach is to consider as many elements as needed in order to develop integrated models of climate change to improve predictions and to quantify and reduce uncertainties. In order to properly test and evaluate the performance of integrated climate models, and to establish mechanisms for the diffusion of effective climate-relevant information to decision makers it is necessary to establish effective monitoring frameworks.

Effective climate monitoring requires a long-term commitment to data quality and network stability, and network adequacy. Climate-related signals can be subtle and are sometimes obscured by short timescale variability; hence, changes in variability arising from changes in the observing system can obstruct efforts at detection of climate change. The integration of measurement programs at mountain research sites with operational and research activities in the region will ensure that the data are state-of-the-art, and that they continue to meet research requirements for studies of climate variability and change (Bradley et al. 2004). The potential impact on the high elevation environments of the American Cordillera is illustrated in Figure 5, which depicts projected temperature changes along a suitable north-south transect of the Cordillera.

Regional studies with high-resolution paleorecords are useful in determining the spatial pattern of past climate variability in the American Cordillera, and are helpful in interpreting possible mechanisms of climate forcing. The research community recognizes the importance of various paleoclimate activities in the region, encourages funding agencies and institutions to continue to support capacity building (scientific education and training) and research focused on climate change and its impact throughout the Americas.

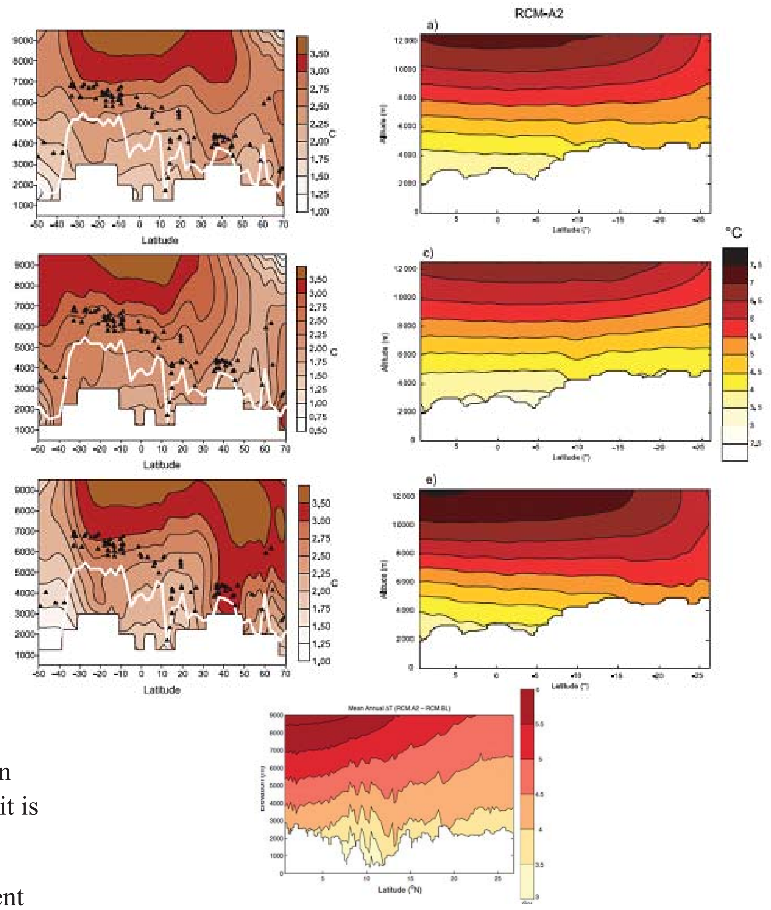


Figure 5. (above, left): Mean change in free air temperature along a transect from 50°S to 70°N (2x CO_2 [=645-700ppmv] minus control runs) for 7 CMIP2 GCMs. Data are displayed only for those latitudes and levels where data are available from all seven models. The solid white line connects elevations of the highest regions in each grid box; those elevations are the maximum of all the 50 x 50 ETOPO5 elevations in the grid box. The black triangles show some of the highest mountain peaks along this transect. The white line crosses the missing data region in a few places due to some rounding in interpolation by the imaging software and to the topography files used by the models, which use sigma (or hybrid sigma) levels. Upper panel: mean annual temperature change; Middle panel: DJF; Lower panel: JJA. These simulations suggest very large impacts throughout the American Cordillera (from Bradley et al., 2004). **(above, right):** Mean annual temperature change from the Equator to 25°S (scenario A2 [=850ppmv] minus the baseline, 1961-90) derived from the Hadley Center regional climate model (PRECIS) with boundary conditions provided by the HadAM3P GCM (top panel: mean annual temperature; middle panel: DJF); lower panel: JJA. (from Urrutia and Vuille, 2009). **(below center):** Mean annual temperature change from the Equator to 25°N (scenario A2 [=850ppmv] minus the baseline, 1961-90) derived from the Hadley Center regional climate model (PRECIS) with boundary conditions provided by the HadAM3P GCM. (from Karmalkar et al., 2011).

Improved high-resolution climate modeling

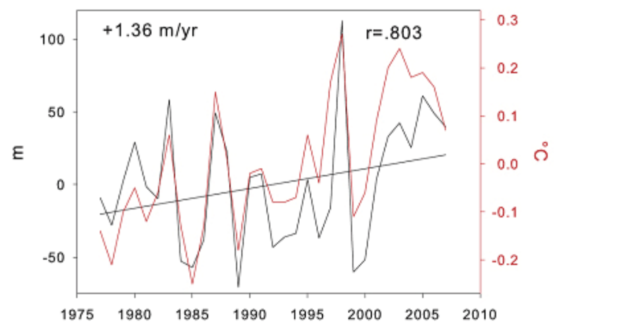
Detailed projections of climate change in the American Cordillera are severely hampered by the very fact of its complex topography. Regional climate models embedded in coupled ocean-atmosphere models and connected to hydrological & glaciological models—and ultimately to ecological models-- are needed to provide decision-makers with the tools for effective climate policy making. Some recent efforts in this direction are encouraging (Rauscher et al. 2008; Karmalkar et al. 2008, 2011; Urrutia and Vuille 2009, Wi et al. 2012, and others).

Role of land cover changes in climate change

Changes in the alpine cryosphere may represent some of the earliest signs of large-scale climate change. A reduction in the area covered by snow and ice not only serves as an indicator of change but also provides powerful feedbacks through changes in albedo. In addition, melting of permafrost destabilizes slopes in areas of high relief, leading to landslides, rockfalls and other climate-impacted geomorphic hazards, such as the formation of proglacial lakes, which can easily breach leading to potentially catastrophic flooding and other significant hazard in many places, as has already occurred in the tropical Andes. Decision support tools that could be used to better understand what is happening in the region include so-called integrated assessment models that consider an ensemble of physical, socioeconomic, and other inputs relevant to mountain environments.

Satellite images and airborne repeat photography of the margins of glaciers in the Cordillera region have documented the significant changes in the extent of glaciers in the past century (Fig. 6). These changes are having, and will have, profound consequences for societies in the region that have depended on water from these previously glaciated catchments for their livelihood and culture. The characterization of land surface changes on regional to continental scales is becoming increasingly important in assessing the impacts of climate change in relation to direct human modification. Changes in biogeochemical cycles are linked to changes in climate, the water cycle, land use patterns (both rural and urban) and changing vegetation types (Ray et al. 2006). Such changes could have adverse impacts on agricultural production, unmanaged systems, and aquatic systems receiving runoff.

Avoiding or mitigating these adverse impacts requires a fundamental understanding of linkages within terrestrial and aquatic systems, and an ability to predict the consequences of climate variability and the adoption of adaptive management practices. This suggests that appropriate downscaling tools (i.e., regional climate models) must be developed in order to improve the utility of the scientific research. The integrated use of regional models for multidisciplinary research should be a high priority of systems modeling activities. Some efforts in this regard are already underway (e.g., Urrutia and Vuille 2008), but an enhancement of these regional modeling activities is urgently needed.



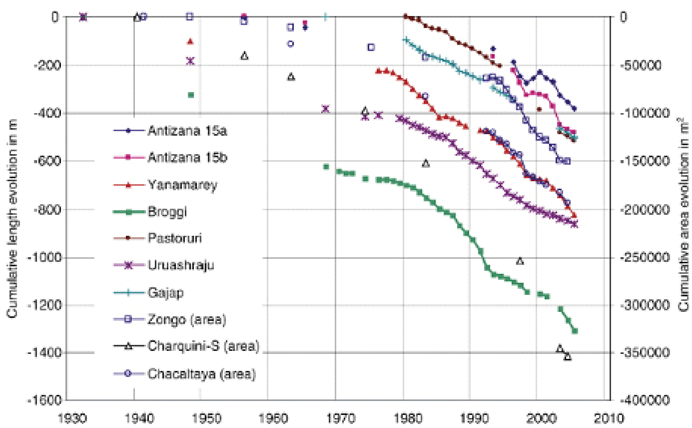


Figure. 6

(above): Mean freezing level height across the entire Tropics (28.75°N–28.75°S) compared to mean sea surface temperatures (ERSST data) in the same region (both expressed as departures from the 1977–2007 average in °C) (from Bradley et al., 2009).

(below): Change in length and surface area of 10 tropical Andean glaciers from Ecuador (Antizana 15a and 15b), Peru (Yanamarey, Broggi, Pastoruri, Uruashraju, Gajap) and Bolivia (Zongo, Charquini, Chacaltaya) between 1930 and 2005 (from Vuille et al., 2008a). Changes in temperature are linked to glacier mass balance through complex linkages involving changes in humidity, sublimation versus melting, cloud cover, albedo and net radiation changes.

Biodiversity

Highland tropical forests are rich in endemic species and crucial in maintaining freshwater resources in many regions. Much of their remarkable biodiversity is due to the steep climate gradients found on tropical mountains. The ecosystems along the mountain slopes are closely stacked due to sharp vertical temperature and precipitation gradients and are particularly vulnerable to climatic changes. The Central American region in particular has been declared a biodiversity "hotspot" based on the existence of a large number of endemic species (Myers et al. 2000); exacerbating the situation has been the exceptional loss of habitat in recent decades. The region is home to lowland dry and montane/cloud forests that host all subtropical and tropical ecosystems from central Mexico to the Panama Canal. Mountain ecosystems and species, where climate zonation is constrained by topography, are particularly susceptible to a changing climate.

Developing effective climate change adaptation strategies in the Cordilleran region

In addition to having direct economic impacts, such changes in mountain hydroclimate presumably would affect ecosystems, upstream as well as downstream. Large areas of the American Cordillera currently are poorly monitored by conventional or remote sensing systems. Large changes in climatic and environmental conditions can occur over small distances in the highly complex topography of the Cordillera, and this points to the need for a multifaceted observational system to monitor and better understand future societal changes in response to global warming.

Critically important to this effort is establishing the ability to communicate key concepts and concerns of the climate science community to stakeholders and decision makers throughout the Cordilleran region. A part of this effort consists of capacity building in the region as part of a long-range strategy to inform society and its leaders about global change issues, and how they might affect different parts of the region.

To that end, we propose that a system of interdisciplinary workshops be initiated, that would implicitly include presentations from stakeholders and decision makers from the region. We envision these workshops as providing the opportunity for science leaders and key decision makers in the region to communicate with each other about mutual concerns and to hopefully develop long-term associations that would benefit both the science and the development of rational long-term policies.

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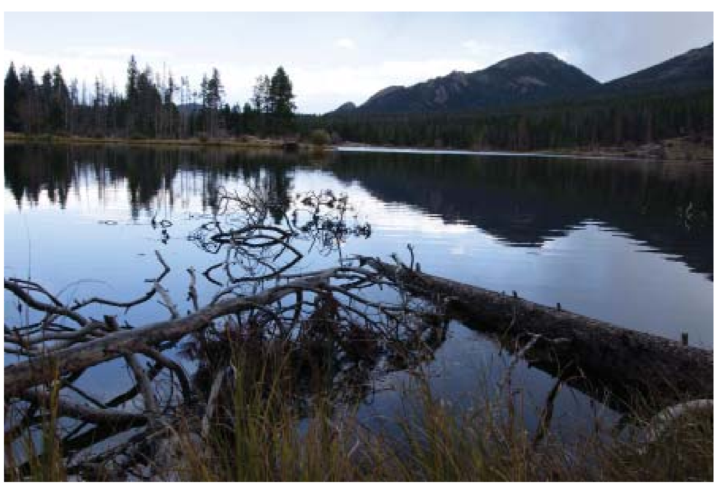

Sprague Lake, Rocky Mountain National Park. Photo: Sherri Eng

The Mountain Research Initiative (MRI): What Comes Next?

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The Mountain Research Initiative (MRI) promotes and coordinates global change research in mountains around the world. It arose from the International Geosphere and Biosphere (IGBP), and the International Human Dimensions (IHDP) Programs in 2002, is funded by the Swiss National Science Foundation and is based at the Geography Institute of the University of Bern.

The MRI continually searches for the next steps in promoting global change research in mountains. Since the Swiss National Science Foundation (SNSF) renewed the MRI's funding in 2010, the MRI has pursued its program of global and regional networking activities, synthesis workshops, and new communication modes, but is going beyond them now to investigate more sustained efforts.

While any research into global change in mountains represents progress, research that adds to an understanding of the "whole system" - the coupled human-natural system within mountains as it is embedded within the planetary earth system of atmosphere, oceans and continents - is one of MRI's principal scientific goals.

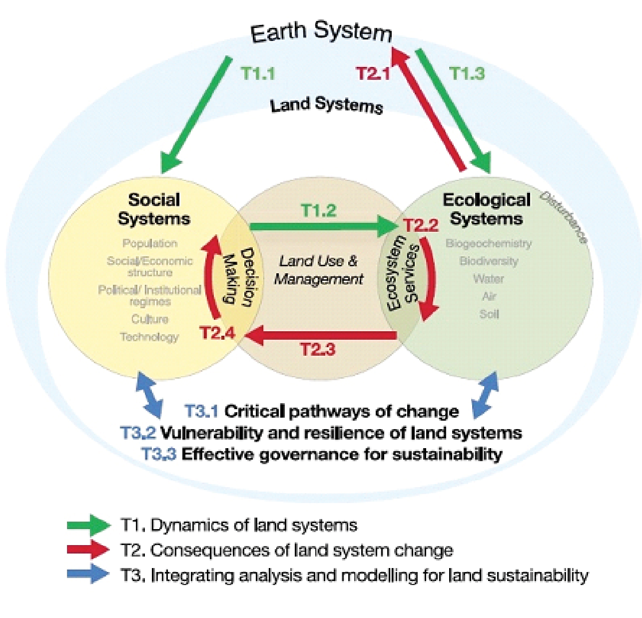

Figure 1. The Global Land Project analytical structure (GLP 2005).

The MRI makes liberal use of the "analytical structure" of its parent scientific organization, the Global Land Project, as it captures the linkages and the embedded-ness and speaks as well to the evolution of the whole system toward or away from sustainability.

This emphasis on whole systems creates a certain tension in MRI's work, as research by its analytic nature, tends to focus on mechanisms and parts of systems. This is as it should be: to create an integrated understanding, one must have parts to integrate! Thus, while encouraging research on specific parts of the coupled human-natural system, MRI must at the same time promote the continual interrogation of how these parts come together to create a whole system.

This whole system knowledge is the scientific analogue to the governance of mountain social-ecological systems. One of the principal problems of mountain regions, often hinterlands within their respective states, is the fragmented nature of governance, with agencies and interest groups focused on only their part of the system - forests, wildlife, water - with no explicit policy recognition of the inter-related whole. Here whole system knowledge portrays to the body politic the full scope of impacts arising from actions in particular sectors.

As researchers often depend on agency funding for their research, the fragmentation of governance finds an echo in the fragmentation of the research community. Thus to achieve an understanding of the whole system, MRI must also work to create true community out of a collection of disparate researchers and institutions. Whenever MRI invokes "community" it is perhaps more a statement of a goal than a characterization of the current condition. MRI works toward community via entities such as its regional networks in Africa, Latin America, and Europe and via sister organizations such as CIRMOUNT under the presumption that more frequent exchange between researchers working in the same region will lead eventually to more collaboration on the understanding of the whole system.

Building community requires years, if not decades, while MRI is funded on a three-year cycle by the Swiss National Science Foundation (SNF). As such each successive proposal to the SNF tracks progress toward this long term goal.

For several years we have been using the "4 I's" as a heuristic to describe out program: initiation of activities, implementation of research, integration of results, and information for stakeholders. To date we have concentrated our effort on Initiation via our Key Contact Workshops and regional networks, Integration via our Synthesis Workshops and Information through Mountain. TRIP. As we are not funded to do research ourselves, it is difficult to approach Implementation directly. The best we can do is to attempt to align researchers in different countries around common research themes, so that their research, funded through their particular mechanisms, creates a longer-term coherent program.

Research Themes Emerging From Perth

The Conference "Global Change and the World's Mountains" in Perth in 2010 provided a snapshot of the current status of global change research in the world's mountains from which the community constructed assessments of important future research themes (Greenwood 2010, Björnsen et al. 2012). The following emerged as important themes over the next 5-10 years:

- Mountains in the Global South
- Nature and Trajectory of Ecological Systems under Global Change
- Institutions and Social Systems
- Interactions between Social and Ecological Systems
- Global Social Drivers
- Long-Term Monitoring (Observing Systems)
- Ecosystem Services
- Human Agency in the Mountains
- Communication
- Human Presence in the Mountains
- Integrated Analysis and Modeling for Land Sustainability

To translate these general themes into more concrete actions, the MRI convened a one-day workshop of the MRI Global Commission at Imperial College, London on 30 March 2012 immediately following the IGBP Planet Under Pressure Conference. The MRI Global Commission consists of the Swiss Principal Investigators who sponsor the MRI at the SNSF and MRI 's Scientific Advisory Board augmented by active mountain researchers.

The Global Commission brainstormed ideas that community could pursue with respect to each of these themes resulting in 10 detailed mind maps (a graphic form of outlining ideas) related to these themes. From these mind maps (available at http://mri.scnatweb.ch/gallery/63) MRI created initial descriptions of nine "Concerted Efforts", projects with a longer time frame, projects that can accurately be characterized as Implementation of research, rather than any of the other three I's in MRI's short-hand description of its operation. A final report on this second Commission meeting contains more specific information on these nine projects, seven of which are further described here.

Figure 2. Brainstorming the MRI's future at Imperial College, London: Hilde Eggermont (UGhent) describes her vision, Greg Greenwood listens while Astrid Björnsen Gurung captures the ideas.

A Union of Mountain Observing Sites

In 2005 the Global Change in Mountain Regions Project (GLOCHAMORE) envisioned a world-wide global change research program using comparable methodologies and supporting comparative whole system analysis implemented over a network of mountain Biosphere Reserves. It was – and still is – a sound scientific idea, but numerous problems, as much institutional as financial, limited the pursuit of the GLOCHAMORE vision.

Rather than declare top-down a global program and then attempt to implement it in specific sites, an alternative route might be to work bottom-up with specific sites and researchers to see what sort of comparative global program could be created from those pieces.

This is how evolution works: it does not create something entirely new by design, but rather uses the pieces it currently has available – the existing programs and researchers in this analogy – to fashion something that serves new purposes – a comprehensive global research program. Much as I would like to enforce "intelligent design", without a sack of money by which to align sites, MRI must work in this more evolutionary mode.

What are these existing sites? Networks such as the Global Observation Research Initiative in Alpine Environment (GLORIA) and the Mountain Invasion Research Network (MIREN) are among the best known and the best working. Key to their success has been their very specific foci, respectively, on alpine plant community composition change due to climate change, and on the invasion of mountain floras by exotic plants. These specific foci map to coherent communities of researchers who fund their activities independently. That these networks are successful without centralized funding indicates that where there is an intellectual will, there is usually a financial way.

Other networks arising from institutional bases include the mountain sites within the South African Environmental Observing Network (SAEON), the five sites of the Western Mountain Initiative (WMI) in the United States, and the multiple mountain sites of the Chinese Academy of Sciences (CAS), among many others. In addition a great variety of stand-alone sites/research teams from around the world, often created through the extraordinary efforts of individuals, such as the site of Jebel-al-Akhdar in Oman, established by Reginald Victor of the Sultan Qaboos University would greatly expand representation of the world's mountains.

It is tempting to think that if one could just convene all of these people in one place at one time a global change network of research sites would naturally emerge. After all, we all want the same thing right?

This is a very naive view. In 2008 in Brig, Jill Baron discussed the Western Mountain Initiative, an effort entirely within one organization (the USGS) at five institutional similar sites (US National Parks) with researchers of similar background (mostly ecologists of various stripes). Even so, Jill reported that it had taken nearly a decade for the group to achieve a level of common perspective before they could develop something akin to a comparative research agenda, oriented around the implementation of a common modeling framework (RHESSys) in each of the sites.

The difficulty even among people of quite similar background of arriving at an overarching program was similarly displayed during the recent launch of a mountain Long-Term Ecological Research network (LTER) under the auspices of GMBA. This meeting, hosted by Sandra Lavorel at the Col de Lauteret in France on 14-15 September 2011 , showed that the "least common denominator" among the six sites, themselves very similar (one in the Rockies and five in the Alp and representative of mid-latitude temperate mountains with a pronounced cryosphere) was not some highly integrative question such as the evolution of the mountain landscape under global warming, but rather the comparability of basic environmental measurements: for instance, do all sites measure temperature the same way?

Figure 3. The MRI Global Commission brought together researchers from around the world and across a wide range of disciplines.

It remains to be seen if this focus is sufficient. The history of GLORIA and MIREN shows that a focus on questions, rather than data, promotes continuity.

Campaign to Detect Accelerated Climate Warming at High Elevations

What are recurrent questions within the community? The rate of climate warming at high elevations is certainly a leading candidate. This uncertainty matters as the mountain cryosphere is a critical reservoir in many parts of the world. Impact assessments based on a global rate of warming will be strongly biased if the rate of warming at high elevations is greater than the global mean.

Rangwala and Miller (2012) reviewed the data and concluded that "a conclusive understanding of these responses will continue to elude us in the absence of a more comprehensive network of climate monitoring in mountains."

It has been an article of faith that high elevations are very poorly represented in the global observing network. It then follows, at least in our minds, that we need more observing stations at high elevations. While this conclusion might be correct it is far from compelling to funding agencies. The community has had very mixed success in establishing more observatories at high elevation using this rationale alone. In contrast, the GLORIA and MIREN experiences teach us that one has a greater chance of success if one focuses on key questions rather than on the deficit of data.

There is a considerable strategic difference between seeking new monitoring infrastructure and seeking an answer to a question. The first is a line agency, rather than a research agency, responsibility, has no final endpoint and leads immediately to questions of recurrent costs. The second, while often requiring new infrastructure, is a scientific question, has a clear endpoint, and leads to a discussion of the activities needed to answer the question.

The logical end point of this concern would be an outline of what might a large but nonetheless finite observation campaign fundable by research rather than by line agencies. It might well be that this question could be a central motivating question for whatever Union of Mountain Observing Sites can be created, but in this case the Union is the means, not the end. A conclusive answer to "is climate warming more pronounced at high elevations?" is the end.

A Global Treeline Network

In the Commission's discussion of the nature and trajectory of ecological systems under global change, the cryosphere and the tree line were singled out as sensitive indicators of climate change. The tree line was a major topic at the 2011 American Geophysical Union (AGU) meeting, is the research focus for many members of the Mountain Geography Specialty Group of the American Association of Geographers, and was a main topic among mountain ecologists at MRI's Key Contact Workshop at the Portland meeting of the Ecological Society of America. It is therefore a bit surprising that there does not yet exist a formal global network of tree line researchers, at either the upper or the lower treeline, though Craig Allen's activities get close to the latter.

This story has its own lessons to impart. The European Council for Science and Technology (COST) is reviewing a proposed Action entitled “Enhancing the resilience capacity of SENSitive mountain FORest ecosystems under environmental change (SENSFOR)”. This COST Action focuses on tree line forests and will create a tree line network of researchers from European nations that sign the enabling MOU. Harald Bugmann, MRI's previous President and an eminent forest ecologist at ETH, organized an outline of Switzerland's interest in this topic. In response to a call for action in North America from MRI’s Director (Greenwood), David Cairns of Texas A&M University, Lara Kueppers of Univ of California Merced, and Connie Millar of USFS PSW Research Stn organized a workshop as part of the *MtnClim 2012* meeting in Estes Park, CO to scope the creation of a North American Treeline Network. As it turns out,. Bugmann was also be at the *MtnClim 2012* meeting, so that, should the North American contingent get organized, they would have someone closely associated with the European effort already in their midst. This is often how viable projects begin: not by "intelligent design" but by "fortuitous coincidence"! (See article on NATN, page 51)

The tree line activity suggests not so much evolution, the metaphor for the union of mountain observing sites, but rather super-saturation in which just a slight vibration leads to a complete change in state. The community just seems ready for a tree line network. And just a little effort may bring forth a functional network. If this situation were more common, MRI and CIRMOUNT’s job would be lot easier!

Modeling Coupled Human-Earth Systems in Mountains

At the Perth Conference, Richard Aspinall, a principal leader within the Global Land Project (GLP), lauded MRI's use of the GLP conceptual framework but noted that Conference participants had barely touched a major theme of GLP: integrated analysis and modeling in support of land sustainability. He challenged the community to make progress in this area.

At the heart of MRI (and GLP) is the concept of the coupled human-earth system (Fig. 1). The land system consists of two large sub-systems, the ecological system and the social system. These sub-systems are coupled through reciprocal relationships. The social system impinges on the ecological system via management actions and pollution, while the ecological impinges on the social system via ecosystem services and their inverse, environmental hazards.

Modeling has been applied to each subsystem, in the form of, for example, watershed models for the ecological system and economic models for the social system. Coupled human-earth system models combine these approaches to better understand the cycles of causality within the land system.

MRI has already begun to address this issue. MRI held a Synthesis Workshop, led by Julia Klein (CSU) and Anne Nolin (OSU), on “Building resilience of mountain socio-ecological systems to global change”, which had at its center the notion of coupled systems modeling. (Presentations are viewable.) Participants outlined not only a synthesis paper, but also a proposal to the US National Science Foundation for a Research Collaborative Network. Such a RCN is an archetype of the kind of longer term implementation efforts that MRI wants to promote.

Quantification of Mountain Ecosystem Services

Ecosystem services constitute an exploding area of research, projecting ecosystem structures and functions into economic space. In doing so, ecosystems services support the conservation of ecosystem structures and functions via economic rationales and demonstrate a principle link in the coupled human-earth system construct, specifically in how ecosystem functions translate into human well-being.

The Commission discussions showed that quantification was a major challenge and a pre-requisite for the second major concern, the development of payment for ecosystem services. If you can't quantify it, how can you get paid for it?

A method of quantifying mountain ecosystem services would make operationally the distinction between ecosystem functions (which occur without human appreciation) and ecosystem services (which require humans to receive the service). It would then provide standard protocols for measuring both function and services. A deeper historical analysis of ecosystem services could show how the current package of ecosystem services from a given mountain region is not an ecological given but rather a function of which social groups have authority over the ecosystem.

The first step in this longer term effort will be an MRI Synthesis Workshop on "Qualities, vulnerabilities and management of ecosystem services in mountain regions worldwide" held in Switzerland on 11 to 14 September 2012. This Synthesis Workshop had its origins in a proposal by Ariane Walz of Potsdam from several years ago. Dr. Walz is working with Prof. Sandra Lavorel and Prof. Regamey on this workshop. This Synthesis Workshop is focused on the publication of a special issue in a journal. Unlike the preceding workshop, this workshop does not explicitly target the creation of a longer-term network, but it may arrive at that point.

Understanding Human Societies in Mountain Regions

The final two lines of inquiry discussed here explicitly address the social system in mountains.

The first involves describing the nature and drivers of human use of mountains. This project could best be described as updating and expanding the only global, data-based summary of mountains, Huddleston et al., 2003, "Toward a GIS-based Analysis of Mountain Environments and Populations" by examining both

- the nature of human presence in the mountains and
- the global social drivers of mountain regions

The nature of human presence in the mountains includes a characterization of mountain inhabitants (demography, education, livelihoods, social capital, identity, vulnerability, etc.), the uses made of mountain environments by inhabitants (e.g. agriculture, pastoralism, tertiary sector), temporary residents (e.g., tourism) and external populations (e.g., energy production, water supply), and the governance systems that mediate these interests.

The global social drivers of mountain regions would address, among others, differential economic development (diversification and specialization), migration, urbanization, cultural globalization, the loss of traditional knowledge and customs, and income inequality.

At the current time, the FAO, which mandated the Huddleston report, is interested in supporting this update. It is not yet clear is this route will actually succeed as participants in the Global Commission have provided a much-expanded outline to the FAO. While this outline comes much closer to an inventory of the social-ecological system in mountains, it may have transformed the project into something that would be better done through or at least in conjunction with a synthesis center such at the USGS Powell Center or the new National Socio-Environmental Synthesis Center.

The final project focuses on defining human agency in the mountains, that is, why and how decisions are made that strongly influence the trajectory of the coupled human-earth system in mountains.

A study of human agency in the mountains would involve a comparative study of the identity, epistemologies and interests of actors, the historical and contextual complexities, the current governance arrangements, and the mechanisms by which change occurs in a range of mountain regions around the world.

While this topic is one that is frequently mentioned, at least by biophysical scientists who clearly see the need for a more rigorous understanding of the social system, it remains the unloved step-child of mountain global change research. MRI has been unable as yet to find those researchers who are interested in this comparative analysis. We may need to do much more scoping and engagement with social scientists before we can frame this inquiry in a form that attracts their interest.

MRI intends to develop further these draft Concerted Efforts and invites members of the community to contribute their thoughts via email. Those efforts that gain traction within the community will certainly be included in MRI's next proposal to the Swiss National Science Foundation in 2013.

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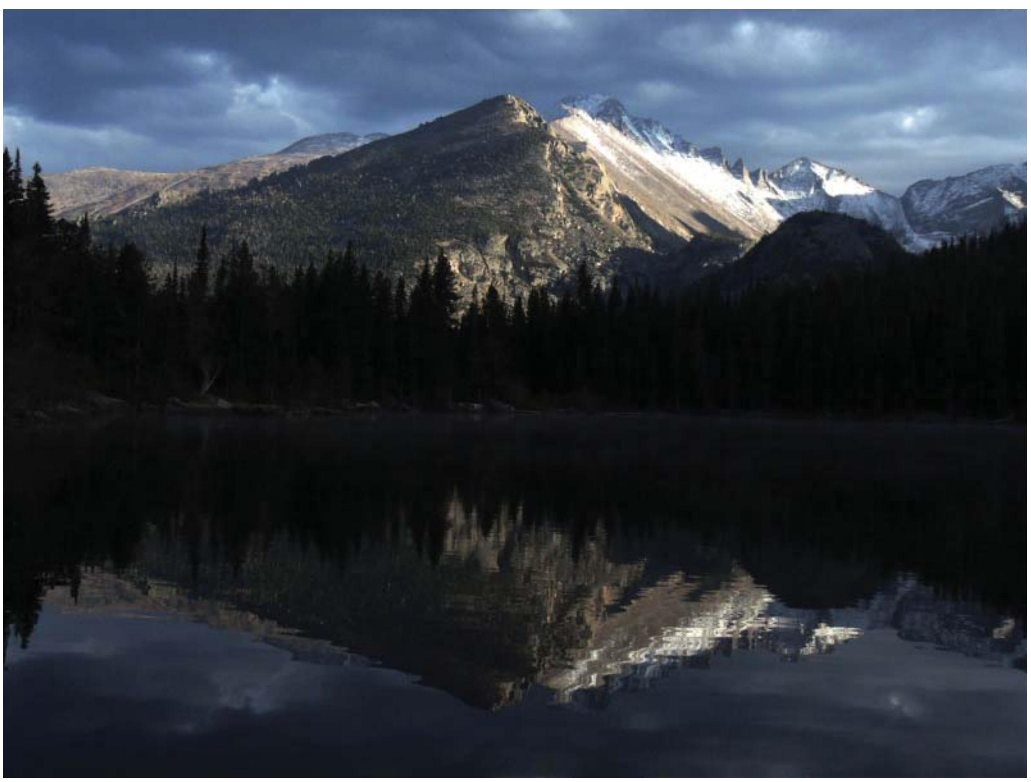

Autumn in Rocky Mountain National Park. Photo: Kelly Redmond

Sing of the Glory of the Mountains: Science, Art, and Humanities Collaboration

Fred Swanson
USDA Forest Service
Pacific Northwest Research Station
Corvallis, Oregon

The pristine mountain
just a little battered now
the smooth dome gone
ragged crown

the lake was shady *yin*—
now blinding water mirror of the sky
remembering days of fir and hemlock—
no blame to the magma or the mountain
& sit on a clean down log at the lake's edge,
the water dark as tea.

I had asked Mt. St. Helens for help
the day I climbed it,   so seems she did…

If you ask for help it comes.
But not in any way you'd ever know
—thank you Loowit, lawilayt-lá, *Smoky Mâ*
gracias   xiexie   grace

—Gary Snyder, from "Pearly Everlasting".

Figure 1: Mount St. Helens emits a little steam and dust in evening light during the 2005 field symposium, described in the book, "In the Blast Zone" (2008, Oregon State University Press). Photo: M. Furniss

Programs in Ecological Reflections

As mountain scientists, we periodically pinch ourselves and ask how we could be so lucky to work in places of such beauty. We find joy in the feeling that our work may nurture the future well-being of the mountains we love. Our appreciation of mountains has been cultivated by the works of inspired communicators over the years – in the Sierra Nevada, for example, by John Muir, Ansel Adams, Kenneth Rexroth, Gary Snyder, and Thomas Killion. From the *Poets on the Peaks* of the North Cascades to Thoreau on Mount Graylock in New England, writers and artists deepen our connections with the mountains.

Figure 2: Campfire discussion of engagement of arts and humanities in consideration of future scenarios of land and human change. Andrews Forest. Photo: M. Furniss

As scientists, we seek to tell stories through our work, and, as with these great communicators, we find the most compelling stories at the interface of good science/natural history and the expressive power of the visual arts and written word. Some people are blessed with strong instincts and skills for both natural history and arts/humanities, but most of us aren't so lucky. In recent years several programs have set out to bring practitioners of the arts, humanities, and environmental sciences together in places committed to long-term learning, and to institutionalize inter-disciplinary practice in a semi-formal way.

Figure 3: A philosopher, watershed scientists, and a medical ethicist converse in Andrews Forest old growth during a workshop entitled, "The Meaning of Watershed Health." Photo: M. Furniss

To date we know of about 20 programs taking an approach that is place-based, takes a long view (spanning decades to a few centuries), and collects and actively shares the works created at the interface of art, humanities, and science. Many programs and facilities aim at one or two of these attributes; sites that undertake the full combination are unusual. This is a grassroots effort to encourage many sites and programs to extend their scope in terms of time horizon and breadth of engaged disciplines. Profiles of many current programs are shared at: www.ecologicalreflections.com. No two sites take the same approach to the participating media, administration, funding, use of landscape, public outreach, and other attributes. Some programs have deep roots in science, such as the National Science Foundation's Long-Term Ecological Research (LTER) program and the US Forest Service's Experimental Forests; other sites have deeper humanities roots, such as the Sitka Center for Art and Ecology at Cascade Head Experimental Forest on the Oregon Coast. Some programs are based in science education; some are viewed as outreach for science-rooted stories; still others engage the humanities as though they were basic science gathering observations over the long term for later assessment of changing patterns.

Despite this diversity, these programs share some essential themes, the accomplishment of outreach to parts of the public not reached before, and growing bodies of reflective works. Sense of place in changing places is emerging as a widespread theme. Sense of place is shared by all of us – some focus on expressing it; others, commonly scientists, are quieter about their feelings. The notion of "changing places" includes environmental change and more specific topics in environmental science circles, such as land use legacies, effects of invasive species, and future scenarios of land change. Commonly, natural places and our sense for them have been viewed as static, but now we confront new scientific and emotional challenges converging on understanding, managing, and accepting change in places we love.

The H.J. Andrews LTER Project

My personal path to this work provides some context. I was part of a large, interdisciplinary team working at the H.J. Andrews Experimental Forest in the Oregon Cascades during the 1970s as part of the Conifer Forest Biome of the International Biological Program (IBP). We studied native forests, which happened to be old growth because of unrelated decisions made 25 years earlier about where to place the experimental forest. In the work of the 1970s we built a body of science, an interdisciplinary team, a collection of stories about how these forests and streams work, and a team of story-telling scientists. That work in that time was deemed by some to be irrelevant, basic science ("The future forests are the plantations, you should study them and not waste taxpayer funds on old growth," said the forest economist Dean to the forest ecologist leader of the science team). But this work and the resulting cadre of scientist storytellers persisted and their work proved to be pivotal a decade later in the transformation of public policy concerning how we deal with public-lands forests, especially old growth. In a narrow, bioregional sense, this transformation was expressed in the Northwest Forest Plan, but the thinking spread globally.

Critical lessons from this experience are: be patient; lay groundwork of sustained, in-place learning with a diverse group of highly collaborative folks; be open to new ways of thinking; share the stories. This spirit continued with inception in 1980 of the Long-Term Ecological Research (LTER) program at Andrews Forest and several other sites in the US, based on National Science Foundation and in some cases US Forest Service support. As important as LTER was to become, its beginning was overshadowed by the May 1980 eruption of Mount St. Helens, which triggered an explosion of long-term ecological sciences in that volcanic landscape. The successes of science in these two charismatic

Figure 4: Upper Lookout Creek, Andrews Experimental Forest. Photo: A. Levno

landscapes and the social network and information-management infrastructure they provided created a platform for engaging the humanities beginning around 2000. Several early events set the path for the Long-Term Ecological Reflections program: a visit to Mount St. Helens with poet Gary Snyder in 2000 (Snyder 2004) (was I a field assistant in poetry field work?), and beginning in 2002 a new collaboration between the Andrews Forest LTER program and the Spring Creek Project for Ideas, Nature, and the Written Word (http://springcreek.oregonstate.edu/). Kathleen Dean Moore, philosophy professor and writer, and poet Charles Goodrich lead Spring Creek with wonderful spirit and openness (see mission in the sidebar). The Reflections program adopts a 200-year horizon of creative, reflective inquiry in parallel with components of LTER science. Writers in residence programs and various types of special events have followed. Objectives of this work are: to honor these places; to share insights and methods of inquiry among diverse disciplines; to enhance public understanding and appreciation of these systems, which may lead to better stewardship of the land; and to have fun. It's noteworthy that these adventures have been marked by unusual levels of joyfulness and increased appreciation for the methods and insights of the many ways of knowing.

To date about 40 writers in residence at Andrews Forest have produced a rich body of work (see the Forest Log on the Andrews Forest webpage – link below) and dozens of writers have participated in group field gatherings at Andrews Forest and Mount St. Helens. Their work conveys wonder and awe in the incredible web of life in these places and from encounters with organisms many centuries old. But the writers also see the forest and the research in terms unfamiliar to the scientists living it day by day. In his essay "The Long Haul" Robert Michael Pyle finds establishment of a 200-year experiment (Oregon State University professor Mark Harmon's log decomposition experiment) as an act of hope. The poet Jerry Martien keys off the large PVC pipe respiration chambers fastened to the flanks of logs for measuring CO_2 exhalations from logs in the log decomposition experiment to give voice to the logs, who invite us to join them in the state of decay. The logs say, "in your breath now, our breath," conveying an intimacy that is both compelling metaphor and biophysical fact. Alison Hawthorne Deming writes of sharing an hour-long stare-down with a northern spotted owl "We exchange the long, slow interspecies stare—no fear, no threat—only the confusing mystery of the other." Scott Russell Sanders, visiting essayist

Figure 6: Log decomposition experiment site in the Andrews Forest. Decomposing logs on the forest floor are fitted with PVC respiration chambers. Photo: T. Iraci

from Indiana, describes his affinity for trees, "While I am drawn to all ages and kinds, from maple sprouts barely tall enough to hold their leaves off the ground to towering sequoias with their crowns wreathed in fog, I am especially drawn to the ancient, battered ones, the survivors." Clearly, these writers experienced the forest in ways scientists seldom articulate; and the writers' works reach idea-leaders through publications in outlets such as *The Atlantic* and *Orion.*

The Cascade mountain landscapes of the Andrews Forest and Mount St. Helens have been stages on which science is producing lasting, yet constantly-evolving, stories that sustain public attention to the power of the places – and their stories. Creative writers and artists also read these landscapes and add breadth and depth to these stories.

Reaching New Heights

Collaborative arts-humanities-science work may literally help shape the future of mountain landscapes. In western mountains of the US, for example, such collaborative story seeking may set the stage for the next big transformation in how we view the public lands. We are building capacity of knowledge and cadres of storytellers for not only the science, but also the values we hold for these lands.

Figure 5: A Northern Spotted Owl in the Andrews Forest. Photo: A. Levno

The Spring Creek Project Mission:
The challenge of the Spring Creek Project is to bring together the practical wisdom of the environmental sciences, the clarity of philosophical analysis, and the creative, expressive power of the written word, to find new ways to understand and re-imagine our relation to the natural world.

Just as law suits in the 1980s threw open the window of opportunity concerning federal forest policy of the timber era, so, too, unforeseeable circumstances may create future opportunities to reassess policy concerning our engagement with these mountain lands, as we face shifting economic and social pressures, climate change, evolving fire regimes and fire management policy, insect outbreaks, competing recreational interests, and many other changes.

One current engagement with federal forest lands is through recreation, minor logging by thinning in plantations, and restoration of meadows, forests, watersheds, and streams with an emphasis on manipulation of the land. But perhaps it is the relationship between people and landscapes we should emphasize – a "re-story-ation" that offers stories appropriate to our desired engagement with the land. The stories native people used to teach the young have been largely scrubbed from the land, as have those people themselves. Stories of early European exploration and natural resource exploitation have their places in history, but are not useful terms of engagement for the future. What will be the stories of our engagement with these lands in the changing future?

A Role for CIRMOUNT?

How might arts-humanities-science collaboration play out in mountain landscapes of the CIRMOUNT community? The experience of the ecologicalreflections.com community offers several suggestions for those interested in developing a program: capitalize on existing infrastructure of programs, facilities, bodies of work, and communities of interested people. Bases of operations in the mountains may be rooted in science (e.g., field stations, experimental forests), in arts (e.g., programs such as the Sitka Center for Art and Ecology), or public education/outreach (e.g., the North Cascades Institute). Expanded collaborations could also be developed in campus settings, such as individual professor's labs and larger, campus-based research and environmental studies programs. In each of these cases, missing elements of potentially fruitful collaborations could be brought into the fold. Also, look to other programs for hints about building new collaborations. For example, the Long-Term Ecological Reflections program has been modeled on the LTEResearch program and capitalizes on the facilities, information management, social network, and other institutional support systems cultivated through NSF and US Forest Service support for science. Examination of existing arts-humanities-science collaborations offers both inspiration and fresh ideas about how to do this work. However, existing programs do not cover some important opportunities, such as pushing scientists hard to do their own reflection and writing or art to express their feelings about the land and their work in it.

The vibrant CIRMOUNT community is well positioned to advance its objectives of creating a better future for mountain landscapes. Expanding collaborations with arts and humanities will be a natural step in that quest.

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Links:

Ecological Reflections – an emerging national network of arts-humanities-science collaborations: http://www.ecologicalreflections.com

Spring Creek Project for Ideas, Nature, and the Written Word: http://springcreek.oregonstate.edu/

Andrews Forest: http://andrewsforest.oregonstate.edu/lter/research/related/writers.cfm

MSH Volcano Log (MSH Institute webpage): We expect to have a section of MSH Institute webpage with the Volcano Log (collected writings) soon.

"The song of a thrush flutters through the quiet, the auditory equivalent to seeing an orchid in the forest. Beauty is what I came here for, a beauty enhanced not diminished by science. If I had only my senses to work with, how much thinner would be the experience. What a record we might have of the world's hidden beauty, if field scientists and poets routinely spent time in one another's company."

Alison Hawthorne Deming – from *The Owl, Spotted*, an essay published in OnEarth

Mass Balance of the Wrangell Range Glaciers, Alaska
The PTAA Glacier Mass Balance Project

Wendell Tangborn
HyMet Inc.
Vashon Island, Washington

Photos: Mendenhall Glacier 1958: From the NSIDC Glacier Photograph Collection, M.T. Millett. The 2011 image from Matthew J. Beedle and GlacierChange.org

Abstract

Daily and annual mass balances (Net, Ablation, and Accumulation) of the Wrangell Range Glaciers are calculated for the 1951-2011 period. Calculations are made with the precipitation-temperature-area-altitude model (PTAA), using daily precipitation and temperature observations collected at the Big Delta and McKinley Park, Alaska weather stations, together with the area-altitude distribution of the approximately thirty glaciers in this range. The average mass balance for 61 years of the south-facing glaciers is – 0.68 mwe (meters water equivalent) and - 0.42 mwe for north-facing. Total thinning of the south-facing glaciers is 47 meters versus 28 meters for north-facing during this period. An unexpected finding is that average annual ablation positive anomalies of the Wrangell glaciers are correlated (r=+0.81) with global temperature positive anomalies averaged for 7000 weather stations in the Northern Hemisphere. Furthermore, the time-trends of glacier ablation and global temperatures are both increasing exponentially, which suggests that the climate is nearing a tipping point.

Introduction

The PTAA Model (precipitation-temperature-area-altitude) is applied to all the glaciers (about 30) in the Wrangell Range, Alaska, shown in Fig. 1. Input to the model are daily temperature and precipitation observations at McKinley Park (elevation = 631 meters) and Big Delta (470 m), Alaska, located approximately 350 km NW of the Wrangell Range, and the area-altitude distributions of the glaciers. The glaciers are divided into two sets of approximately equal areas based on their north-south orientations. For mass balance analyses, the total areas of north and south facing glaciers are treated as two large glaciers. The area-altitude distributions of both north and south-facing glaciers are shown in Fig. 2.

Figure 1. Google Maps image of the Wrangell Range showing the 30 + glaciers in this range

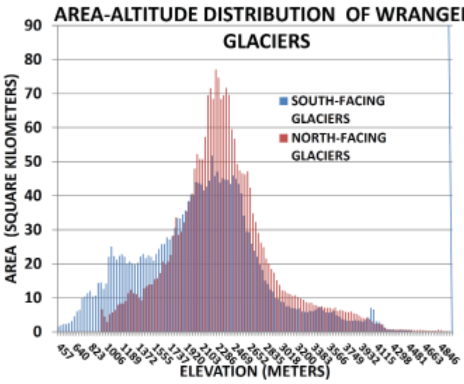


Figure 2. Area-altitude distribution of the north and south-facing Wrangell Range glaciers. The total area of these glaciers is 4786 km2 and there are 150 altitude intervals spaced at 30.5 m (100 feet), ranging from 427 to 4850 meters in elevation. The difference in area distributions of the two sets is due to unequal erosion rates of the south and north-facing glaciers.

The Wrangell Range has 12 south-facing glaciers with a total area of 2308 square kilometers. The largest is the Kennicott (551 square kilometers), followed by the Regal, Rohn, Frederika, Middle Fork, Nizina , West Fork Glaciers and 5-6 that are unnamed. There are also about 12 named north-facing glaciers that have a total area of 2418 square kilometers. The largest is the Nabesna (253 square kilometers) and numerous smaller glaciers, both named and unnamed. The varied orientations together with the calculated mass balances provide a unique combination for understanding how mass balance, glacier flow and the current weather in this region are linked.

A major goal of this project is to explain the physical mechanism(s) that can force the daily and annual mass balance of a glacier by applying weather observations collected at distant stations to the unique area-altitude distribution of each glacier's surface.

The study is part of a larger project which will eventually display the mass balances of 200 glaciers worldwide in near real-time (depending on when weather data will be available on-line after it is collected). Both the current year and historical balances (Net, Accumulation and Ablation) will be shown, primarily in a graphical format. The altitude distribution of area, average snow accumulation, ablation and balance will also be shown for each glacier.

Mass Balance

The daily and annual mass balances for the Wrangell Range glaciers are determined with the PTAA model using daily precipitation and temperature observations collected by the National Weather Service and the area-altitude distributions of each glacier's surface. There is a significant difference in the area-altitude distributions of the south facing versus the north facing glaciers (Fig. 2) that can be attributed to greater erosion of the bedrock underlying the south facing glaciers. The difference is also reflected in the mass balances due to higher ablation rates for glaciers with a more southern exposure. The annual balances of south- facing versus north-facing glaciers, shown in Fig. 3, are approximately 0.3 mwe more negative because of higher ablation rates (Table 1).

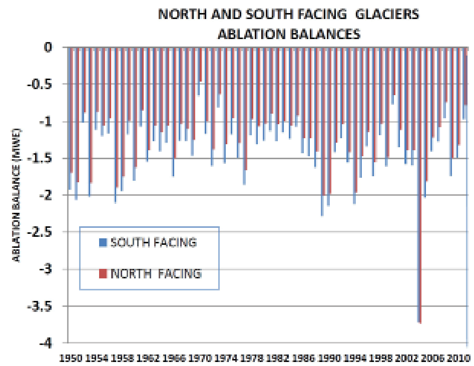


Figure 3. Annual ablation balances of south and north facing glaciers for the 1951-2011 period. The average annual ablation balance for south-facing is -1.46 mwe, for north-facing is -1.28 mwe.

Table 1. Mass Balances of Wrangell Glaciers (1951-2011 averages, mwe)

	South-Facing	North-Facing
Net Balance (Bn)	-0.7	-0.4
Ablation Balance (Ba)	-1.5	-1.3
Accumulation Balance (Bc)	+0.8	+ 0.9

Mass balance terminology used in this report deviates slightly from that proposed by the WMG Working Group (Cogley, 2011). Prior to approximately 1995, mass balance is defined by b(z), or balance is dependent on elevation. In recent decades this relationship has been reversed so that elevation is now a function of mass balance, which is both physically and mathematically incorrect. Also, the terms Accumulation Balance and Ablation Balance are preferred over Winter Balance and Summer Balance. For most Alaskan glaciers, snow accumulation at higher elevations occurs throughout the year and can be especially heavy in August and September. For many Himalayan Range glaciers, snow accumulation is greatest during the Monsoon season, from June through September, and at lower elevations ablation often occurs during the winter months (Yang, 2011).

Ablation is approximately 14 % greater on a glacier that flows in a southward direction in the Wrangell Range. Daily ablation is calculated by the PTAA model for both north and south sets.

Ablation is greater for south-facing glaciers because solar radiation strikes their surfaces at a slightly less oblique angle than it does for north-facing glaciers. Thus, there is a greater amount of solar energy absorbed and consequently more ablation, greater turnover of mass and increased flow rates of these glaciers, resulting in greater erosion of the underlying bedrock. A comparison of AA (area-altitude) distributions for the two sets of glaciers in Fig. 2 reflects these differences. There is a greater surface area at lower elevations of the south facing glaciers and more surface area at mid-elevations of north facing glaciers. These unique patterns have developed throughout geologic time and reflect the climate that existed as these glaciers developed. The influence of glacier aspect variations on mass balance has been emphasized in previous studies (Evans and Cox, 2010). Most studies indicate glacier altitudes, especially equilibrium-line altitudes (ELAs), as climate indicators. Variations of glacier aspect can provide useful information on cloudiness and wind patterns at or near the glacier (Evans, 1977).

The PTAA Mass Balance Model

The PTAA model relies on the climate history that is embedded in a glacier's area-altitude (AA) distribution. The AA distribution is developed by glacier flow and erosion of the underlying bedrock, both of which are dependent on long-term-mass balances and on the climate. The current mass balance is calculated by combining precipitation and temperature observations at a regional weather station with the glacier's current area-altitude distribution to produce daily and annual balances. Seven different balance variables are found for each day of the period of record and regressed against each other. The average regression error produced by all regressions (several hundred) is used as an optimizing function to determine coefficient values that produce the minimum calibration error. The model has been applied to determine annual balances of South Cascade Glacier and compared with manually measured balances for the 1959-1996 period (Tangborn, 1999). It has also been applied to several glaciers in Alaska to determine annual balances that are compared with manually-measured balances (Bhatt, et al, 2007), Korn, (2010), Zhang, et al, (2007a, 2007b).

The difference in the AA distributions of south and north-facing glaciers determines the differences in the total annual ablation of both sets of Wrangell glaciers (Fig. 3). Average annual ablation of south-facing glaciers is approximately -1.5 mwe and north-facing is -1.3 mwe, or 0.2 mwe (15%) greater for those glaciers oriented to the south. Total thinning of the south-facing glaciers during this 61 year period is 60% greater than north-facing (47 versus 28 meters of ice).

The cumulative mass balance of the Hintereisferner in the Austrian Alps for the 1953-2003 period, based on manual measurements, is -26.2 mwe (total thinning of 28 meters or 0.6 m per year) (Fischer, 2010). Thus, the mass loss of the Hintereisferner during the past half-century is nearly identical to the rate of mass loss of the north-facing glaciers in the Wrangell Range. The Hintereisferner is also a north-facing glacier.

Model Calibration

The model is calibrated for each glacier by calculating the daily balance using 15 coefficients that convert precipitation and temperature observations to snow accumulation and snow and ice ablation for each elevation interval. One iteration performs this operation for each day of the full period of record and for each elevation interval, from the terminus to the head of the glacier. Both the annual balance and calibration error are calculated for each iteration. In Fig. 6a, the first 16 iterations use pre-set coefficients; the remaining are determined automatically by the Simplex optimizing procedure. In Fig. 6b, the annual balance and calibration error is shown for each iteration.

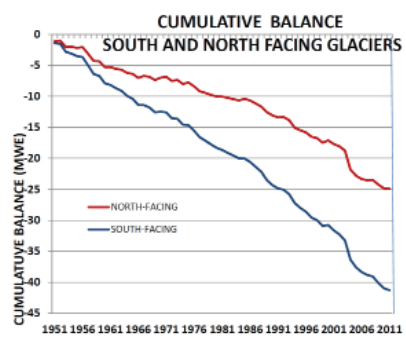


Figure 4. Cumulative balance of the north and south-facing glaciers. South- facing glaciers thinned 19 meters more than north-facing during the 61 year period. Total thinning of the south-facing glaciers 47 meters or 0.8m of ice per year, and the north facing is 28 meters of ice or 0.5 m per year.

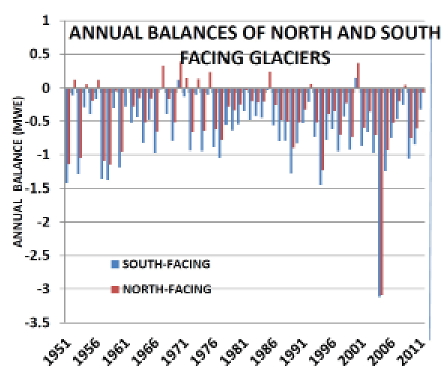


Figure 5. Annual net balances of north and south facing glaciers. The average annual balance for north-facing glacier is -0.42 and for south facing is -0.68 mwe.

Optimum coefficient values are found by minimizing the error that occurs when one balance variable is regressed against another in a linear, least squares fitting process. Nine different, but not independent regressions are made for each day throughout the summer ablation season. From June 1 to– September 30, approximately 120 regressions are made for each set of variables. Thus, over 1000 regressions are run for each iteration of the Simplex. The calibration error determined for each iteration is the average root-mean-square-error (in percent of the mean) for all regressions that are run. The calibration error is minimized by simultaneously and minutely adjusting the 15 coefficients for the next iteration. Minimizing the calibration error produces an internal consistency in the processes within the PTAA model that cause snow and ice ablation and snow accumulation.

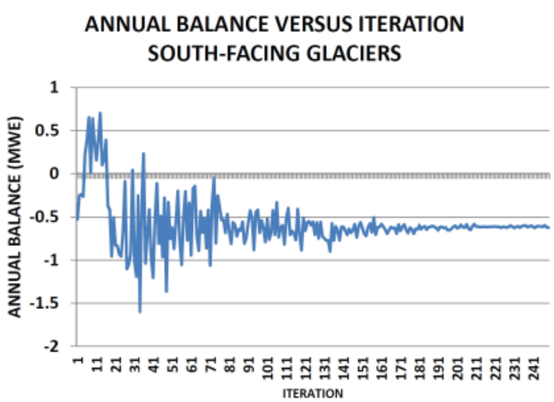


Figure 6a. Mean annual balance of south-facing glaciers for the 1951-2011 period for each iteration of the Simplex. Each point represents 61 years of model runs, calculating daily and annual balances. The first 16 iteration balances are calculated from pre-set coefficients, and the remainder are calculated by the Simplex optimizing process. The final mean annual balance after 250 iterations is -0.60 mwe.

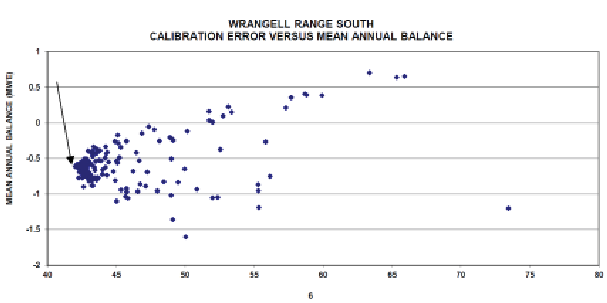


Figure 6b. Mean annual balance of south-facing glaciers for the 1951-2011 period versus calibration error. Each point represents 61 years of model-runs calculating daily and annual balances. The minimum calibration error is 42 % when the balance is – 0.68 mwe.

Balance Versus Elevation

The Net, Accumulation, and Ablation balances as functions of elevation for the south-facing glaciers is shown in Fig. 6a, and for north-facing glaciers in Fig. 6b. The difference between these balance versus elevation curves provides an insight into heat balance processes of the two sets of glaciers. The Equilibrium Line Altitude (ELA) is 200 meters higher for north-facing glaciers (2300 versus 2100 meters), which is inconsistent with the expected ELA for these orientations. The annual balances at the termini are -8.0 mwe for south-facing and -6.0 mwe for north-facing, which is consistent for south and north orientations. Except at lower elevations, the north-facing glaciers have more negative balances at each elevation interval. The average annual balance is more negative for south-facing glaciers because of the greater mass loss of these glaciers in the terminus area.

The significance of the balance versus elevation differences for south and north-facing glaciers is the generally higher ablation rates of north-facing glaciers, which indicates that air temperature has greater influence than solar radiation on ablation of these glaciers. Such a finding is especially important for relating global temperatures to glacier ablation.

Real-Time Mass Balances

The glaciers will be monitored daily when temperature and precipitation observations for the appropriate weather stations used in the PTAA model are routinely available. The ability to simultaneously compare the daily balances of all the glaciers in the project (200 eventually) will provide the information needed to assess glacier-climate interactions. n8 shows the daily Net,

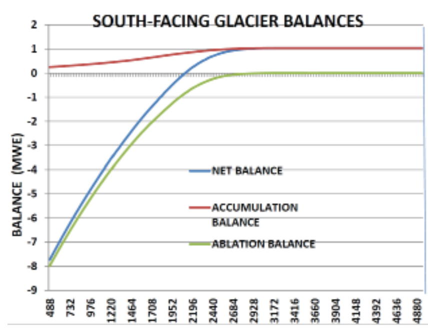
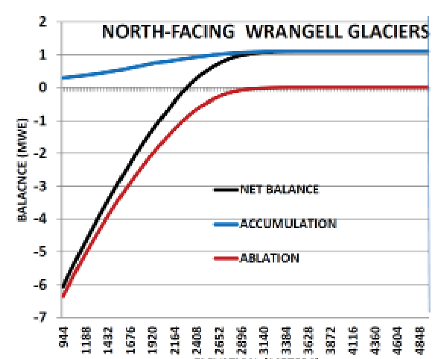


Figure 7a. Average Net, Accumulation and Ablation balances of south-facing glaciers as a function of elevation, averaged for the 1951-2011 period. The ELA is 2100 meters.

Figure 7b. Average Net, Accumulation, and Ablation balances of north-facing glaciers as a function of elevation, averaged for the 1951-2011 period. The ELA is 2300 meters.



Ablation, and Accumulation balances for the full 2011 balance year. The accumulation balance is +0.62 mwe, the ablation balance -1.0 mwe and the annual balance -0.35 mwe on September 30, 2011.

Predicting Wrangell Glacier Ablation From Global Temperature Anomalies

The difference in ablation rates between the two sets of glaciers provides the means to analyze the effect of global temperatures on the mass balances of these glaciers. Average annual ablation of south-facing glaciers in the Wrangell Range is approximately 0.2 mwe greater than north-facing glaciers (-1.46 mwe versus -1.28 mwe) because the south sloping surfaces receive greater solar radiation and the greater surface area at lower elevations of south facing glaciers that has higher ablation (Figs. 3 and 4). However, there is an increasingly greater daily variation in the north-south differences likely caused by variations in global temperature anomalies. Fig. 9 demonstrates that until about 1990,

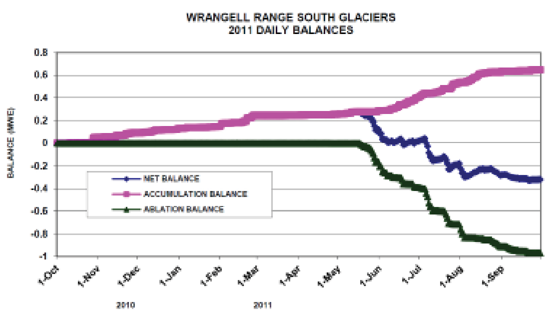


Figure 8. Daily balances (Net, Accumulation and Ablation) throughout the 2011 balance year. The accumulation balance is +0.62 mwe, the ablation balance -1.0 mwe and the annual balance -0.35 mwe on September 30, 2011. In future years balances will be monitored daily when it is feasible.

north-facing glacier ablation is frequently greater than south-facing. After 1990, ablation of south-facing glaciers is dominant.

Ablation of north-facing glaciers is less reliant on solar radiation than south- facing, and more dependent on air temperature. Therefore, temperature anomaly variations influence north-facing glaciers to a greater degree than does radiation.

Two major shifts in the earth's temperature patterns (Fig. 10) appear to be related to these glacier ablation anomalies. The shifts are revealed by summing the difference between the maximum and minimum daily temperature anomalies:

CTR = $\sum (dTx - dTn)$, where CTR = cumulative daily temperature range, dTx and dTn are the maximum and minimum temperature deviations from the 1961-1990 period, averaged for 7000 global weather stations by the Hadley Climatic Center (Caesar, et al, 2006). Daily anomalies of both temperature and glacier ablation are based on departures from the 1961-90 reference period. The first shift on about 1977-78 occurred when minimum temperature anomalies are positive more frequently than maximum anomalies, which translates to a decrease in cloud-cover (an above normal temperature range usually means less cloud-cover). The second shift occurred on about 1999-2000 when maximum temperature anomalies are more frequently positive, and have remained dominant since then. An unusual feature of cumulative anomalies during this period is the annual cyclic perturbations

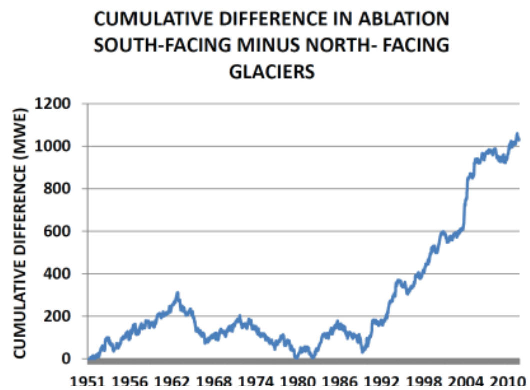


Figure 9. Cumulative difference in ablation anomalies of south facing minus north facing glaciers. Before 1990, daily ablation rates on north and south facing glaciers are nearly equal. After 1990, south-facing glacier ablation is predominately greater than north-facing.

occurring in mid-January, caused by winter warming episodes lasting several weeks (Tangborn, 2003). Similar temperature patterns found in the Austrian Alps, based on cumulative anomalies from the climatologic mean (1961–90), are shown to be linked to mass and area changes of glaciers in that region (Abermann et al, 2009, Abermann et al, 2011).

The curves generated by cumulative glacier ablation differences (Fig. 9) and those produced by the cumulative global temperature range (Fig.10) both show significant increases in the past two decades, suggesting that both variables are now controlled by the same physical mechanism. Annual averages of positive anomalies of both ablation and maximum temperature plotted as line graphs suggest similar non-linear trends (Fig. 11).

The correlation between annual ablation for south-facing glaciers and maximum global temperature anomalies (Fig. 12) equates ablation partly caused by solar radiation with maximum temperature anomalies. The correlation between annual ablation of north-facing glaciers and minimum global temperature anomalies (Fig. 13) equates ablation due primarily to warmer air with minimum temperature anomalies.

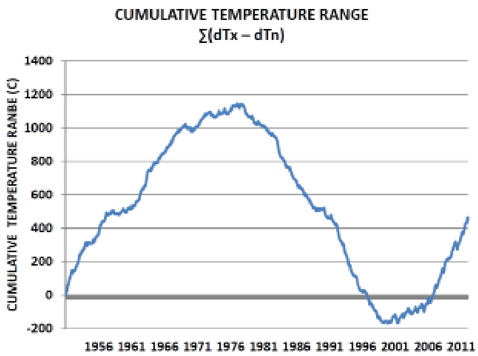


Figure 10. The cumulative difference between global maximum and minimum temperature anomalies produced from the Hadley Climate Center data set (HadGHCND). Major shifts in worldwide temperature patterns occurred in 1976-77 and 2000-2001. After 2000 there are small cyclical perturbations of temperature increases occurring in mid-January and lasting for several weeks.

The similarity of the annual ablation and temperature trends shown in Fig. 11 and the significant correlations (r=+0.80) in Figs. 12 and 13 suggest that a common heat source is controlling both glacier ablation and temperatures at weather stations throughout the Northern Hemisphere. These results could also be explained by a relatively abrupt increase in solar radiation. However, there is no evidence that the sun's irradiance has changed more than +/- 0.5 % in recent decades – not enough to significantly affect the earth's mean temperature (Wild, et al, 2005).

The earth is currently taking in more energy than it radiates to space causing its surface temperature to increase approximately 0.015 C each year (Hansen et al., 2005, 2011). As the concentration of carbon dioxide increases, the atmosphere will become more unstable and respond to the overload of CO_2 in ways that are not easily understood or predictable. One response might be pulses of abrupt heating, such as is indicated after the year 2000 in Fig. 10. Another sign of instability is that glaciers are now losing mass at rate greater than the global temperature increase predicts, which suggests that factors other than simple atmospheric heating are responsible for the current high rate of glacier ablation.

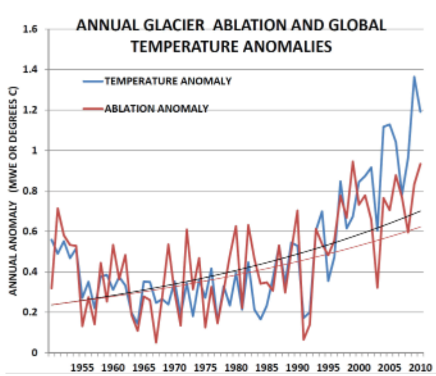


Figure 11. Annual averages of positive anomalies of south-facing glacier ablation and global maximum temperature anomalies. The exponential trend lines indicate both are increasing at similar rates and have been accelerating since the mid-1980s. Although trend-line correlations are only +0.40, they are considered significant.

The steady rise in the concentration of carbon dioxide in the atmosphere will eventually reach a critical threshold, if it has not already, so that heating variations due to trapped radiation override temperature variations produced by atmospheric circulation. Fig. 11 suggests such a threshold was reached about 1990 and that the earth's climate will be undergoing a major shift within the next 2-3 decades.

Conclusions

The annual mass balances of glaciers that are south-oriented are more negative than those oriented to the north, but the balances at lower elevation intervals are more negative for north-oriented glaciers. The cause of this disparity is the difference in the area-

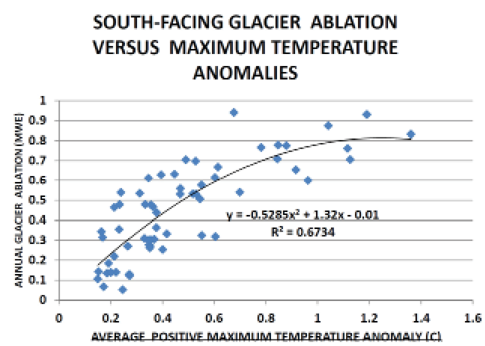


Figure 12. Annual ablation anomalies of south-facing glaciers versus global maximum temperature anomalies (the same annual averages as Fig. 11). The daily temperature anomalies, provided by the Hadley Climate Center, are averages of observations at 7000 weather stations in the Northern Hemisphere, referenced to the 1961-90 period.

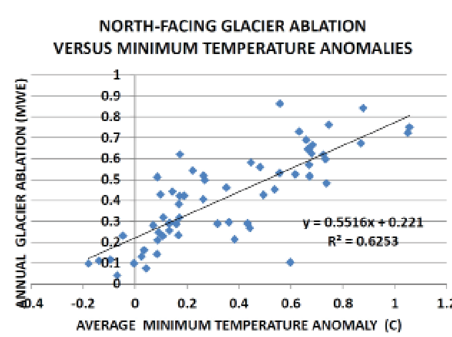


Figure 13. Annual ablation anomalies of north-facing glaciers versus global minimum temperature anomalies.

altitude distributions of south and north-facing glaciers due to differences in erosion rates throughout geologic time. Ablation of the Wrangell Range glaciers is predicted from global temperatures because uniformly distributed atmospheric heating is controlling both glacier ablation and worldwide surface temperatures.

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BREVIA

Accelerating the Incorporation of Climate Change into Natural Resource Management

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There is a growing recognition that physical and ecological responses to climate change may necessitate a reconsideration of conventional natural resource management goals and actions (National Research Council 2010). General principles for conserving species and ecosystems as climate changes include creating more and larger protected areas, increasing connectivity between protected areas, and reducing non-climate stressors (e.g., Heller and Zavaleta 2009, Lawler 2009, Hansen et al. 2010). As natural resource practitioners seek to develop on-the-ground actions for sustaining specific species and ecosystems, there is a need for practical planning approaches that help transform these general principles for adaptation into site- and target-specific strategies for action (Enquist et al. 2009).

We present one such tool – the Adaptation for Conservation Targets (ACT) planning framework – specifically aimed at helping practitioners derive place-based adaptation actions for particular species, ecosystems, and ecological functions using a simple yet structured process. The ACT approach intentionally draws on familiar decision support tools (e.g., structured decision-making, adaptive management, Open Standards for the Practice of Conservation) and common elements of conservation planning (e.g., local knowledge, conceptual models, scenario planning) to facilitate the ease of adoption without requiring specialized training. These familiar concepts are integrated into a process that is tailored to considering the effects of climate change. The framework is designed to motivate collaborative planning by a multi-disciplinary group of experts and practitioners through a series of steps (Fig. 1):

Step 1. Identify the feature (e.g., species, ecosystem or ecological function) targeted for conservation and specify a management goal for that feature

Step 2. Assess the potential effects of plausible future climate scenarios on that feature:

- Build a conceptual model that illustrates the climatic, ecological, social, and economic drivers affecting the feature;
- Develop a suite of plausible climate change scenarios;
- Examine how the feature and its non-climatic drivers may respond to each scenario.

Step 3. Identify management actions to achieve the stated goal under each scenario;

Step 4. Prioritize management actions;

Step 5. Implement priority actions; and

Step 6. Monitor action effectiveness and progress toward objectives; adjust ineffective actions or revisit planning as needed.

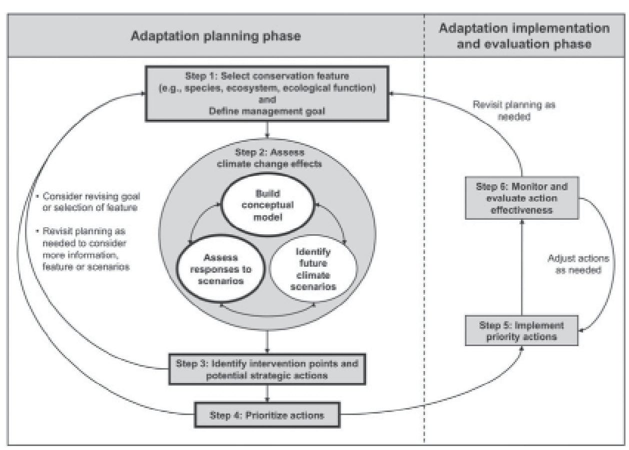

Figure 1. The Adaptation for Conservation Targets (ACT) framework for natural resource management planning in light of climate change. During the Southwest Climate Change Initiative workshops, facilitators led participants through the planning phase steps outlined in bold.

Following the basic "plan-do-check-adjust" approach of most adaptive management cycles (Williams et al. 2009), ACT steps can be repeated to accommodate monitored and projected changes in climate conditions, ecological responses, and management and social values. To address uncertainty in climate projections and ecological impacts, we recommend scenario-based planning techniques to identify management actions that would be justified under all or most future climate scenarios. If no actions are capable of achieving the stated goal under most or any of the climate change scenarios considered, it may be necessary to revise the goal or objectives. If no achievable goal can be identified, it is important to acknowledge that the feature's long-term persistence in the focal area may be unlikely and consider the consequences for setting management priorities. Initially focusing on a single feature (or a finite set of related features), rather than simultaneously considering all of the species or ecosystems within a planning area, increases the feasibility of planning. Managers can incrementally apply the ACT planning steps to additional features to more fully capture the complexity of an area or ecosystem.

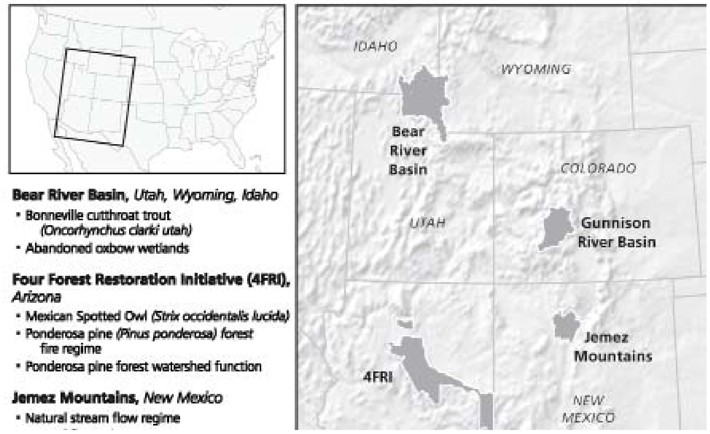

Figure 2. Pilot landscapes and conservation features addressed during Southwest Climate Change Initiative climate-change adaptation planning workshops.

Early efforts to test and refine the ACT planning framework were led by the Southwest Climate Change Initiative (SWCCI), formed by The Nature Conservancy, Wildlife Conservation Society, Climate Assessment for the Southwest at the University of Arizona, Western Water Assessment at the University of Colorado, University of Washington, U.S. Forest Service, and the National Center for Atmospheric Research. One of the primary goals of the SWCCI is to cultivate expertise in climate-change adaptation by linking local practitioners to a regional community of practice (McCarthy 2012). As one approach to meeting this goal, the SWCCI launched adaptation-planning efforts using the ACT framework in four landscapes in the Four Corners region of southwestern United States: the Jemez Mountains, the upper Gunnison River basin, the Bear River basin, and the four National Forests and surrounding lands that comprise the U.S. Forest Service's Four Forest Restoration Initiative (Fig. 2). The pilot landscapes were chosen because of their conservation significance, degree of exposure to climate changes, strength of local partnerships, and availability of localized scientific information about climate change and its ecological effects. We selected two or three species, ecosystems or ecological functions to serve as the focus of adaptation-planning exercises at each workshop (Fig. 2) on the basis of pre-workshop surveys and interviews.

We designed the workshops to: 1) facilitate cross-jurisdictional, multidisciplinary dialogue on the consequences of climate change for selected features, 2) move participants beyond simply assessing effects to identifying practical strategies for reducing adverse effects on those features, and 3) accelerate the implementation of priority adaptation strategies. Each workshop followed a similar format that included introductory presentations, small-group adaptation-planning exercises, and full-group discussions of challenges, opportunities, and next steps for action. During small-group breakout sessions, facilitators led participants through the planning steps of the ACT framework (Steps 1-4, Fig. 1). Summary reports for each workshop document discussions and provide detailed adaptation plans for each conservation feature, including conceptual models, expert assessments of the effects of climate change for two future climate scenarios, and proposed strategic actions (Table 1) (Enquist et al. 2009, Degiorgio et al. 2010, Neely et al. 2010, Smith et al. 2011). Roughly 45-60 participants attended each workshop, representing natural resource managers, scientists, and conservation practitioners from local, state, tribal, and federal agencies and organizations.

Post-workshop surveys indicated the ACT workshops successfully increased participants' self-reported capacity to address climate change by providing them with a better understanding of potential effects and guiding the identification of solutions. For example, 33 of 35 respondents to the Gunnison River basin exit survey said they "mostly" or "absolutely" gained a better understanding of climate change on the Gunnison Basin. Thirty of 34 respondents thought the ACT framework was "mostly" or "absolutely" useful for developing climate adaptation strategies. The workshops also fostered cross-jurisdictional and multidisciplinary dialogue on climate change through active participation of scientists and managers in assessing climate change effects, discussing the implications of those effects for determining management goals and activities, and cultivating opportunities for regional coordination on adaptation. Facilitated application of the ACT planning steps advanced group discussions beyond just assessing effects, to revisiting conservation goals for specific targets and devising strategies for meeting those goals as climate changes. Participants outlined opportunities and next steps for implementing several actions, and local partnerships have begun implementing some of those actions and conducting additional planning (McCarthy 2012).

Although the SWCCI workshops and ACT planning steps provided a valuable launching point for multijurisdictional climate-change adaptation planning and action in the pilot landscapes, a single two-day workshop was insufficient for comprehensive adaptation planning. Successful adaptation will require on-going engagement of local scientists and managers toward refining understanding of climate-change effects across a broad range of plausible climate scenarios; evaluating and modifying management goals; refining and setting priorities among adaptation strategies; considering additional conservation features; and constituency building and fund raising for implementation. We therefore recommend that the ACT framework be applied in the context of sustained science-management partnerships, such as the regional SWCCI and associated landscape working groups.

Additional adaptation planning efforts that use the ACT framework have engaged scientists and managers in the Greater Yellowstone Ecosystem (Montana, Wyoming and Idaho), the transboundary USA-Canada Rocky Mountains, New York, Oregon and the Great Plains Landscape Conservation Cooperative region, for a diversity of species, ecosystems and ecological functions (http://www.wcsnorthamerica.org/ConservationChallenges/ClimateChange.aspx)

Table 1. Example climate-adaptation actions recommended for achieving management goals in light of actual or hypothesized climate change effects under two climate scenarios considered at each Southwest Climate Change Initiative workshop.

Landscape	Conservation feature	Management goal	Actual or hypothesized climate-change effects	Strategic adaptation actions
Jemez Mountains, New Mexico	Natural stream flow regime	Maintain sufficient water in the system to support aquatic species and riparian vegetation	Reduced snowpack and greater variability in precipitation; reduced stream base flows.	• Restore beaver to streams. • Build artificial structures to increase floodplain aquifer recharge. • Apply forest thinning treatments that maximize snowpack retention and provide optimal shade to minimize sublimation and evaporation losses.
Gunnison River basin, Colorado	Gunnison Sage-Grouse (*Centrocercus minimus*)	Increase and maintain the Gunnison population of Sage-Grouse at >3,500 individuals and the Crawford population at >200 individuals.	Loss of nesting habitat due to increased fire frequency, cheatgrass invasion, and sagebrush dieback; decreased habitat quality due to a decline in forbs and perennial grasses; reduced recruitment.	• Improve or restore nesting and wintering habitats. • Improve or reestablish leeward mountain shrub habitats [e.g., snowberry, serviceberry] via fencing and planting. • Maintain and expand perennial grass and forb cover by planting and fencing; abate/prevent cheatgrass encroachment by spraying.
Four Forests Restoration Initiative area, Arizona	Ponderosa pine (*Pinus ponderosa*) forest watershed function	Maintain or improve watershed function in systems dominated by ponderosa pine by maintaining and improving water quality, quantity, and timing of flow for surface and ground water; soil productivity; and recharge-to-runoff ratio.	Increased temperature leads to increased potential evapotranspiration and decreased recharge; increased moisture stress for plants and lower base flows in rivers and streams that affect aquatic species.	• Apply forest-restoration treatments (e.g., thinning, controlled burns) to reduce fire risk and drought-induced tree mortality, increase herbaceous ground cover, and enhance infiltration, soil moisture and recharge. • Plan for 6-year (on average) fire rotation to maintain water yield benefits.
Bear River basin, Utah/Wyoming/ Idaho	Bonneville cutthroat trout (*Oncorhynchus clarki utah*)	Maintain or expand the number of viable populations of Bonneville cutthroat trout in the Bear River Basin by maintaining or restoring Bonneville cutthroat trout habitat, ecology and life history.	Higher air temperatures increase evapotranspiration, decrease summer base flow, and raise summer water temperature, resulting in an expansion of uninhabitable reaches.	• Restore connectivity between river mainstem and tributaries by rewatering streams to facilitate trout dispersal. • Protect habitat in reaches that provide thermal refugia. • Lower the depth of water outflow from hydropower and irrigation reservoirs to reduce downstream water temperature.

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Overlook on Ridge Road looking southwest towards the Front Range, Rocky Mtn National Park, Colorado. Photo: Sherri Eng

BREVIA

Structural Changes in Subalpine Forests of the Sierra Nevada

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Dolanc, C. R., J. H. Thorne, and H. D. Safford. 2012. Widespread shifts in the demographic structure of subalpine forests in the Sierra Nevada, California, 1934 to 2007. Global Ecology and Biogeography DOI: 10.1111/j.1466-8238.2011.00748.x

Information on how ecosystems have changed during the last 100 years is important for our understanding and prediction of their future change, particularly with respect to climate change. To refine their predictions, it is important that bioclimate models, which often lack important elements of ecology (Pearson and Dawson 2003), incorporate more empirical data that capture real-world ecological relationships. Historical data have the potential to be extremely useful in this endeavor. For example, subalpine and alpine vegetation is predicted to experience an areal reduction of 54 to 78% over the next 100 years (Lenihan et al. 2008). This timeframe seems short for an ecosystem made up of slow-growing, long-lived vegetation that has likely already lived through climatic change (Millar and Woolfenden 1999). A better understanding of how subalpine and alpine vegetation in California have changed over the last several decades, in correspondence with climate during that period, should help us understand whether a reduction of 54-78% over the next 100 years is plausible.

Dolanc et al (2012) re-sampled 139 subalpine forest plots from 2007 to 2009, originally surveyed from 1929 to 1934 in the central Sierra Nevada (California, USA; Figs. 1, 2). The historical plots were part of the Wieslander Vegetation Type Mapping (VTM) project, which mapped vegetation throughout California and established ~18,000 plots to validate mapped polygons (Keeler-Wolf 2007, Thorne et al. 2008). Re-sampled plots were 800 m2, designed to extract data equivalent to the VTM plots, and of the same orientation and sample area as VTM plots. The study area was restricted to elevations above 2300 m, where disturbance from factors such as logging and fire suppression is minimal. Comparisons of the number of tree stems per plot between historical (VTM) and modern (re-sampled) stand densities were made for four diameter [diameter at breast height (dbh)] size classes: Size Class 1 (SC1, 10.2 – 30.4 cm); Size Class 2 (SC2, 30.5 – 60.9 cm); Size Class 3 (SC3, 61.0 – 91.3 cm); and Size Class 4 (SC4, ≥ 91.3 cm). Shrub and herb data were also collected in both time periods but the VTM protocol for these two vegetation layers is incomplete and thus not considered here; see the VTM manual, accessible online (Wieslander et al. 1933; http://vtm.berkeley.edu/) and Dolanc et al. (2012) for more details.

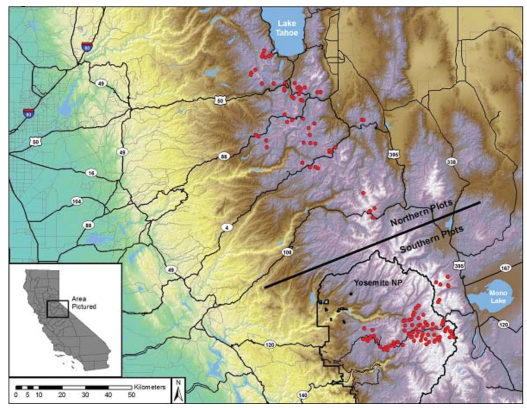

Figure 1. Map of the study area in the central Sierra Nevada, CA, USA showing re-sampled Vegetation Type Mapping (VTM) Project plots (n = 139; red circles). Re-sampled plots were located in minimally-disturbed, wilderness areas within national parks and forests and occur from 2300 m up to treeline (approximately 3400 m). For analysis, plots were blocked by different groups: low/high elevation, cool/warm slopes, gentle/steep slopes and northern/southern plots (indicated by the solid black line.

Subalpine Forests Have Gained Small Trees & Lost Big Trees

Subalpine forests of the central Sierra Nevada have increased in density by 30.4% since the 1930s. Small trees (SC1) have increased by 63.3% while large trees have decreased by 20% (Fig. 3). Trends of increasing small trees and decreasing large tress were observed on both warm and cool slope aspects, low and high elevation bands, steep and gentle slopes and southern and northern portions of the study area (Fig. 3). Though there are differences in magnitude, all eight species sampled showed similar demographic shifts since the 1930s (Fig. 4). At the same time, species composition appears to have changed very little,

Figure 2. Photographs of four typical resampled Vegetation Type Mapping (VTM) Project plots, showing variability in subalpine forest structure by elevation and location. All plots in these photos come from Yosemite National Park. Each photo was taken from plot center, looking down the long axis of the 10 X 80 m plots. Note the sparse distribution of trees and lack of live and dead matter (fuel) in three of four plots.

with no species shifting its relative dominance by more than 2%. Further, no lower-elevation species absent in VTM plots moved upslope and was counted in the re-sampled plots. Thus, subalpine forests of the Sierra Nevada appear to be going through major demographic changes without shifting their composition.

The increased density of small trees confirm what studies of photographic records and stand reconstructions of high-elevation forests have previously concluded (Vankat and Major 1978, Vale 1987, Taylor 1995, Gruell 2001). Recent studies have also reported a decline in large trees in the Sierra Nevada (Smith et al. 2005, Lutz et al. 2009), and have generally attributed the decline to mortality. Since the re-sampling protocol included snags, Dolanc et al. (2012) was also able to conclude that large tree decline was likely due to mortality; when snags were added to modern stem counts of large trees, there was no difference between VTM and modern stem counts.

Are Changes Driven by Climate?

Over the course of the last 75-80 years, it appears as though recruitment and survival of small trees (10.2 to 30.4 cm) has been good, while mortality of large trees has been high (Figs. 3, 4). What could be driving such contrary and yet consistent, widespread trends? Climate change does seem a likely culprit. Climate stations on either end of the study area recorded minimum temperatures that were on average 1.4°C higher from 1976-2005 than they were from 1916 to 1945, when VTM plots were originally sampled. These stations also show an increase in annual precipitation between these same time periods of approximately 230 mm/yr. Of course, these are just trends over two points in time but aggregated climate station data from the Sierra Nevada region indicate warming temperatures of about the same magnitude and a modest rise in annual precipitation over the twentieth century (WRCC 2012).

Other studies have documented increased recruitment of small trees in subalpine regions, into meadows, snow fields, forest-tundra ecotones and upland forest (Jakubos and Romme 1993, Rochefort and Peterson 1996, Hessl and Baker 1997, Klasner and Fagre 2002, Millar et al. 2004) and all of these attributed the change to warmer 20th century temperatures. Warmer temperatures have likely increased the growing season by reducing the depth and/or duration of winter snowpack. Spring melt dates of snowpack in the Sierra Nevada do appear to be moving earlier in the year (Kapnick and Hall 2010). In areas of deep snowpack, we might expect longer growing seasons to facilitate tree recruitment leading to an increase in small trees. Increased mortality rates across the west, including the Sierra Nevada, have also been attributed to warming (Guarin and Taylor 2005, Smith et al. 2005, van Mantgem et al. 2009). Warmer temperatures can increase the likelihood of drought-induced mortality in trees (Adams et al. 2009) and make them more susceptible to insect and pathogen attack (Allen et al. 2010).

Though the precise mechanism is unclear, it seems likely that the opposing trends of demographic change in the subalpine reflect the evolution of climate change since the beginning of the 20th century. Many of the studies reporting increased recruitment of small trees documented a peak of establishment around the middle of the 20th century (e.g. Millar et al. 2004) while the uptick in mortality appears to have been more recent (van Mantgem and Stephenson 2007, van Mantgem et al. 2009, Millar et al. 2012). Thus, climatic changes that occurred mid-century may have been favorable to recruitment/establishment, while keeping mortality low; then, since that time mortality has increased but has not yet compensated for the increased establishment of small trees. Major hydrological disturbances in the Sierra Nevada are correlated with positive phases of the Pacific Decadal Oscillation (Benson et al. 2003), which switched to positive phase around 1976-1977 (Mantua and Hare 2002). This switch corresponds well with the rise in tree mortality in the Sierra Nevada.

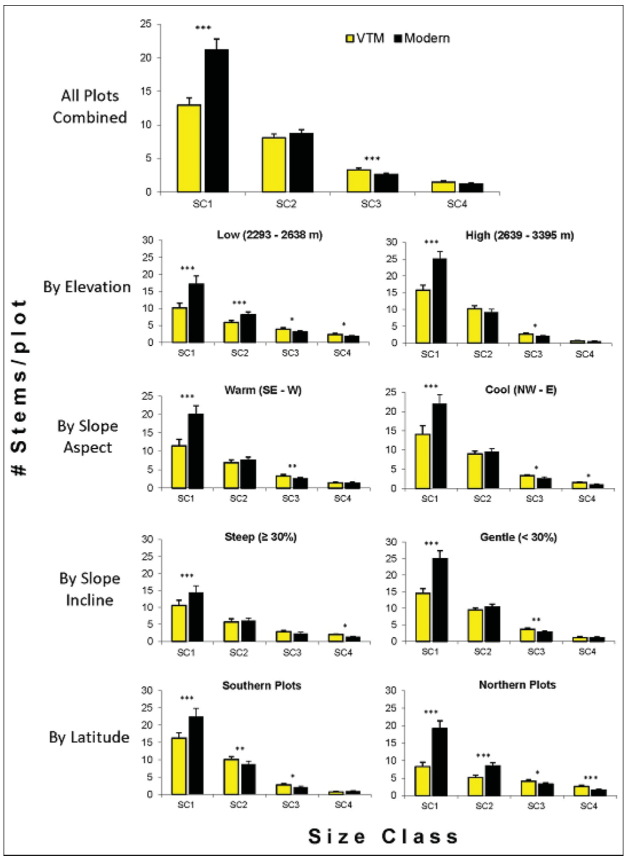

Figure 3. Comparison of historic [Vegetation Type Mapping (VTM) Project Plots; yellow bars] and "Modern" plots (black bars) for number of stems per plot + SE for all species combined (top panel) and comparisons of different groups of plots by elevation, slope aspect, slope incline and latitude (lower four panels). Tree size classes were as follows: SC1: 10.2 - 30.4 cm diameter; SC2: 30.5 - 60.9 cm; SC3: 61.0 - 91.3; SC4: ≥ 91.4 cm. Statistically significant differences are indicated by * = $0.01 < p < 0.05$; ** = $0.001 < p \leq 0.01$; and *** = $p < 0.001$. See Dolanc et al. (2012) for more information on analyses.

There are certainly other possible drivers of the observed changes in subalpine forests. Fire suppression has led to denser forests at lower elevations of the Sierra Nevada (Parsons and Debenedetti 1979, Ansley and Battles 1998). The subalpine zone, however, has very short growing seasons, shallow fuel beds and generally open canopies (Fites-Kaufman et al. 2007), leading historically to very long fire-return intervals (van Wagtendonk and Fites-Kaufman 2006) and making it unlikely that 20th century fire suppression has impacted these elevations much. Other factors, such as grazing abatement, nitrogen deposition and other human-induced disturbances cannot be ruled out, but the widespread, consistent nature of the structural changes in subalpine forests since the 1930s support climate change over these arguably more localized, heterogeneous factors.

Implications for the Future and Model Predictions

The changes required to reduce subalpine and alpine vegetation by 54-78% over the next 100 years, via upslope movement of lower-elevation vegetation (Lenihan et al. 2008), are not apparent in the current trends in subalpine in the Sierra Nevada. The changes in demography since the 1930s are relatively consistent from species to species and composition has not changed. The shifts predicted by models such as Lenihan et al. (2008), which predicts vegetation in 2090, might be expected to already be visible as increased recruitment/decreased mortality of lower-elevation species, and/or decreased recruitment/increased mortality of higher-elevation species. Widespread mortality may be occurring, but does not appear to be especially strong in higher-elevation species such as whitebark pine (*Pinus albicaulis*) and mountain hemlock (*Tsuga mertensiana*; Fig. 4). At the same time, recruitment of high-elevation species like whitebark pine (*Pinus albicaulis*) and mountain hemlock (*Tsuga mertensiana*) appears to be as good as lower-elevation species (Fig. 4), and currently appears to be outpacing mortality. For high-elevation vegetation types, long-term change is likely to take hundreds of years to come to fruition and modelers should re-consider the timeframe if change in these systems. On the other hand, disturbance factors such as bark beetles and pathogens could quickly reach a critical threshold and tip the scales in favor of vegetation-type shifts. Bark beetles and white-pine blister rust have caused massive die-back in western mountains (Kurz et al. 2008, Logan et al. 2010, Tomback and Achuff 2010) but thus far have had minimal impact on the Sierra Nevada (Maloney 2011).

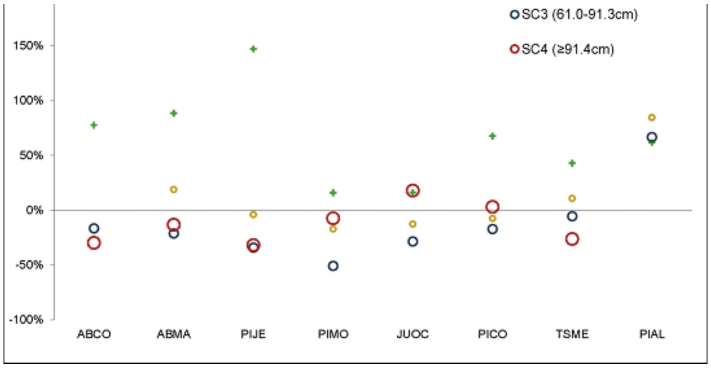

Figure 4. Percent change of stem abundance (# stems/plot), by size class (SC), from historic [Vegetation Type Mapping (VTM)] plots to modern plots for each of the eight conifer species sampled: ABCO (*Abies concolor*), ABMA (*Abies magnifica*), PIJE (*Pinus jeffreyi*), PIMO (*Pinus monticola*), JUOC (*Juniperus occidentalis var. australis*), PICO (*Pinus contorta subsp. murrayana*), TSME (*Tsuga mertensiana*), and PIAL (*Pinus albicaulis*). Species are listed approximately in order of elevational distribution, from lower to higher within the subalpine zone of the central Sierra Nevada.

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BREVIA

Winds of Change: Characterizing Windthrown Trees in a Sierra Nevada Mixed Conifer Forest

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Hilimire, K., J. Nesmith, A. Caprio, and R. Milne. In Revision. Field Note: Attributes of Windthrown Trees in a Sierra Nevada Mixed Conifer Forest. Western Journal of Applied Forestry

An unusual wind event affected significant portions of the southern Sierra Nevada November 30 to December 1, 2011. The wind event was caused by an extreme pressure gradient from north to south over Nevada and the Sierra Nevada and was unusual for the region in three ways: 1) long duration, 2) atypical wind direction, and 3) high intensity wind. Extreme wind speeds lasted for 12 hours, from 6 pm to 6 am, with strongest winds occurring from 10 pm to 4 am. An anemometer at Mammoth Mountain, California recorded winds that exceeded 145 km.h-1, with a predominantly NNE direction. Extensive windthrow of trees occurred in Devils Postpile National Monument, Yosemite National Park, and Sequoia and Kings Canyon National Parks as well as in large portions of the Inyo National Forest (Fig. 1). The wind event is the most extensive on record for California's Sierra Nevada range and may have long lasting impacts on forest composition and function.

In this study, we characterize the attributes of windthrown trees in a mixed-conifer forest in Devils Postpile National Monument. The monument is 322 ha and is surrounded by Inyo National Forest land in the Upper Middle Fork of the San Joaquin River watershed. Elevations range from 2,182 to 2,485 m. The mixed-conifer forest is composed primarily of red fir (*Abies magnifica*), white fir (*A. concolor*) and lodgepole pine (*Pinus contorta*) (Caprio and Webster 2006). Jeffrey pine (*P. jeffreyi*) is also prevalent at lower elevations, while mountain hemlock (*Tsuga mertensiana*) and western white pine (*P. monticola*) are found at higher elevations (Caprio and Webster 2006).

Specific study objectives were to:

1) Understand the relationship between tree size and wind damage,

2) Assess factors associated with uprooting versus snapping caused by wind, and

3) Compare vulnerability by species of the windthrow by assessing species composition of the forest pre- and post-blowdown.

We took advantage of a pre-existing set of fire effects monitoring (FMH) plots to compare forest attributes before and after the blowdown event. These plots were initially installed to assess the

Figure 1. Pre- blowdown 2010 image (left) and post-blowdown (right) 2012 image of the northwest portion of Devils Postpile National Monument where the most severe windthrow occurred. The green line is the northern monument boundary, the red lines are roads, and the yellow dotted lines are trails. Imagery from the National Agriculture Imagery Program of the US Department of Agriculture.

effects of fire on forest ecosystem processes and to detect trends over time (USDI-NPS 2003). Eight FMH plots were installed in 1992 following the Rainbow Falls fire and re-measured in 2002 with two additional unburned plots added in 2005. These data included 390 live trees, which we used to assess pre-blowdown forest structure and composition. The plots also provided photo points where repeat photos could be taken to illustrate localized effects of tree blowdown (Fig. 2). We established 13 100-m long transects in May 2012 and used a line intercept transect methodology to locate and characterize new windthrown trees. More details about the specific data collected and analyses done are available in Hilimire et al. (in review).

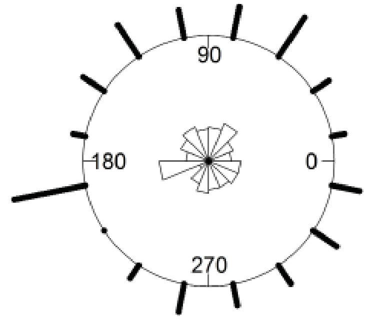

Figure 3. Distribution of fall angles of windthrown trees. Tree fall angles were grouped into 16 bins for plotting.

Figure 2. Fire effects plot (unburned) photographed in 2005 (left) and the same photopoint re-photographed in May 2012, 6 months after the blowdown (right). NPS photos from the Sequoia and Kings Canyon National Parks Fire Ecology program.

Figure 4. Example of consistent fall angle of trees in the monument. Photo: Kathleen Hilimire

We sampled 154 trees across the 13 transects (range = 0-40 trees/transect) and found that windthrown trees had a mean density of 118.5 (SD=104.6) trees.km-1and an average volume of 959.3 (SD=1480.3) m3.ha-1. Mean fall angle was strongly SSW (NNE wind direction) (Figs. 3, 4). Average windthrown tree diameter was 2.2 times greater than pre-windstorm standing trees (55.36 cm and 24.cm respectively). Damage type varied: 86% of trees were uprooted and 14% were snapped. Standing live trees were far more likely to uproot than snap (Fig. 5). Species composition and abundance of windthrown trees were representative of pre-blowdown stand composition and abundance.

These results are consistent with other studies that documented a strong relationship between tree size and amount of damage from windstorms (Canham et al. 2001, Peterson 2000, Veblen et al. 2001, Xi et al. 2008). By primarily affecting larger trees, windstorms are likely to have different impacts on forest regeneration and function than other disturbances such as fire (D'Amato et al. 2011, Gandhi et al. 2008).

Uprooting was the most common type of damage. Whether a stem is uprooted or snapped by wind has been attributed to precipitation, stem rot, tree species growth form, specific gravity of the wood, status (living or dead), slope, soil tension and shear, root-soil resistance, and stem size (Everham and Brokaw 1996, Nicoll et al. 2005, Peltola 2006, Veblen et al. 2001, Xi et al. 2008). In this study, tree status (living or dead) at the time of the wind event played a role in determining whether a tree would uproot or snap. Living trees were far more likely to uproot than snap, while snags were only marginally more likely to uproot than snap. Advanced root rot and decay in the stem contribute to the increased likelihood of snags to snap (Veblen et al. 2001).

The type of wind damage (uprooted vs. snapped) has important ecological implications for both wildlife and forest regeneration (Schaetzl et al. 1989). Uprooting can create mounds of exposed soil that can facilitate seedling establishment while snapping can create dead snags that are important habitat features for wildlife such as cavity nesting birds.

The relative overall standing forest species composition and abundance were not substantially affected by the blowdown. However, given the edaphic, light, and bare ground changes caused to the forest ecosystem by this blowdown, what successional trends will now occur remain to be seen (Woodall and Nagel 2007). This study describes the forest stand structure at time zero after this unusual windstorm. Implications for future forest structure and diversity remain to be understood and described.

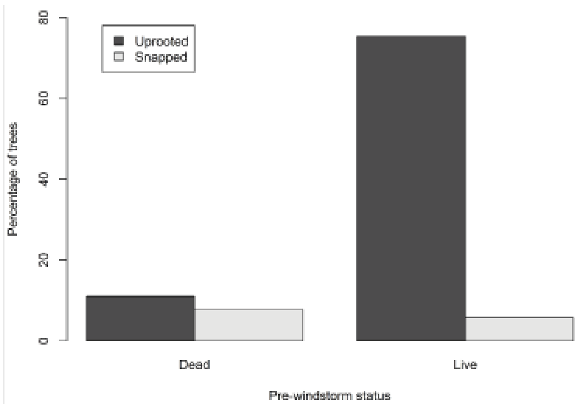

Figure 5. Percentage of windthrown trees that were uprooted or snapped as a function of pre-windstorm status (live or dead).

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BREVIA

Representing Atmospheric Moisture Content in the Sierra Nevada, California

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Feld, SI, NC Cristea, and JD Lundquist. Representing atmospheric moisture content along mountain slopes: Examination using distributed sensors in the Sierra Nevada, California (submitted to Water Resources Research, 2012).

Atmospheric moisture content, typically measured as dewpoint temperature or relative humidity (RH), is a critical factor in modeling both the energy and water balances in a river basin. However, these variables are sparsely measured, particularly at high elevation. Given that limited measurements exist, we investigated options for representing dewpoint temperatures in two study sites in the Sierra Nevada, California. These sites are the American River Basin (ARB), for water years 2008 through 2010, and Yosemite, for water years 2003 through 2005 (Fig.1). The study sites contain both permanent meteorological stations and temporary sensors. Permanent meteorological towers included Hydrometeorology Testbed stations (http://hmt.noaa.gov) from 7 m to 2100 m in the in the ARB (15 stations) and California Department of Water Resources Data Exchange Center stations (http://cdec.water.ca.gov/intro.html) from 311 m to 3031 m in Yosemite (9 stations).

A dense network of temporary stand-alone sensors was created by deploying hygrochron iButtons from elevations of 424 m to 2429 m (64 sites represented) in the ARB and Hobo sensors from elevations of 1309 to 3205 m (25 sites represented) in Yosemite. We considered (a) simple empirical algorithms for two cases: 1) no measurements are available in a watershed (Kimball et al., 1997; Running et al., 1987), and 2) only one point measurement is available, which must be distributed across a basin (Cramer, 1961; Franklin, 1983; Kunkel, 1989; Wigmosta et al., 1994), (b) the Parameter-elevation Regressions on Independent Slopes Model (PRISM), which uses local lapse rates based off observations (Daly et al., 2008), (c) the basic atmospheric structure as seen in upwind data from a nearby radiosonde sounding at Oakland and (d) the Weather Research and Forecasting (WRF) model, which is a numerical weather prediction system informed by surface and upper-air measurements (Skamarock and Klemp, 2008). These methods were selected to test the transferability of empirical fits

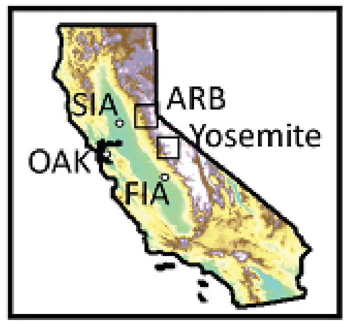

Figure 1. Study site locations, the American River Basin (ARB) and Yosemite. Sacramento International Airport (SIA) and Fresno International Airport (FIA), for projecting dewpoint temperatures across a basin, and Oakland radiosonde soundings (OAK) locations are shown.

to our study site (empirical methods), whether physical principles of conservation of moisture in a lifted air mass are an appropriate metric for the basin, whether uniform advection of the free atmosphere describes moisture dynamics in the mountain range (radiosonde data), or whether a full atmospheric physics model is necessary to capture dewpoint variations (WRF).

We consider that we are given one station that measures dewpoint temperature, using observations at the Sacramento International Airport (SIA) and Fresno International Airport (FIA) stations (Fig.1) to represent typically available data. Performance is limited by the choice of the base station, whether the modeled lapse rate fits the observed lapse rate, and whether dewpoint temperatures decrease with elevation linearly at all. We found that the assumption of a constant mixing ratio with elevation (Cramer, 1961) and of the almost equivalent -1.25°C km-1 lapse rate (Franklin, 1983) did not lose moisture quickly enough with gains in elevation (median biases as high as 9.9°C), although these improved during the warmer months when there are smaller moisture declines with increases in elevation (Fig. 2). This indicates that the moisture variations cannot be represented by the adiabatic rising of an air parcel up a mountain slope. Adjustments to vapor pressure (Kunkel, 1989) or assuming constant RH with increases in elevation (Wigmosta et al., 1994) are closer to representing the decreased moisture at elevation, with better performance during the winter months (Fig. 2). PRISM is available in monthly-average datasets. At this resolution, PRISM improves upon the empirical lapse rate methods by using local observations to determine linear regressions of dewpoint temperature with elevation changes (Daly et al., 2008), however performed better in the ARB (median bias = -0.3 °C) than in Yosemite (median bias = 3.3°C).

Empirical algorithms that derived dewpoint from air temperature include assuming that the dewpoint is the minimum daily air temperature (Running et al., 1987) and employing an aridity correction to this minimum temperature (Kimball et al., 1997). These empirical methods showed a seasonal variation in performance (Fig. 2), with summer median bias values 0.6°C to 8.2°C wetter than winter bias values.

Large biases between radiosonde readings interpolated to the level of observations and measured dewpoint indicate that assuming uniform advection of the vertical moisture structure above Oakland does not represent the observed moisture patterns in the Sierra Nevada well, particularly during the warmer months (Fig. 2c,f). WRF (Skamarock and Klemp, 2008), which used a reanalysis product based on the Oakland sounding data for boundary conditions, greatly improved on the free-air data, performing well in representing the overall trends in both study sites, with median biases of -0.9°C and -1.0°C.

When modeling a geographically simple basin such as the ARB, one base station within the basin paired with PRISM lapse rates will be representative of overall moisture trends most of the time. Use of a high-elevation station that records atmospheric moisture reduces average modeled bias in a basin. However, if the basin is more geographically complex like in Yosemite, with air masses not only due to predominant weather patterns, but micro-topography effects and transport along the mountain range, a physically-resolved model such as WRF improves representations of dewpoint variations.

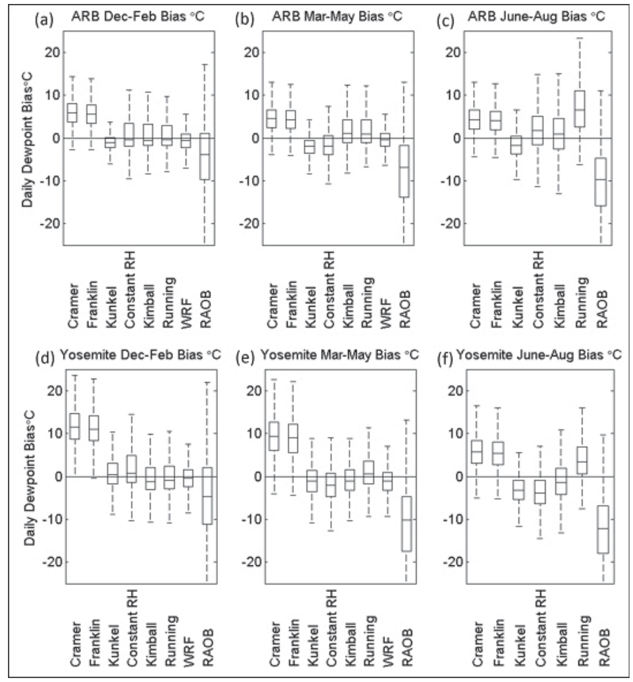

Figure 2. Bias between methods of estimating dewpoint temperature and observations in the American River Basin and Yosemite with daily-averaged data during the winter (Dec-Feb) (a,d),spring (Mar-May) (b,e), and summer (June-Aug) (c,f). Methods shown include projections from a low elevation base station (constant mixing ratio with elevation (Cramer, 1961), -1.25°C km-1 lapse rate (Franklin, 1983), adjustments to vapor pressure (Kunkel, 1989), constant RH with increases in elevation (Wigmosta et al., 1994)), dewpoint temperatures calculated from air temperature measurements ((Kimball et al., 1997; Running et al., 1987)), the WRF mesoscale model (WRF) (Skamarock and Klemp, 2008), and radiosonde data (RAOB). PRISM is not included in this plot as it is resolved to monthly averages.

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Voices in the Wind; Views from *MtnClim 2012*

Borrowing shamelessly from a new section in *Science* magazine, I thought it would be interesting to pose questions to our mountain-climate community and capture their replies in *Mountain Views Newsletter*. Sherri Eng, Public Affairs Specialist at USFS PSW Research Station, traveled to Estes Park, CO for the *MtnClim 2012* conference. She kindly interviewed nine of our younger colleagues and transcribed their answers below. *--Editor*

The Question we posed:

What burning climate change research question would you like to have answered in coming decades?

Sarah Hart

Department of Geography, University of Colorado, Boulder, CO

"I would like to know how fire disturbances will change both in response to changes in climate and also in response to other disturbances. How will fire frequency and severity change in the future in relation to not only warming and drying, but also in relation to other disturbances that may affect the probability of fire, including bark beetle outbreaks and blow-downs which may be driven by climate change as well."

Christopher Kopp

Division of Biological Sciences, University of California, San Diego, CA

"I have been looking at species distribution and how they've shifted in response to historic climate change. What can we expect as temperatures continue to rise? What are we going to see 50, 100 years from now?"

Chris Crawford

Department of Geography, University of Minnesota, Minneapolis, MN

"I would want to know about the rain-snow transition, the increasing snow line. I would want to know where it is, where it is happening and pinning down where snow is melting the fastest. It's important to know where the snow-fed freshwater resources are really coming from, and to understand the vertical change in snowpack relative to the amount of water coming down the mountain. Understanding that rain-snow transition is really important for streamflow forecasting."

Lara Kueppers

School of Natural Sciences, University of California, Merced, CA

"As we try to project how the climate system is going to evolve, a key question is: How well do we have to represent the nitty-gritty ecological details to capture climate extremes or climate change? Do we need to know a lot of details about ecology to understand local and regional climate systems? Or, can we get away with crude approximations? Models have become infinitely complex, but they don't necessarily become infinitely better. I don't think we have a great handle on how much complexity is enough. I would like to know this answer sooner rather than later because that would direct the research we do."

Jonny Armstrong

School of Aquatics and Fishery Sciences, University of Washington, Seattle, WA

"Where I work up in Alaska, we've already seen substantial climate change – it's one of the most rapidly warming areas on the planet. Over the last 100 years, we've seen striking shifts in the productivity of salmon. Fishing districts and watersheds that were previously not very productive, are very productive now. And others that everyone relied on to catch fish are no longer productive. You can see the complex ways in which the changing climate expresses itself in biological responses. But what we don't have is a mechanistic understanding – what is it that produces these patterns of the sea? Why do some populations respond differently to climate change than others? Salmon have such a crazy life cycle – they are born in fresh water, but swim across the Pacific Ocean to come home. To understand what in that life cycle is causing some populations to benefit from climate change and some to do worse would be something that I would be fascinated to know."

Koren Nydick

Sequoia and Kings Canyon National Parks, National Parks Service, Three Rivers, CA

"I think our ability to understand what kind of variability to expect across the landscape is really important to making management decisions. We need to improve our understanding of the system so that we can understand the spatial variability a lot better than we do now."

Alessandra Bottero

Department of Geography, University of Colorado, Boulder, CO

"I would want to figure out the best management of our forests to compensate for the effects of climate change in response to natural disturbances."

Anne Kelly

Department of Earth System Science, University of California, Irvine, CA

"I would like to know the thresholds of ecosystem resiliency and when do they hit tipping points where they change into different ecosystems? I'm interested in using the natural differences in climate that exist now, rather than waiting for things to change to look at thresholds… how ecosystems develop, grow and die in the current regime, to determine how things might change in the future."

Janet Prevéy

Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, CO

"It would be interesting to know if warming temperatures and changing precipitation patterns are actually going to lead to the extinction of plant species that live above treeline. For people who care about biodiversity, knowing the answer to this might make them more interested in climate change, especially if it's going to lead to the extinction of plants."

Initiating the North American Treeline Network, NATN

Dave Cairns[1], Lara Kueppers[2], and Connie Millar[3]
[1]*Texas A & M University, College Station, Texas*
[2]*University of California Merced, Merced, California*
[3]*USDA Forest Service, PSW Research Station, Albany, California*

In spring 2012, Greg Greenwood of the *Mountain Research Initiative*, Bern, Switzerland approached a group of mountain-climate scientists regarding their interest in developing a research effort in North America to parallel a similar program launching in Europe. The proposed focus would be on interdisciplinary dynamics of the upper treeline in mountains as a zone sensitive to climate. The three of us (Dave, Lara, and Connie) agreed to coordinate the launch of such a network, and have been gathering names of interested scientists along with their ideas and proposals for how such a group might function. A subset of 25 mountain scientists met after the *MtnClim 2012* conference in Estes Park in early October to discuss scope and next steps.

At this meeting, Harald Bugmann (Swiss Federal Institute of Technology [ETH], Zürich) briefed the group on the European initiative, and then we discussed the range of interests likely in North America, gaps in understanding and interdisciplinary synthesis, how we might initiate a research network, and its potential scope and focus. We agreed on two activities for the coming months: 1) to distribute information about preliminary goals and invite those interested to join in the initial efforts, and 2) develop a proposal for submission to NSF for a Research Coordination Network.

If you are interested in participating in a NATN or just learning more, please email Dave Cairns (*cairns@tamu.edu*). A draft description of NATN goals follows:

The upper treeline ecotone in mountains is the transition zone between forest and alpine environments and a potential bellweather for responses of marginal ecosystems to climate change. Although trees are the traditional focal point of the ecotone, this complex system is shaped by interactions among vegetation, soils, animals, climate, topography, and disturbance regimes. As such, treelines have been the subject of study by many disciplines across the natural sciences, yet cross-disciplinary integration of both theory and observations is lacking, which has prevented pattern-to-process understanding of this sensitive ecosystem. The goal of the North American Treeline Network (NATN) is to integrate research efforts across disciplines, scales, and methodologies. Specifically, NATN will catalyze efforts to characterize and understand past and present treeline dynamics and facilitate projections of future changes in treeline ecotones across mountain regions of North America.

Historic divisions in treeline research have been drawn along pattern and process boundaries. Much work has been done to characterize the pattern and position of the treeline ecotone. Similarly, process studies have striven to answer questions of why changes in treeline occur. NATN will promote interactions between these largely separate approaches to build a conceptual framework that reflects comprehensive systems understanding. Our approaches may include common experimental and data acquisition protocols that encompass elements of pattern and process, data synthesis efforts, and opportunities for scientific exchange.

NATN will bring together ecologists, ecosystem scientists, geographers, ecophysiologists, hydrologists, and others to explore and solidify understanding of treeline dynamics across domains of time and space. NATN will sponsor local, regional, and international meetings of treeline scientists to enhance communication across disciplinary boundaries. In addition, student exchanges will serve to diversify experience in field and laboratory settings among the members of NATN. The network will place emphasis on professional development of students and early career scientists through creation of a series of webinars that promote new lines of inquiry and collaboration. Establishment of NATN corresponds with a companion activity in Europe that seeks to integrate treeline research across disciplinary and national boundaries. The time is ripe for the North American treeline community to coalesce around a common effort that will involve significant synergies with our European colleagues.

The legacy of NATN will be a set of common protocols for experimental and observational studies, an extensible treeline database, a robust communications network among treeline scientists both in North America and Europe, and a cohort of interdisciplinary researchers prepared to advance treeline science into the future. It is only through these integrated efforts that sound projections of a future treeline system will be possible.

The Climate Adaptation Fund; Wildlife Conservation Society

With funding provided by the Doris Duke Charitable Foundation and managed by the Wildlife Conservation Society (WCS), the WCS Climate Adaptation Fund provided up to $3 million in competitive grant funding over the past two years to non-profit conservation organizations for applied, on-the-ground projects focused on implementing priority conservation actions for climate adaptation at a landscape scale.

The program seeks to support actions that anticipate and respond to potential climate change impacts and maximize long-term conservation goals. To achieve these ends, the program prioritizes projects that manage for dynamic ecological processes, landscape functionality, and species assemblages, rather than those aimed at maintaining historic conditions or individual species.

WCS anticipates releasing another Request for Proposals to the Climate Adaptation Fund in Spring 2013. For more information on the WCS Climate Adaptation Fund, a summary of grants made to-date, and information about future grant opportunities, please visit our web site:
http://www.wcsnorthamerica.org/ClimateAdaptationFund

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Figure 1. The Trust for Public Land was granted an award in 2012 for their work within the 2.7 million-acre White Mountain to Moosehead Lake region. Widely recognized as an enduring landscape providing critical refugia for species, this project will use the latest climate science data to inform conservation easement terms and ecological reserve design on more than 18,000 new acres of protected land.
Photo: Jerry and Marcy Monkman, ecophotography.com.

Update from the California / Nevada GLORIA Project (Global Observation and Research Initiative in Alpine Environments)

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Department of Ecology and Evolutionary Biology
University of California, Santa Cruz, California

Rising global temperatures are widely predicted to disproportionately affect alpine ecosystems. The plants at the tops of the highest mountains, unlike sub-alpine species, cannot migrate to new locations upslope as the climate warms. One of the most ambitious global projects for vegetation assessment in the alpine zone is the international GLORIA project (Global Observation and Research Initiative in Alpine environments), a standardized assessment protocol for monitoring changes in plant distribution and abundance on high-elevation summits every 5 years. Globally, there are over 350 sites that have been surveyed using this protocol. At each site plant abundance data is taken for 8 sections of the summit (divided by aspect and elevation), smaller permanent plots are established for more detailed abundance data, the entire summit is extensively photographed, and temperature loggers are installed to measure soil temperatures.

CIRMOUNT sponsored the establishment of the first North American GLORIA summits in California between 2004-6. Fourteen summits in California have been resurveyed (5 yrs after the initial survey); 3 in the Carson Range near Tahoe, 4 near Yosemite, and 7 in the White Mountains (3 summits in the Sweetwater Range and 4 near Mt. Langley are also established and awaiting resurvey). In 2013, there will be a resurvey of 4 summits in Great Basin National Park and tentatively the establishment of new sites Death Valley National Park. This ambitious project is staffed largely by volunteers with botanical expertise. The GLORIA methodologies are designed to record slow changes in alpine plant communities over multiple decades, thus it is somewhat early to make speculations about potential changes in species composition from our 5-yr resurvey data of 14 summits, although we have documented a number of new species on certain sites and a die-back of some shrubs on others.

Our most notable result to date is the soil temperature data, from each of 4 aspects on 14 summits, including 8 years of data from the White Mountains, 5 years of data from the Carson Range, and 7 years of data from the Sierra Nevada sites. Temperature data is taken hourly, by loggers buried to 10cm, on each cardinal direction line exactly 5-meters below the highest summit point (e.g., four measurements per hour for each peak, 14 peaks total, 56 loggers total, ~2 million data points). Between 2004 and 2012, the most remarkable finding is a very significant rise in maximum daily temperatures. The slope of a regression line indicates a 1.3°C rise in daily maximums over 8 years (Fig. 1). While this observation of increasing temperature extremes is not surprising, it confirms that California's alpine communities deserve increasing attention in the immediate future.

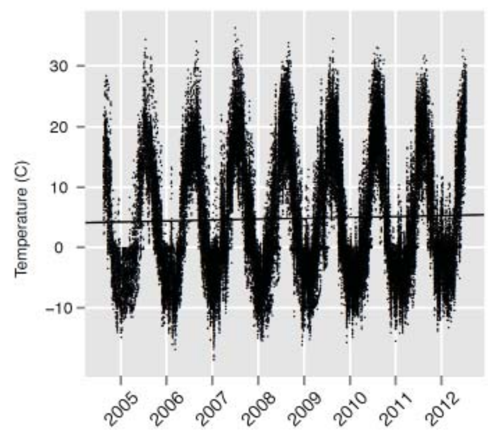


Figure 1. Rising daily maximum temperatures on 14 California alpine-zone summits, 2004-2012.

Figure 2. The GLORIA set-up team on the top of Wheeler Peak in the Sweetwater Range in July, 2012. Photo: Jane Schmidt

* The GLORIA project is includes many participants and volunteers, including but not limited to: Connie Millar (North American Chapter Chair), Jim and Catie Bishop, Chris Kopp, Colin Maher, Jan Nachlinger, Angie Evenden, Ann Dennis, and Dylan Neubaurer.

Data Available from the Center for Snow and Avalanche Studies

For the past nine years, the Center for Snow and Avalanche Studies has conducted integrative 24/7/365 monitoring that captures weather, snowpack, radiation, soils, plant community and hydrologic signals of regional climate trends. Their study site, Senator Beck Basin, is located near Red Mountain Pass in the northern San Juan Mountains, Colorado. Comprehensive data from each of the four study plots within Senator Beck Basin is now available for download at http://snowstudies.org/data1.html.

For more information, contact Kim Buck: kbuck@snowstudies.org

PACLIM Conference Announcement

The Pacific Climate (PACLIM 2013) Workshop will be held March 3-6, 2013 at the Asilomar Conference Center, Pacific Grove, CA.

For more information, contact Scott Starratt (sstarrat@usgs.gov)

New Book on Alpine Treelines

Alpine treelines mark the low-temperature limit of tree growth and occur in mountains world-wide. Presenting a companion to his book *Alpine Plant Life*, Christian Körner provides a global synthesis of the treeline phenomenon from sub-arctic to equatorial latitudes and a functional explanation based on the biology of trees. The comprehensive text approaches the subject in a multi-disciplinary way by exploring forest patterns at the edge of tree life, tree morphology, anatomy, climatology and, based on this, modeling treeline position, describing reproduction and population processes, development, phenology, evolutionary aspects, as well as summarizing evidence on the physiology of carbon, water and nutrient relations, and stress physiology. It closes with an account on treelines in the past (paleoecology) and a section on global change effects on treelines, now and in the future.

Körner , Christian (2012) Alpine Treelines - Functional Ecology of the Global High Elevation Tree Limits, 220 p., Springer, Basel, Switzerland

More information: http://www.springer.com/life+sciences/ecology/book/978-3-0348-0395-3

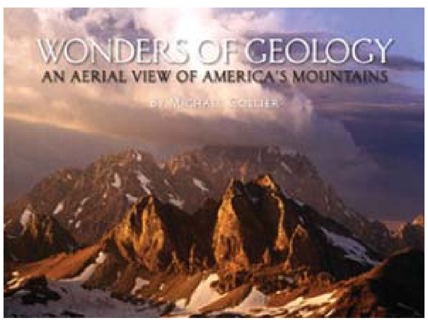
Fall aspen. Photo: Chris Kopp

REVIEW

Wonders of Geology; Getting High on Mountains

Veronique Greenwood
Staff Writer, Discover Magazine
Review reprinted with permission from Download the Universe

Wonders of Geology; An Aerial View of America's Mountains by Michael Collier. Published by Mikaya Press. An IPad App



"All true paths lead through mountains." When I was growing up in the foothills of the Sierra Nevada, this line from the poems of Gary Snyder was a family touchstone. It probably came via my dad, who is mountain-obsessed, a chaser of summits and cirques who has hiked and trekked on five continents and now lives in the Alps. I've felt vaguely uneasy the past eight years or so, living here among the extremely low hills of the Eastern United States, and the photographs of Michael Collier, in the *Wonders of Geology* app, bring it all back: Yes, mountains really are where it's at.

The app was written and narrated by Collier, a geologist and physician who has been taking photographs from the cockpit of his 1955 Cessna professionally for more than 40 years. Based on his book *Over the Mountains (An Aerial View of Geology)*, it is laid out in several sections that first teach you how to read a landscape's history from geological cues, then lead you through various American ranges to see for yourself how the mountains were formed.

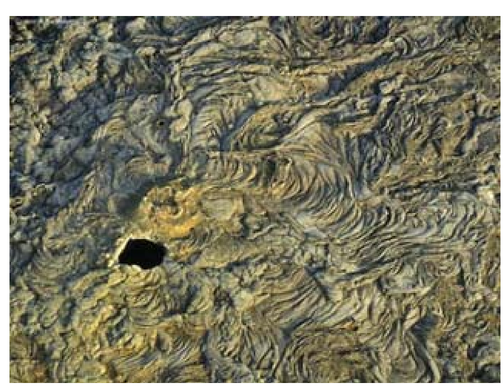
Most of the information comes to you in Collier's own rich, craggy voice. He describes the Earth's inner workings while a seemingly endless parade of fantastic scenes slips by--dunes, alluvial fans, thick, crystalline glaciers. The images are stunning, saturated with color and full of light. In one of my favorites, a Sierra valley cradles a string of glacial lakes that reflect a fierce gray-blue sky. In another, a peak in Morro Bay is bathed in the soft pink of a sunrise, and you can zoom in to see the ripples of the surf.

Collier is a deft and expressive narrator, peppering his explanations with charming turns of phrase. Tectonic plates bomb around the Earth's surface like "irresponsible bumper cars"; ridges caused by spreading centers ring the planet "like the stitches on a baseball." He shifts expertly from the profound to the colloquial. "Plate tectonic theory has ushered in a new consciousness of the Earth's age," he says, with grave wonder. Then his voice slips into a smile, and he quips: "How much time we talkin' bout? *Lots.*"

In fact, *Wonders of Geology* is less an ebook than a kind of hand-held, interactive exhibit, with ever-present audio guide. Photos and explanatory graphics outnumber pages of text many times over. When you do come across a page of prose, it's almost an interruption. I found myself thinking petulantly, Wait, I have to read this?Why aren't you reading it to me?!

Occasional textual interruptions aside, the app is a delight. I particularly enjoyed seeing glamor shots of mountains I know well, like the Panamints of Death Valley and the sere Eastern Sierra, where I learned to core bristlecone pines as a high school kid. The app includes so many ranges that any fan of North American mountains should be able to find their own familiar faces.

To be honest, though, I don't remember these mountains ever reaching quite the height of gorgeousness evident in Collier's photographs. Maybe you have to be several hundred feet up in a 57-year old biplane to get this level of insight. Maybe, it occurs to me, this is how my dad experiences them: intoxicatingly beautiful, mountains as drug.



Craters of the Moon, from *Wonders of Geology*

Did You See (Hear, Touch, Smell, Feel) It?
Oddities of Mountain Weather and Climate

This section of *Mountain Views Newsletter* highlights unusual mountain-weather events or climate-related phenomena of western mountains. We welcome your comments on processes and observations described, and invite submissions for future issues. --*Editor*

Acute Cold Exposure of Winters 2011 – 2012; Will Similar Events Increase with Warming Temperatures?

Connie Millar
USDA Forest Service, Pacific Southwest Research Station, Albany, California

In the Sierra Nevada, as in many mountain regions of the West, snowpacks of the past two years reached opposite extremes: high in the 2010-2011 winter (6th highest in the 89-yr record) and low in the 2011-2012 winter (10th lowest yr on record, Fig. 1). Already highlighted in *Mountain Views Newsletter* were the unusual landscape-wide ice events witnessed directly during the cold and dry winter past ("The Sierran Frood [Rhymes with 'Flood'] of Winter 2011/2012", *MVN* Spring 2012). Not until the warm season, however, did many of us start indirectly encountering effects from cold-exposure on vegetation, which appears to have resulted from the late and low winter snowpack of 2011-2012.

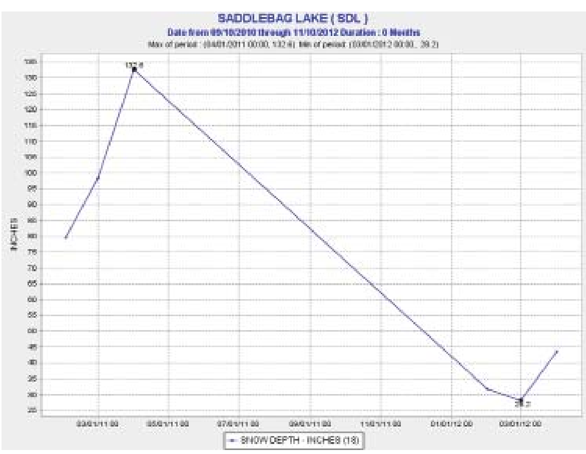


Figure 1. Snow depth during winters of 2010-2011 and 2011-2012 from snow course data at Saddlebag Lake, 2971 m, Sierra Nevada, CA.

During a trip in early May 2012 through the Madeline Uplands north of Honey Lake, CA, I saw for the first time extensive slopes of tobacco brush (*Ceanothus velutinus*) at relatively low montane elevations (2000 m) having dead foliage and blackened crowns. I filed this observation away, thinking perhaps it was due to a local insect or fungal effect. Soon thereafter, however, I started to observe the same situation in tobacco brush along many locations of the lower eastern Sierra Nevada escarpment. Once I began field work in the high Sierra in June, it became clear that this condition was a common phenomenon for many species and upland locations (Table 1 and Figs. 2-9).

Over the course of summer 2012, my colleagues and I looked for patterns to this mortality as we worked through the eastern Sierra Nevada and adjacent ranges of Nevada. Although we couldn't detect obvious trends in aspect or micro-site, we did observe crown mortality over wide elevation ranges from basin-levels to mountain summits, and noted both partial- and entirely dead crowns. Affected were evergreen shrubs and subshrubs that attain heights below ~2 m; we did not observe mortality in species with deciduous leaves, or in tall evergreen trees (conifers) or evergreen tree-shrubs over ~2 m height, such as curl-leaf mountain mahoghany (*Cercocarpus ledifolius*). Further we did not observe mortality in a few evergreen species less than 2 m height, including alpine sagebrush species (*Artemisia spp*), nor in evergreen alpine cushion plant species. Although I have observed sporadic mortality in crowns of evergreen species in prior years in this region, in those cases the situation was limited in extent and taxa affected, occurring locally and almost always on krummholz whitebark pines (*Pinus albicaulis*) in exposed, windswept locations.

From these anecdotal observations, we posit that lack of snowpack throughout much of the 2011-2012 winter exposed crowns of evergreen shrubs to acute cold (below 0°C). Normally these low shrubs are protected by insulation from snow, which both buffers extreme temperatures and protects crowns from desiccating winds. Deciduous species, evolved for exposure to sub-freezing temperatures, are apparently unaffected.

Crown mortality persisted through to the end of summer, although in some cases shrubs that had partially dead crowns re-sprouted a sparse layer of new leaves in late summer. The long-term effects (plant death or recovery) remain to be seen.

Fig. 10 shows temperature traces from August 2010 to September 2011 at one of our American pika (*Ochotona princeps*)-monitoring sites at 3445 m in the eastern Sierra Nevada, Greenstone Lake, upper Lee Vining Canyon. This site is less than 1 km from the Saddlebag Lake snow course location depicted by the graph in Fig. 1. At these habitat sites, we position thermochrons at 3.0 m in the crown of a conifer tree (red curve, "tree") and on the ground surface <10 m distant (on talus, blue curve, "surface").

During the heavy winter of 2010-2011, the surface temperatures remained near freezing whereas in the dry winter of 2011-2012, surface temperatures were persistently below 0°C (as low as -11°C). The 2010-2011 tree trace suggests that 3.0 m air temperatures were colder and often more extreme than during the winter of 2011-2012, but that ground level temperatures remained near freezing. Thus it seems likely that ground-level shrubs with sensitive foliage (evergreen leaves) were protected during winter 2010-2011 but exposed to unusual circumstances of persistent sub-freezing temperatures in winter 2011-2012. Such phenomena, if they become more common under warming temperatures with less snow and shorter snowpack duration of the future, may have a long-lasting effects on plant species diversity and abundance in mountains such as the Sierra Nevada.

All photos: Connie Millar

Table 1. Species observed in the eastern Sierra Nevada during summer 2012 that had extensive crown mortality, apparently affected by winter cold exposure.

Conifers
Juniperus communis (common juniper)
Pinus albicaulis
(whitebark pine; krummholz forms and small trees only)
Pinus contorta (small trees only, lodgepole pine)
Tsuga mertensiana (small trees only, mountain hemlock)

Evergreen Shrubs and Subshrubs
Arctostaphylos spp (manzanita species)
Cassiope mertensiana (white heather)
Ceanothus velutinus (tobacco bush)
Chrysolepis sempervirens (Sierra chinquapin)
Phyllodoce brewerii (red heather)
Primula suffrutescens (Sierra primrose)
Rhododendron columbianum (*Ledum glandulosum*; Labrador tea)

Mosses

Figure 2. Red heather (*Phyllodoce brewerii*), Warren Fork, Lee Vining Canyon, Sierra Nevada, CA.

Figure 3. Red heather (*Phyllodoce brewerii*), Warren Fork, Lee Vining Canyon, Sierra Nevada, CA.

Figure 4. Common juniper (*Juniperus communis*) and red heather (*Phyllodoce brewerii*), Dana Plateau, Sierra Nevada, CA.

Figure 5. Lodgepole pine (*Pinus contorta*) and whitebark pines (*P. albicaulis*), Saddlebag Lake, upper Lee Vining watershed, Sierra Nevada, CA.

Figure 8. Sierra primrose (*Primula suffretescens*), Mammoth Crest, Sierra Nevada, CA.

Figure 6 (far left). Sierra chinquapin (*Chrysolepis sempervirens*), Virginia Canyon, east Walker River drainage, Sierra Nevada, CA.

Figure 9 (near left). Moss polster below the Kuna rock glacier, Kuna Crest, Yosemite National Park, Sierra Nevada, CA.

Figure 7. Manzanita shrubs (*Arctostaphylos spp*), Warren Fork, Lee Vining Canyon, Sierra Nevada, CA.

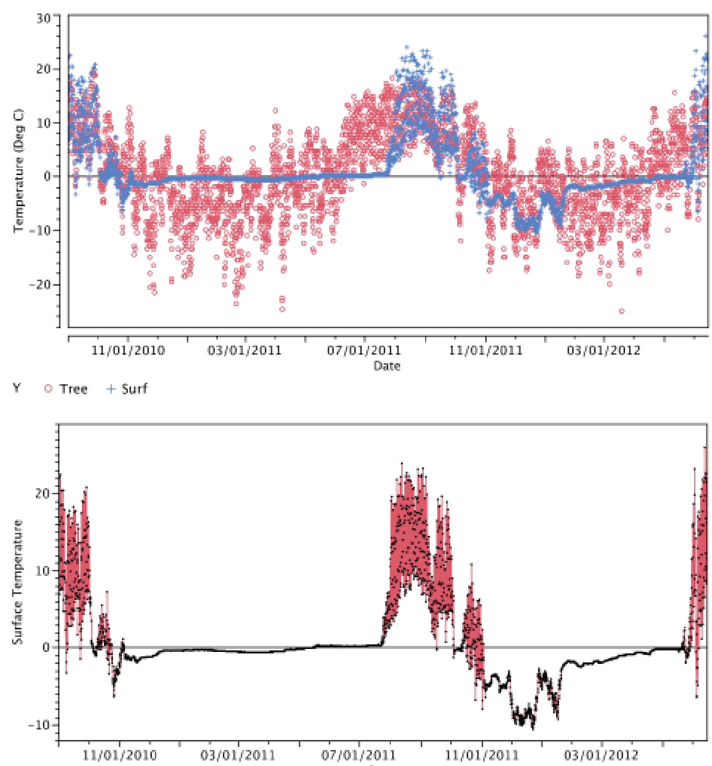


Figure 10. Temperature trace, summer 2010 through summer 2012, from thermochrons placed on ground (talus) surface and at 3.0 m height in nearby tree crowns (**upper graph**) and ground surface only (**lower graph**); Greenstone Lake, 3445 m, near Saddlebag Lake, Sierra Nevada. Thermochrons recorded at 4-hr intervals.

Contributing Artists

Many members of our CIRMOUNT community have artistic as well as scientific skills, the output of which complements our research in important ways. Please feel free to share with me your prose, poetry, sketches, photographs, or other mountain artistry for future issues of *Mountain Views*. -- *Editor*

This month we include work by several of our CIRMOUNT colleagues:

Photographs

Jim Bishop is a retired fire manager from California Dept of Forestry and Fire Protection and active with the California Native Plant Society, which honored him as a CNPS Fellow in 2012. Jim and his wife Catie Bishop are also leaders in the California and Nevada GLORIA program, and have been present for all but a very small number of summit installations and re-measures. The Bishops live in Oroville, CA.

Bill Bowman is Professor in the Department of Ecology and Evolutionary Biology and Director of the INSTAAR Mountain Research Station with the University of Colorado, Boulder, CO. His many years of field research in high-elevation systems, and particularly leadership and research at Niwot LTER, have provided a vast backdrop for his remarkable photography. Bill's work highlights our *MVN* front and back covers; the front-cover image was as well the logo for *MtnClim 2012*.

Sherri Eng is the public affairs specialist at the USDA Forest Service, Pacific Southwest Research Station, Albany, CA. As a journalist she has many media talents in addition to photography. She traveled to Estes Park with us to help summarize events for *MVN*, and we include some of her imagery from Rocky Mountain National Park and the YMCA venue for *MtnClim 2012*.

Chris Kopp is a Ph.D. student in the Ecology, Behavior and Evolution Section at the University of California, San Diego, CA. Chris is researching effects of climate change on alpine shrub systems, with focus on the White Mountain Plateau of California, where he is often hiking the highlands and capturing images of remote Great Basin mountain ecosystems and weather. He also shared images from his trip to Estes Park for *MtnClim 2012*.

Kelly Redmond is Deputy Director of the Western Regional Climate Center and Regional Climatologist, based at the Desert Research Institute, Reno, NV. Kelly is famous for his photographs of mountains from the air, which seems to be a place he spends much of his time (i.e., traveling). In this issue, we include his ground-level images from near our *MtnClim 2012* venue in Rocky Mountain National Park, CO.

Jeff Wyneken is an avid and experienced mountain wanderer and photographer in his time away from main work as a book editor in the Bay Area, California. He gets to visit awesome mountain locations when following his wife, *MVN* editor Connie Millar, through mountains of the Great Basin, where he kindly helps with field work.

Poetry

Larry Ruth is Principal and Chief Research Analyst of Lawrence Ruth and Associates, formerly Policy Analyst with the University of California, Berkeley, College of Natural Resources and Center for Forestry. When Larry isn't consulting with natural-resources agencies he is most likely writing mountain poetry, which he has been studying and publishing for many years.

Rock Work

Tim Forsell manages the high-elevation Crooked Creek facility of the University of California's White Mountain Research Center, above Bishop, California. Most importantly Tim feeds the exhausted and famished researchers who come through Crooked Creek in summer; Tim's knowledge of White Mountain natural and cultural history are also legendary, as is his artwork using rock, stone, and other natural materials to adorn the Crooked Creek grounds.

Mountain Visions

Sunset wave cloud over Mono Basin. Photo: Jim Bishop

Ecotone

Three in a line-
lodgepole, foxtail,
whitebark pine.

– Larry Ruth

Lodgepole, foxtail, and whitebark pines at treeline in the Cottonwood Basin, southern Sierra Nevada, CA.
Photo: Jeff Wyneken

Climbing Mount Ritter
after Gary Snyder

Last time there
I went up Banner Peak
with a friend. Full of ourselves
and July, we looked south
across the saddle, our eyes
tracing the route, a scramble
through scree and snow

not too hard, thought
we'd get up Ritter by
mid-afternoon. Then
we broke out a little snack
and stopped
had a long lunch
reclined
on our knapsacks
and did

as little
as possible
for the rest
of the afternoon.

– Larry Ruth

Mounts Banner and Ritter. Photo: Larry Ruth

Milky Way shines above the Indian Peaks demarcating the Continental Divide, Front Range, Rocky Mtns, Colorado.
Photo: Bill Bowman